ALTERNATIVES TO AGRICULTURAL WASTE BURNING OF RICE STRAW IN CALIFORNIA

Prepared for

State of California
Air Resources Board
Research Division
Contract No. A8-149-31

by

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July 18, 1980

ABSTRACT

This study assesses the technical and economic potential of various waste burning-utilization alternatives of rice straw to include: soil incorporation, livestock feed, direct combustion, gasification, pyrolysis, anaerobic digestion, cellulose conversion to alcohol, and fiber for production of corrugating medium and fireboard. Other miscellaneous uses for rice straw were examined. Direct combustion and cellulose conversion to alcohol showed the greatest potential for commercial or industrial application.

The soil types incidence of stem rot disease, crop suitability and recommended areas for rice straw incorporation and burning were delineated for California rice growing areas in map form. Approximately 80 percent of the rice growing area was determined to be least suitable for incorporation based on soil quality alone. Stem rot disease incidence is estimated to exist on the majority of rice acreage in California. Approximately half of the rice soils in the State as a whole could support the production of alternate crops from an agronomic standpoint.

Five collection and removal systems were evaluated: 1) mobile field cubing, 2) portable cubing, 3) custom baling, 4) self-propelled baling, and 5) total harvest of rice straw. Each system provides special merits depending on the use of the collected rice straw. In most cases small size farms are at a disadvantage over large farms in respect to total costs of collection and removal.

Projected farm incomes for small, medium, and large farm-size categories are negative in the short-run. If subsidies could be made available to rice growers then this may stimulate investment of collection and removal systems assuming a demonstrated demand for rice straw exists. Incorporation of rice straw is the least attractive of the waste burning alternatives with respect to farm production costs.

ACKNOWLEDGEMENTS

Copley International Corporation gratefully acknowledges the assistance of the California rice growers in the conduct of this study. The quality of results was enhanced by their cooperation in responding to the survey questionnaire. Of particular note was the fine cooperation so freely given by numerous rice growers who willingly discussed at great length their respective operations which provided the nucleus around which this report was prepared.

Of special mention are the members of the Technical Evaluation Committee who contributed their time and energy by providing data and valuable comments on the findings contained in this study. These individuals are:

- Robert K. Webster, Ph. D., Plant Pathologist
  University of California, Davis, CA
- George Miller, Jr., Agricultural Engineer
  University of California, Davis, CA
- Marlin Brandon, Agronomist
  Louisiana State University, Crawley, LA
- Jack Williams, Farm Advisor
  Sutter and Yuba Counties, Yuba City, CA
- A. A. Grigarick, Ph.D., Entomologist
  University of California, Davis, CA
- R. A. Kepner, Agricultural Engineer
  University of California, Davis, CA

In addition, Copley International Corporation appreciates the valuable contribution of the California Air Resources Board staff for their assistance on this study. Special recognition should be given to Dr. Robert Grant, for his valuable technical assistance during the conduct of this study.

Other individuals and groups who contributed significantly to the research effort are:

- Virgel Backland, Civil Engineer
  Soil Conservation Service, Davis, CA
- Walter A. Bunter, Jr., State Agronomist
  Soil Conservation Service, Davis, CA
- John Goss, Agricultural Engineer
  University of California, Davis, CA
- Garth Nelson, Papakuke Corporation
  San Diego, CA
- George Sato, Chief, Land and Water Use Section
  California Department of Water Resources,
  Sacramento, CA
- Milton Serjesse, Engineer
  Butte County Rice Growers Assoc., Richvale, CA

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INTRODUCTION

The extent of open-field burning of rice straw occuring in the Sacramento and San Joaquin Valleys compromises the local Air Pollution Control District's (APCD's) ability to comply with EPA air quality standards. In order to alleviate this situation, research has been undertaken to identify economically and technologically feasible alternatives to the waste burning of rice straw so that further degradation of air quality and visibility in these areas can be controlled and minimized.

The rice burning problem encompasses two major air basins within California, they are the Sacramento and San Joaquin Valley air basins. Of the 522,000 acres of rice grown in these areas in 1979, nearly all of this was burned prior to preparation for the 1980 rice crop. An estimated 8,550 tons of hydrocarbons and particulate emissions were created during this period; with a majority of the burning taking place in October, November, and April. This means that an average daily emission of 95 tons per day could occur during these three months.

Many APCD officials consider rice straw burning to be the single largest source of emissions into the atmosphere. Although rice straw burning does represent a significant source of emissions it will likely continue until economically and technically feasible alternatives are identified and made available at the farm level. At the present time, open-field burning represents an inexpensive and convenient method to control plant disease, eliminate surface organic matter, and promote quick return of nutrients to the soil. The imposition of burning restrictions will assuredly effect the technology of rice growing as well as impose financial burdens on the rice growers.

In this study, Copley International Corporation has examined alternatives to the waste burning of rice straw in relation to incorporation, collection and removal systems, and utilization technologies. Five collection and removal systems were assessed along with eight utilization technologies. Finally, the effects of employing these systems were analyzed in relation to farm-size by geographical location.

The first major phase of the project entailed a comprehensive literature review of all relevant data. A computerized literature search of Commonwealth Agricultural and Agricola data bases was initially conducted in topics pertaining to rice straw incorporation, collection systems, utilization alternatives, cultural practices, and economics. Also, contact with researchers in various disciplines was made which provided an additional source of published material. Once collected, these publication were reviewed, abstracted and the findings presented in a literature review.

Prior to the commencement of this project, research efforts on the various factors of waste burning were characterized by specific independent studies. For example, in the area of incorporation, research on equipment, disease, and soils was engaged in independently of each other. This isolated environment prohibited a comprehensive analysis of waste burning to be undertaken. The major theoretical concept behind this project is to bring together these areas of research supplemented with primary data collection, so that the nature of the waste burning problem can be adequately reviewed and evaluated technically as well as economically.

The second major phase of the project entailed the design and implementation of the farm survey. The first step in designing the survey was to establish the survey respondents and to design and pretest the actual questionnaire. The survey was then conducted in two waves of mailings. An additional sampling of those who had not responded to the mailed questionnaires was made. The final portion of this phase involved the development of descriptive statistics and the analysis of the survey data.

The sample of rice growers in both the San Joaquin and Sacramento Valleys was obtained through the Agricultural Stabilization and Conservation Service (ACSC) county offices. These branches provided names and addresses of all persons farming rice in their respective counties. A few county offices responded with names only, and addresses were looked up in local phone directories. Approximately 1,200 survey points were established.

Based on information learned during the literature review and interviews with rice researchers, a pretest questionnaire was developed in order to solicit baseline information from 25 rice growers on various aspects of rice production. CIC utilized the comments and suggestions of rice researchers to adapt the questionnaire into final form. The pretest questionnaire was sent to 25 rice growers on August 30, 1979. Eight questionnaires were returned by September 15, 1979. The responses were evaluated and modifications were made to complete the final questionnaire format. (Refer to Appendix A.)

With these tasks completed, CIC began the final mailings of the questionnaires on October 8, 1979. Approximately 900 rice growers were sent questionnaires by CIC. An additional 200 questionnaires were sent to various county Agricultural Extension offices so that they could be distributed to persons for whom CIC had no address. Due to the fact that the timing of this first mailing coincided with the rice harvesting period, only 85 questionnaires were returned.

In order to obtain a larger data base, CIC mailed a second wave of questionnaires to those rice growers who had not originally responded. This mailing of 1,185 questionnaires was completed on November 19, 1979. This wave resulted in 192 responses, establishing a total of 277 responses for the survey.

To assure that a bias had not resulted from the responding versus non-responding rice growers, CIC set up a telephone survey. The questionnaire included the main questions from the original mail questionnaire. A random sample of rice growers who had not returned the original questionnaire were telephoned and interviewed to determine their characteristics. Fifty-eight non-response interviews were completed. A copy of the non-response questionnaire as well as some descriptive statistics may be found in Appendix A.

In order to ultilize the time between the questionnaire mailing and the receipt of the final response, CIC edited, coded, keypunched and performed quality assurance techniques to the questionnaires as they were received. Each response for an open-ended question was given a number "code", thereby assuring consistent answering (e.g., for question 1, "corn" was always coded as "6"). Obvious errors such as arithmetic mistakes or spelling errors, especially for rice varieties were corrected. The coded data was then keypunched into CIC's computer system and each questionnaire was rechecked for errors-- 100 percent validation of the survey. The same procedures were followed for the non-response questionnaires. All of the mail questionnaires formed one data set on the computer while the non-response questionnaires formed a completely separate one.

After completion of the keypunching and quality assurance, descriptive statistics were developed for the data sets. The sets were described as a whole and then disaggregated into valleys, areas, and counties. Using the information obtained from these statistics, additional analysis was devised. Cross-tabulations or the study of relationships between the responses to two or more selected questions were studied, and other statistical procedures were performed. The results of these data were used to formulate recommendations and to compile the tables found in Chapters 2, 4, and 7.

In conjunction with the mail survey, CIC personally conducted face-to-face interviews with 25 rice growers at various locations throughout the State. Information pertaining to cultural practices by geographical area, utilization alternatives, types of machinery used, and other relevant data was ascertained. Rice growers were very candid about their operations and exhibited a willingness to tackle the serious issues of employing new technologies to offset the air quality problems inherent in open-field burning of rice straw. The face-to-face interviews with rice growers enabled CIC to contrast and highlight the findings contained in other published materials in addition to information collected from the mail survey.

A separate major phase of the study included the mapping of rice growing areas in California. Soil surveys conducted by the Soil Conservation Service were very useful in this effort. Once the rice growing areas were identified from published information and survey findings; the soils at these locations were mapped on an "association basis." Additional map overlays were prepared which show: 1) stem rot disease incidence, 2) crop suitability and 3) burning and incorporation areas. These maps are submitted along with a map supplement to provide supportive documentation.

Together with the collected literature, survey results, and mapping information the final assessment of economic and technical feasibility of waste burning alternatives was made.

Due to the breadth of material covered in this study, the findings were presented in a highly aggregated fashion. The preliminary resource information on rice straw production and soil suitability is given in Chapters 2 and 3 respectively. Chapter 4 deals entirely with the issues of incorporation and Chapter 5 deals with collection and removal systems. A detailed assessment of the technical and economic feasibility of rice straw utilization alternatives is presented in Chapter 6; eight major utilization alternatives are considered. In Chapter 7, the impact of employing alternative rice straw utilization schemes are assessed in light of farm-size and prevailing economic conditions.

DRAFT

PRODUCTION AND UTILIZATION OF RICE STRAW

This chapter provides information concerning the characteristics of rice production in California, the varieties grown, and current methods of rice straw disposal. The majority of data used in this chapter was developed from Copley International Corporation's survey of rice growers. Additionally, telephone and written correspondence with informed sources in California and other leading rice producing states were used to expand the data which was extracted from the literature.

The majority of rice production is concentrated in four of the 18 rice-producing counties in California. An analysis of farm-size distribution showed that the majority of rice growers in this state farm relatively small amounts of acreage. The vast majority of the rice acreage, however, is farmed by approximately one-third of the rice grower population. In terms of the economic analysis regarding waste burning alternatives, farm-size distribution is an important variable.

The rice varieties which are grown in California are unlike varieties grown in the rest of the United States. In part, this factor restricts the ability of growers to utilize any rice straw disposal techniques other than burning. The Indica varieties grown in California have stronger stalks and have proven to be more resistant to decay than the Japonica varieties found in the southern United States. In addition to the above, plant geneticists have developed short-statured Indica varieties which are becoming exceedingly popular in California due to their high yielding potential and resistence to lodging.

The various methods growers have found for disposal of rice straw are discussed in this chapter. Information on rice straw utilization and disposal methods is provided for both foreign and domestic rice producing areas. It was found that, unlike California, foreign rice producers make considerable use of their rice straw. Economics are a large factor which enables countries to substitute rice straw for relatively more expensive fiber sources. California remains an enigma however, since virtually all the rice straw is disposed of by burning.

RICE PRODUCTION

The United States production of rice grain in 1979 amounted to over 187,800 hundred weight (cwt). The acreage of land used for producing this all time record crop was estimated at three million acres (Federal State Market News Service, April, 1980). During this same year, California achieved a record 33,669 cwt yield which accounted for 522,000 acres of land. With respect to the major crops produced in the United States, rice is ranked about 15th in value for cash receipts. California's annual share of total U.S. rice receipts ranges from 20 to 25 percent, trailing behind Arkansas with about 30 percent. In

1979, rice ranked 12th among all California commodities accruing approximately 326.6 million dollars in receipts.

Although rice is a minor crop in the United States it is a major crop in areas where it is grown. In California, for instance, leading rice producing counties include Colusa, Butte, Sutter, and Glenn. Rice ranks as either the leading or second leading commodity in cash value for each of these counties.

Table 2.1 shows the distribution of rice acreage in California during 1978 (1979 figures are not compiled for all counties). Table 2.1 illustrates rather clearly the concentration of rice acreage in the Scaramento Valley. In 1978, 92.5 percent of the rice harvested in California was in Sacramento Valley. More specifically, the four northern most counties, i.e., Butte, Colusa, Glenn, and Sutter, accounted for approximately 79 percent of total production (cwt). This table also shows that Sacramento Valley growers obtain consistently higher yields than their southern counterparts. Clearly, this demonstrates the commitment to rice farming in the Northern Sacramento Valley.

Acreage Distribution of Rice Farms in California

The size of farms which make up a particular sector of the agricultural industry tells a great deal about its nature. Farms with large holdings of land, for instance, tend to be more diversified with respect to the crops that are grown. Alternatively, small farms tend to be more specialized and generally their labor needs are reduced since much of the work is accomplished by family members.

Table 2.1

DISTRIBUTION OF RICE ACREAGE IN CALIFORNIA

County	1978			
	Acres Seeded	Acres Harvested	Yield Per Acre lbs.	Production (cwt)
Sacramento Valley				
Butte	103,200	103,000	5,300	5,493,000
Colusa	126,300	126,000	5,300	6,641,000
Glenn	75,000	75,000	5,400	4,047,000
Placer[(a)]	8,000	8,000	5,700	457,000
Sacramento	12,000	12,000	5,200	630,000
Solano	700	700	4,900	34,000
Sutter	84,500	84,000	5,400	4,529,000
Tehama	1,000	1,000	3,200	32,000
Yolo	29,000	29,000	5,200	1,519,000
Yuba	23,000	23,000	5,200	1,196,000
Total	462,700	461,700	5,320	24,578,000
San Joaquin Valley				
Fresno	13,000	13,000	3,900	508,000
Kern	1,500	1,500	3,500	53,000
Kings	700	700	3,600	25,000
Madera	100	100	5,000	5,000
Merced	10,000	10,000	4,800	482,000
San Joaquin	6,000	6,000	5,300	320,000
Stanislaus	3,000	3,000	5,600	167,000
Tulare	3,000	3,000	3,700	110,000
Total	37,300	37,300	4,480	1,670,000
State	500,000	499,000	5,260	26,248,000

[(a)] Placer County is not normally included as part of Sacramento Valley.

Source: California Crop and Livestock Reporting Service .

The ability of large farms to absorb new capital intensive technology is demonstratively better than that of small farms. This is primarily due to the fact that large farms can spread equipment investments over a larger number of acres. Also, more efficient equipment utilization can be achieved on large farms. Research points out that small farms may achieve higher yields due to more careful management. Generally though, the ability to raise venture capital for expansion or integration is reduced with small farms since their borrowing capacity is limited by low equity.

The farm-size phenomenon has special significance for the various waste burning alternatives. Since the ability of farms to absorb new technology will be based on economic viability, the distribution of rice farms in California is essential to understanding the economic impacts of waste burning alternatives.

The information given under this section was generated from a survey of rice growers in California. Approximately 158,994 acres of actual rice farming was accounted for in this survey. For 1980, this represents nearly 30.5 percent of the harvested rice acreage. Rice growing activities in the farm survey were disaggregated according to growers who exclusively farmed rice and those who farmed rice and alternate crops.

The actual rice acreages that were planted in a typical year were tabulated for the State as a whole. Categories were delineated to determine representative small, medium, and large size rice acreage categories. These categories for rice acreages are as follows:

- small rice acreages, 0 to 320 acres
- medium rice acreages, 320 to 820 acres
- large rice acreages, 820 acres and greater

The size of rice acreages in the state ranged from 9.3 acres to 5,025 acres. To disaggregate this range of rice acreages into manageable categories, the following criteria were considered:

- frequency of farm sizes within a category
- land size as it corresponded to township and range boundaries (e.g., one section equals 640 acres)
- the amount of equipment required to meet acreage demands (e.g., one combine for approximately 300 acres)

Since the majority of rice growers raise rice in conjunction with other crops, a total farm size category was determined also. It was felt that the disaggregation of data in this manner, would permit a better estimate of the ability of rice growers to absorb new technology into their operations. Also, by working on this level of detail, it would be possible to investigate the relationship of production costs with respect to rice acreage and total farm size. The total range of farm sizes encountered extended from 13.5 to 8,000 acres. The total farm-size categories were delineated as follows:

- small farms, 0 to 640 acres
- medium-small farms, 640 to 1,280 acres
- medium-large farms, 1,280 to 2,240 acres
- large farms, 2,240 acres and greater

The criteria used to develop farm-size categories are the same as for the actual rice acreage categories. These data on actual rice acreage and total farm-size were cross-tabulated in order to illustrate their relationships in both the Sacramento and San Joaquin Valley Air Basins, and five major growing areas.* These data, which are presented in Tables 2.2 and 2.3, graphically point to the relative abundance of small rice acreages and small farms comprising California's commercial rice industry.

The tables are presented on an area and valley basis. The numerical figure relates to the number of respondents for each cross-tabulation. The percentage figure corresponds to the number of respondents in the respective area or valley.

In Areas 1 and 2 the relationship of rice acreage to total acreage is nearly equal. Approximately 40 percent of the respondents in both areas are operating small farms (less than 640 acres) with rice acreages of less than 320 acres. Approximately one-quarter of the respondents in both areas operate rice acreages greater than 820 acres. Area 3, which included only 20 respondents, shows a similiar trend; however, there is a larger proportion of total farm sizes greater than 1,281 acres. For the Sacramento Valley as a whole, nearly 33 percent of all rice farmers operate small farms (less than 640 acres with less than

*Area 1 includes Glenn and Colusa Counties. Area 2 includes Butte, Sutter, Yuba, and Placer Counties. Area 3 includes Yolo, Sacramento, and Solano Counties. Area 4 includes San Joaquin, Stanislaus, Merced, and Madera Counties. Area 5 includes Fresno, Kings, Tulare, and Kern Counties.

Table 2.2

FARM ACREAGE DISTRIBUTION FOR SACRAMENTO VALLEY

Actual Rice Acreage	Total Farm Acreage[a] Less Than 640 Acres	640 to 1,280 Acres	1,281 to 2,240 Acres	Greater Than 2,240 Acres	Row Total
Area 1					
Less Than 320 Acres	40 37.7	3 2.8	0 0.0	1 0.9	44 41.5
320 to 820 Acres	15 14.2	16 15.1	6 5.7	1 0.9	38 35.8
Greater Than 820 Acres	0 0.0	7 6.6	2 1.9	15 14.2	24 22.6
Column Total	55 51.9	26 24.5	8 7.5	17 16.0	106 100.0
Area 2					
Less Than 320 Acres	38 33.0	4 3.5	3 2.6	1 0.9	46 40.0
320 to 820 Acres	19 16.5	13 11.3	5 4.3	3 2.6	40 34.8
Greater Than 820 Acres	0 0.0	9 7.8	13 11.3	7 6.1	29 25.2
Column Total	57 49.6	26 22.6	21 18.3	11 9.6	115 100.0
Area 3					
Less Than 320 Acres	2 10.0	0 0.0	4 20.0	3 15.0	9 45.0
320 to 820 Acres	2 10.0	4 20.0	1 5.0	0 0.0	7 35.0
Greater Than 820 Acres	0 0.0	0 0.0	2 10.0	2 10.0	4 20.0
Column Total	4 20.0	4 20.0	7 35.0	5 25.0	20 100.0
Sacramento Valley					
Less Than 320 Acres	81 32.9	8 3.3	7 2.8	6 2.4	102 41.5
320 to 820 Acres	36 14.6	33 13.4	12 4.9	4 1.6	85 34.6
Greater Than 820 Acres	0 0.0	16 6.5	19 7.7	24 9.8	59 24.0
Column Total	117 47.6	57 23.2	38 15.4	34 13.8	246 100.0

[a]The first figure in each row corresponds to the actual number of observations; the second figure reflects the percentage response for each geographical area.

Source: Copley International Corporation.

Table 2.3

FARM ACREAGE DISTRIBUTION FOR SAN JOAQUIN VALLEY

Actual Rice Acreage	Total Farm Acreage[a] Less Than 640 Acres	640 to 1,280 Acres	1,281 to 2,240 Acres	Greater Than 2,240 Acres	Row Total
Area 4					
Less Than 320 Acres	17 77.3	0 0.0	0 0.0	0 0.0	17 77.3
320 to 820 Acres	2 9.1	1 4.5	1 4.5	0 0.0	4 18.2
Greater Than 820 Acres	0 0.0	0 0.0	0 0.0	1 4.5	1 4.5
Column Total	19 86.4	1 4.5	1 4.5	1 4.5	22 100.0
Area 5					
Less Than 320 Acres	1 8.3	0 0.0	2 16.7	2 16.7	5 41.7
320 to 820 Acres	0 0.0	1 8.3	2 16.7	2 16.7	5 41.7
Greater Than 820 Acres	0 0.0	0 0.0	1 8.3	1 8.3	2 16.7
Column Total	1 8.3	1 8.3	5 41.7	5 41.7	12 100.0
San Joaquin Valley					
Less Than 320 Acres	19 52.8	1 2.8	2 5.6	2 5.6	24 66.7
320 to 820 Acres	2 5.6	2 5.6	3 8.3	2 5.6	9 25.0
Greater Than 820 Acres	0 0.0	0 0.0	1 2.8	2 5.6	3 8.3
Column Total	21 58.3	3 8.3	6 16.7	6 16.7	36 100.0

[a]The first figure in each row corresponds to the actual number of observations; the second figure reflects the percentage response for each geographical area.

Source: Copley International Corporation.

320 acres of rice. Forty-one percent of all Sacramento Valley rice growers raised less than 320 acres of rice.

The survey results obtained from San Joaquin Valley are more illustrative of the large proportion of small rice acreages which are farmed relative to large acreages. For example, in Area 4, which comprises the majority of rice farming activity in San Joaquin Valley, 77.3 percent of the respondents farmed small farms (less than 640 acres) with rice acreages of less than 320 acres. There were 36 respondents in the San Joaquin Valley which accounts for 12.7 percent of the total frequency and size.

Of special significance is the realtive frequency and size of farms which exclusively grow rice. These growers are facing greater financial risks than mixed crop growers since low revenues from a bad rice year can't be offset by alternate crops. The frequency and acreage distribution of these growers are shown in Table 2.4.

Twenty-five percent of all survey respondents grew rice exclusively. Of these 72 growers, 86 percent resided in Sacramento Valley. The tabulation of rice acreages for these growers show that 50 and 80 percent of the "rice only" respondents operate 320 acres or less in the Sacramento and San Joaquin Valleys, respectively. Of the remaining respondents in Sacramento Valley, the majority farmed medium-size rice acreages ranging from 320 to 820 acres. Only 16 percent operated large rice farms in Sacramento Valley. There were no large operators in the San Joaquin Valley.

Table 2.4

ACREAGE DISTRIBUTION OF RICE ONLY GROWERS

	Rice Only Acreage			
	Less Than 320 Acres	320 820 Acres	Greater Than 820 Acres	Total
Sacramento Valley				
Number of Respondents	31	21	10	62
Percentage of Rice Only Respondents	50.0%	33.9%	16.1%	100.0%
Percentage of Respondents in Sacramento Valley	13.0%	8.6%	4.1%	25.7%
San Joaquin Valley				
Number of Respondents	8	2	0	10
Percentage of Rice Only Respondents	80.0%	20.0%	0.0%	100.0%
Percentage of Respondents in San Joaquin Valley	22.2%	5.5%	0.0%	27.5%

Source: Copley International Corporation.

The information presented in this section shows that rice farming in California is conducted on a relatively small scale. In general, there appear to be twice as many small farms as there are large farms. The significance of this will become very apparent in Chapter 7 which discusses the economic viability of various farm-size categories.

With respect to acreage, however, this situation is entirely different. Of the 284 respondents, 68 percent operate rice acreages of less than 320 acres. These 126 growers, however, account for only 18,014 acres which amounts to 11.3 percent of the rice acreage surveyed. The vast majority of rice acreage (i.e., 89,493 acres or 56.3 percent of rice area) is composed of 62 respondents operating farms with greater than 820 acres of rice.

The majority of the rice acreage farmed in California is by large operators who are diversified in other crops. For example, it was found that 88 percent of California's rice acreage is being farmed by only 32 percent of the operators. This has enormous implications on economic viability issues in addition to to waste burning policy issues which are entertained on a State level.

With respect to economics, farm size and acreage distribution will be discussed more thoroughly in Chapter 7. It is important to recognize though, that the majority of rice growers are living the idealogy set forth by the "Jeffersonian" concept of the small, rural family farm. In fact, in the San Joaquin and Imperial Valleys of California this family farm concept has promulgated the Department of Interior to develop acreage limitations on farm owners utilizing federally funded reclamation waters for irrigation. It is ironic that small farmers, although abundant, farm only a minor portion of the rice acreage in California.

RICE VARIETIES IN CALIFORNIA

In contrast to the rest of the United States the rice varieties grown in California belong to the Japonica (short grain) group. Most of the varieties grown in the southern United States belong to the Indica (long grain) group or are a hybrid derivative of the two types. The Japonica rices generally are adapted to cooler climates and longer photoperiods than the Indica rices (Leonard and Martin, 1963). The Japonica rices also have shorter, stronger stalks which makes them less subject to lodging under heavy fertilization (Leonard and Martin, 1963).

Frequency and Distribution

There are numerous rice varieties suitable for commercial production in California. Research to develop and improve these varieties is a result of the continuing effort of the University of California, the USDA and the California Cooperative Rice Research Foundation. Of the numerous varieties available for distribution, four of these California varities account for approximately 80 percent of the planted acreage on an annual basis. Table 2.5 shows the approximate acreage and percentage distribution of these varieties in California.

Table 2.5

ACREAGE OF RICE VARIETIES PLANTED IN CALIFORNIA IN 1979

Variety	Acres	%	Variety	Acres	%
Short Grains			Medium Grain (cont'd.)		
S6	159,000	30.0	Earlirose	5,500	1.0
Colusa	10,600	2.0	Earlirose 76	2,650	0.5
Medium Grain			CS-M3	2,650	0.5
			M-101	200	0.1
M9	153,700	29.0	M-301	260	0.1
M7	79,500	15.0			
M5	37,100	7.0	Long Grain	600	0.1
Calrose	37,100	7.0	Specialty Types	9,340	1.8
Calrose 76	31,800	6.0			
			Total	530,000	100.0

Source: Federal-State Market News Service, 12/11/79 .

Three varieties are predominate in California rice production: S6, M9, and M7. They are all considered to have very good to excellent yield potential and good resistance to lodging. The S6 and M9 are early maturing rice varieties requiring approximately 133 days to reach maturity (Cooperative Extension, 1979). The M7 requires approximately 165 days to reach maturity.

A description of the plant characteristics of California rice varieties is summarized in Table 2.6.

Rice growers combine a mixture of varieties into their farm management plan. The varieties chosen usually correspond to the grower's familiarity with certain varieties, the need to offset risk in light of uncertain weather conditions, the variation in fertility conditions on the farm, and external market conditions. As is shown in the remainder of this section, certain varieties predominate in the State and in selective regions.

Table 2.6

CHARACTERISTICS OF CALIFORNIA RICE VARIETIES

Variety by Maturity Group	Grain Type[a]	Pubescence[b]	Relative Height[c]	Average Maturity[d] (Days)	Major Advantages and Disadvantages
Early Group					
Colusa	S	P	Tall	136	Average yield potential, cold sensitive and lodges.
Earlirose	M	P	Tall	133	Good yield potential, poor grain quality and lodges. Should not be planted early.
Earlirose 76	M	P	Tall	136	Good yield potential, larger seed than E.R., lodges.
M5	M	G	Tall	150	Good yield potential, lodges.
S6	S	G	Tall	140	Very good y ld potential, lodges less than Colusa. Non-uniform heading, maturity
M9	M	G	Short	133	Short stature, exceptional yield potential, good lodging resistance, threshes hard.
M101[e]	M	G	Short	130	Best for cool areas and late plantings
Late Group					
Calrose	M	P	Tall	165	Widely adapted, relatively cold tolerant, good yield potential, lodges.
Calrose 76	M	P	Short	165	Short stature, exceptional yield potential, lodging resistant, profuse awning at Biggs, "Short Calrose."
CS-M3	M	G	Tall	165	Widely adapted, good yield potential, very tall at high nitrogen lodges.

(continued)

Table 2.6 (continued)

Variety by Maturity Group	Grain Type[a]	Pubescence[b]	Relative Height[c]	Average Maturity[d] (Days)	Major Advantages and Disadvantages
Late Group (cont'd)					
M7	M	G	Short	165	Short stature, exceptional yield potential, lodging resistant, "Short CS-M3."
M301[e]	M	---	Short	---	Similar to Calrose 76 in yield.
Kokuho Rose	M	P	Tall	165	Fair yield potential late maturing, unique grain type.
Terso	M	G	Tall	165	Average yield potential, tall, lodges, grain similar to Kokuho Rose
Tsuri Mai	M	P	Tall	155	Average yield potential, earlier, lodges, grain similar to Kokuho Rose

[a]S = Short (Pearl), M = medium, L = long.

[b]P = Pubescent (rough), G = Glabrous (smooth).

[c]Tall = 100 cms (40 in.), Short = 100 (40 in.).

[d]Based on average days to 50 percent heading in several statewide locations. Will vary depending on location and other factors. Given in days to field maturity.

[e]Inserted into table based on available data. Copley International Corporation.

Source: Cooperative Extension, 1979 .

The distribution of rice varieties throughout the State is shown in Tables 2.7 and 2.8. It was originally anticipated that the distribution of varieties would be given in map form. Due to the volume of data received, a map would not be suitable for depicting varietal distribution. The data on rice varieties were compiled on a countywide basis and then aggregated by area. A small error exists in the tabulated percentages since some growers reported that their operations encompassed portions of two counties and, in some cases , two areas.

Table 2.7

RICE VARIETIES BY AREA
(percent)

	Area 1	Area 2	Area 3	Area 4	Area 5	Total State
Calrose	4.2%	4.9%	12.5%	15.9%	33.2%	7.3%
Calrose 76	3.0	1.2	10.3	19.5	24.1	4.7
M9	19.4	39.0	28.1	16.5	17.6	28.5
Earlirose	1.6	3.9	16.4	20.9	3.2	4.9
Earlirose 76	0.4	0.6	---	7.2	20.9	1.9
S6	26.4	29.8	20.3	13.1	---	25.3
M5	7.8	4.6	3.4	6.2	---	5.6
Terso	3.1	0.9	0.4	---	---	1.6
1600	1.1	0.5	---	---	---	0.7
M7	20.6	11.5	8.2	0.9	---	13.7
Kokuho	6.1	1.6	---	---	---	3.0
CS-M3	1.8	---	---	---	---	0.7
Other	4.5	1.5	0.4	---	1.0	2.1
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Source: Copley International Corporation.

Table 2.8

RICE VARIETIES BY AREA
(acres)

	Area 1	Area 2	Area 3	Area 4	Area 5	Total State
Colusa	---	145	---	---	80	225
Calrose	2,401	3,319	1,408	1,325	2,569	11,022
Calrose 76	1,719	783	1,162	1,627	1,860	7,151
M9	11,085	26,216	3,165	1,370	1,365	43,201
Earlirose	895	2,634	1,850	1,729	250	7,358
Earlirose 76	230	412	---	600	1,620	2,862
S6	15,605	19,977	2,301	1,087	---	38,430
M5	4,505	3,105	382	517	---	8,509
Terso	1,778	638	---	---	---	2,416
1600	644	350	43	---	---	1,037
M7	11,745	7,727	921	72	---	20,465
Kokuho	3,498	1,092	---	---	---	4,590
Sweet Rice	408	---	---	---	---	408
CS-M3	1,025	---	---	---	---	1,025
M1	75	75	---	---	---	150
Pearl	750	86	---	---	---	836
Ampex	462	---	---	---	---	462
M101, S201, M301	---	55	---	---	---	55
PRJ111	450	---	---	---	---	450
Short Grain	---	600	---	---	---	600
F6	400	---	---	---	---	400
M101	---	38	43	---	---	81
Total	57,135	67,252	11,275	8,327	7,744	151,733

Source: Copley International Corporation.

These data show that there are notable preferences for certain varieties from one area to the next. Key aspects of the common varieties are discussed below.

Calrose. This is the most popular variety in the San Joaquin Valley (Areas 3 and 4). It is a tall, late maturing variety. The total acreage is rather equally distributed throughout the State. Calrose is widely adapted in California and has good tolerance of low temperatures which may explain its frequency in all five areas.

Calrose 76. This was the first short statured variety released in California. Similar to Calrose, this late maturing variety is equally distributed throughout the State. In percentage terms, Calrose 76 was the second most prevalent variety in the San Joaquin Valley. It has good tolerance of low temperatures.

M9. The survey showed M9 to be the most popular variety in the State. It is a short statured, high yielding, early maturing variety, with good resistance to lodging. It is decidedly more prevalent in the Sacramento Valley (Areas 1, 2, and 3) than in the San Joaquin Valley. M9 is a little cold sensitive which may account for its popularity in the Sacramento Valley. In Areas 2 and 3, M9 was the most popular variety being utilized on 39 and 28.1 percent of the acreage, respectively. For the State as a whole, M9 was grown on 28.5 percent of the rice acreage.

Earlirose. This early maturing, tall variety was found to be the most prevalent in Area 4. Percentagewise it is favored in both Areas 3 and 4. Area 2, however, can claim the most acreage devoted to Earlirose. This variety is said to be widely adapted in California. Its susceptibility to lodging and poor milling quality probably accounts for its relative scarcity in the State.

Earlirose 76. In the southern portion of the San Joaquin Valley (Area 5) Earlirose 76 comprises 20.9 percent of the planted rice acreage. In other areas of California, it is seldom planted. This variety is similar to its predecessor, Earlirose, although it exhibits better resistance to lodging and matures a few days earlier.

S6. The Federal State Market News Service reported S6 to be the most popular variety in the State followed closely by M9. Clearly, these two varieties are the most prevalent in California. A survey of California rice growers indicated that S6 composed 25.3 percent of all varieties grown. Areas 1 and 2 accounted for over 91 percent of S6 plantings. In Area 5 there were no reported plantings of this tall variety. S6 has a very good yield potential and lodges less than its small grain bearing counterpart, Colusa. It is certain that, of the small grain rice produced in California, S6 comprises nearly all of it.

M5. This is a medium grain, early maturing, tall rice variety. M5 accounts for approximately 5.6 percent of the planted acreage in California. It is reported to have good yield potential, although it lodges under high nitrogen fertility conditions. Area 5 was the only area that did not report any planted acreage of it. Areas 1 and 2 accounted for over 89 percent of acreage distribution in California.

M7. This is a relatively popular variety in California. Approximately 13.7 percent of the State's rice acreage in 1979 was devoted to M7. It is a short statured variety, with exceptional yielding potential, and good resistance to lodging. It is widely distributed in Area 1 and to a lesser extent in Areas 2 and 3. Very little acreage is devoted to M7 in Area 4 and none in Area 5. It is presumably widely adaptable in California and has good tolerance to low temperatures.

Summary of Varieties. The survey supports the figures cited by the Federal-State Market News Service. There appears to be a distinct difference in preference of varieties in Sacramento Valley (Areas 1, 2, and 3) as opposed to San Joaquin Valley (Areas 4 and 5). In the southern valley the older Calrose and Earlirose varieties are most popular.

An estimated 47 percent of the planted acreage in 1979 was devoted to short statured crops. It is expected that greater acreages will be devoted to short statured varieties in the future. Based on a list of rice growers who applied to the California Crop Improvement Service for certified seed approval in 1979, 61 percent of 1980's acreage will be devoted to short statured varieties. This is consistent with information ascertained during field interviews with selected rice growers throughout the state. Virtually all growers interviewed stated that impressive yields were obtained with short statured varieties in 1979 and that greater amounts of acreage will be devoted to such varieties in the future. Rice growers will remain cautious however, and not risk all of their acreage on short statured varieties. Tall varieties such as the short grain S6 and medium grains M5 and Calrose are expected to maintain a high proportion of the total rice acreage. S6 alone is expected to capture at least 25 percent of the planted acreage in 1980.*

*Based on certified seed grown in 1979 as reported by the California Crop Improvement Association.

The straw yields of two short-statured varieties (Calrose 76 and M7) were compared with a tall variety (CS-M3) under various fertility and environmental conditions. "Straw yields of the short-stature cultivars were 13 percent less than the tall cultivars when averaged over all nitrogen rates and locations." (Brandon, 1978). Additionally, it was found that straw yields increased linearly with additions of nitrogen; however, this also depended on the cultivar and the location where it was grown. "CS-M3 was more nitrogen responsive relative to straw yield than Calrose 76 and M7." (Brandon, 1978).

A separate study suggests that for every ton of grain 4.35 tons of straw remain in the field as residue (Horsefield, Becker, and Jenkins, 1977). Assuming an average yield of 3.0 tons per acre (60 cwt), 4.05 tons of straw remains at 14 percent moisture content. If, at a minimum, short statured varieties reduce the straw by 10 percent the average field would contain 3.64 tons of rice straw per acre.

WORLDWIDE UTILIZATION OF RICE STRAW

The production of rice in the United States is relatively small compared with the rest of the world. While it is true that the U.S. is a major exporter of rice, its domestic production accounts for only 1.6 percent of the world's supply of rice.* The major world producers of rice are denoted in Table 2.9.

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*In 1979, the United States accounted for 19.7 percent of world rice exports.

Table 2.9

WORLD RICE PRODUCTION
(In Millions of Metric Tons)

	1978/79	----------1979/80-	
Production[a]			
Bangladesh	18.5	18.8	18.8
Burma	10.5	9.9	9.9
India	80.8	65.0	65.3
Indonesia	25.8	24.3	26.3
Japan	15.7	15.0	14.9
Korea Rep of	7.4	7.7	7.7
Pakistan	4.9	4.8	4.8
China	137.0	140.5	140.5
Vietnam	9.9	11.0	10.6
Thailand	17.0	15.8	15.8
Sub-Total	327.4	312.6	314.6
EC-9	1.0	1.0	1.1
Australia	0.7	0.7	0.7
Argentina	0.3	0.3	0.3
Brazil	7.6	8.6	9.0
All Others	42.1	42.7	42.9
Total Non-US	379.1	366.0	368.6
U.S.	6.0	6.2	6.2
World Total	385.2	372.2	374.8

[a]The world rice harvest stretches over six to eight months. Thus, 1978/79 production represents the crop harvested in late 78 and early 79 in the northern hemisphere and the crop harvested in early 1979 in the southern hemisphere.

Source: Federal State Market News Service, 4/1/80 .

Clearly, the majority of rice produced in the world occurs in Asia. All other countries make up less than 13 percent of the world's rice production. The practices which rice farmers employ to handle the rice straw residue are suited to their respective economic conditions. The disposal methods of rice straw for the major rice producing areas of the world are given below.*

Burma

There are two distinctly different rice growing regions in Burma; upper Burma which is characterized as a dry zone and lower Burma which is a heavy rainfall area. In upper Burma rice straw is exclusively used as a cattle feed. In the heavy rainfall region of lower Burma, rice straw is mainly burned in the field in order to facilitate plowing and sowing of dry season crops.

India

The greatest use of rice straw produced in India is for cattle feed and for thatched roofs on houses. A small proportion of rice straw is used in making compost, packing materials, and ropes. The demand for rice straw as a cattle feed is often greater than the supply.

Malaysia

The Malaysian rice farmers burn the straw and incorporate the ash and stubble into the soil. The burning of rice straw is suggested to be beneficial for certain types of soil. Apparently, the burnt residue improves the reduction/oxidation potential of the soil. Future possible uses of rice straw in Malaysia include mushroom culture and manufacture of paper and cardboard.

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*This information was made available by Dr. Fleet N. Lee, University of Arkansas, Agricultural Experiment Station.

Philippines

Disposal of rice straw in the Philippines includes burning composting, mulching, feed for carabou and cattle, use in mushroom culture, and miscellaneous uses such as thatching for roofs and fiber for chicken brood nests. It is believed that burning the straw increases the fertility of the soil as does composting. When green grass is unavailable, rice straw is used as a substitute for cattle feed. Rather than utilizing loose straw, mushroom producers collect the field stubble, including the roots, since this practice is supposedly easier than sorting out straw piles left from grain threshing operations.

Taiwan

Rice straw in Taiwan is a valued commodity. Since the price of straw is high, it is sold to paper manufacturers, mushroom growers, and rope makers. It is also used as bedding for livestock and as a mulch for the cultivation of vegetables, fruit crops, and fall-planted soybeans.

Korea

The majority of rice straw in Korea is used as a roofing material. Second to this, rice straw is used as a cattle feed and for barnyard manure or compost. Lessor uses include straw for bags, ropes, and mulches. The addition of rice straw to soils is recommended on heavy clay soils, gravelly sandy soils or newly reclaimed paddy soils with a low organic matter content.

Pakistan

Rice straw is used mostly for feeding draft animals in Pakistan. With the introduction of high-yielding stiff-strawed, dwarf rices, there has been a corresponding decline in the palatability of rice straw for animal feed. Some straw is used for the manufacture of straw board, although wheat straw is more popular for this purpose. Since firewood and other fuels are so expensive in Pakistan, rice straw is used as a fuel for heating and to a limited extent for cooking.

Peru

Most of the rice straw in Peru is removed by hand after threshing and stacking. The stubble remaining in the field is burned. Stacked straw is utilized as a cattle feed, or as a fiber for making mattresses.

Australia

The most common practice of rice straw disposal in Australia is burning. Residues of the unburned straw and ashes are incorporated in the soil. Where livestock are abundant, farmers may graze the stubble heavily with sheep or cattle before burning. Cultivating and land levelling operations are made more difficult when large quantities of plant material are incorporated. Burning is the most economical method for disposal of rice straw in Australia.

United States (Arkansas)

During harvesting operations rice straw is spread by either a straw chopper or a spreader. Following this, the straw may be handled by one of the following methods:

- The stubble is incorporated with a heavy disc or field cultivator. Incorporation is most effective during the fall thereby allowing the straw to decompose over the winter months.

- A device called a Water Buffalo or Snake Killer, is used to cut the straw and bring it in contact with the soil. The Water Buffalo is a roller with hard steel blades welded to it. As the implement rolls over the soil the rice straw is cut and mashed into the soil. For best results, this is done when the fields are very wet.

- The fields are flooded and used as winter habitat for waterfowl. This is particularly effective when used in combination with rolling the straw.

- The straw is burned, although this method will be banned at some future date.

- Some field baling is done, but this accounts for an insignificant portion of total straw tonnage.

<u>United States (Louisiana)</u>

In Louisiana the disposal of rice straw is not seen as a major problem. Rice straw is handled in respects similar to Arkansas:

- The straw is either spread or deposited in windrows behind the combine. A large disc is used to incorporate a portion of the straw in the fall. After the straw has been allowed to decompose over the winter, the remaining residue is incorporated during seedbed preparation. Soybeans are often rotated after rice.

- A limited amount of rice straw is baled for use as animal feed. Alternatively, some rice fields are used for limited grazing of cattle.

- Only a very limited amount of the total rice acreage is burned.

United States (Mississippi)

The normal method of rice straw disposal in Mississippi is soil incorporation. The primary method of incorporation is with disc harrows. The use of the Water Buffalo/Snake Killer is increasing in popularity. Field baling is done on a limited basis as is burning. Field burning is not generally used because of wet soil conditions (Fagala, 1980).

United States (Texas)

Usually directly following harvest rice growers will disc the rice straw into the soil. During the winter, microbial activity and winter rains allow for decomposition of the straw.

There is a limited market for rice straw as a feedstock for extracting furfural. Quaker Oats Company has a furfural plant at Bayport, Texas which utilizes rice hulls and limited amounts of straw. The demand for rice straw as a feedstock for Quaker Oat's process is unknown.

United States (California)

California operates under an entirely different set of environmental and cultrual conditions than the rest of the United States. The strong-stalked and short-statured rice varieties (Japonica) grown in California do not lend themselves to microbial breakdown as does the Indica varieties grown in the Southern United States. California's heavy-textured, clay soils make it difficult for even the largest mechanical tools to incorporate three to six tons of rice straw per acre. Unlike the southern United States where abundant winter rains and warm humid climate encourage microbial decomposition of rice straw, California's arid climate induces only a moderate effect on microbe activity. As solutions are found for the utilization of rice straw they can be applied to all rice producing areas of the United States. It must be emphasized, though, that California's cultural conditions are unique and recommendations for California rice straw problems must be tailored to this State's particular needs.

The major methods by which straw is disposed in California was ascertained from a survey of rice growers. Growers were asked to indicate their main and alternate methods of rice straw disposal. In several cases growers indicated two or more methods as their main disposal technique. A large portion of the growers did not identify alternate methods. The results of these survey responses are shown in Tables 2.10 and 2.11.

Table 2.10

RICE DISPOSAL METHODS IN CALIFORNIA (MAIN)
(Frequency of Occurrence; Number of Respondents)

Residue Disposal Method	Area 1	Area 2	Area 3	Area 4	Area 5
Headfire	13	9	3	6	9
Backfire	55	81	13	12	5
Perimeter Burn	13	9	2	4	1
Into-the-Wind	50	59	5	4	3
Rake/Pile	--	--	--	--	--
Center Field Ignition	1	--	--	--	--
Soil Incorporation	--	--	--	--	--
Collect and Remove	--	--	--	--	--
Total Responses	133	158	23	26	18
Actual Respondents	107	123	21	22	14

Source: Copley International Corporation.

Table 2.11

RICE DISPOSAL METHODS IN CALIFORNIA (ALTERNATE)
(Frequency of Occurrence; Number of Respondents)

Residue Disposal Method	Area 1	Area 2	Area 3	Area 4	Area 5
Headfire	9	6	6	2	--
Backfire	11	11	1	2	1
Perimeter Burn	14	3	--	1	--
Into-the-Wind	10	18	4	2	--
Rake/Pile	2	2	--	--	--
Center Field Ignition	1	1	--	--	--
Soil Incorporation	3	8	--	1	1
Collect and Remove	--	--	--	--	--
Total Responses	50	49	11	8	2
Actual Respondents	107	123	21	22	14

Source: Copley International Corporation.

In all five areas the most popular method of rice straw disposal was backfiring followed by into-the-wind striplighting. Both of these methods are considered to be the most effective in reducing particulate emission levels. Even though rice growers are prohibited to use headfires in the Sacramento Valley, this method of burning frequently occurs. It is unclear whether growers utilized headfiring as a main residue disposal method because wind changes often cause a backfire to turn into a headfire, or because they are ignorant of the present regulations prohibiting backfiring.

In the survey, rice growers were also asked to indicate any alternate methods of rice straw disposal which they used. These alternate disposal methods used by rice growers are shown in Table 2.11

The survey results showed that backfiring and into-the-wind striplighting were leading alternative disposal methods. Perimeter burn was frequently used in Area 1 and not at all in Areas 3 and 5.

Of particular significance is the frequency of growers who chose soil incorporation as an alternative disposal practice. During the course of this study several of these respondents were contacted. It was learned that soil corporation was tried on an experimental basis only. None of the growers contacted considered soil incorporation as a viable rice disposal alternative unless the rice ground was to be left fallow the following season.

None of the respondents indicated that they had attempted to collect and remove rice straw from their fields. It is evident, therefore, that any alternative to the wasteburning of rice straw is going to be met with a substantial amount of caution since growers are undoubtedly inexperienced when it comes to disposing of rice straw by any means other than burning.

SUMMARY

The production and utilization of rice straw was discussed in the chapter for the world in general and California in particular. California ranks as the second leading state in the union for gross receipts due to rice production. Four California counties, Butte, Colusa, Sutter, and Glenn account for 79 percent of the State's total rice production. In respect to the rest of the world, the United States produces a relatively small percentage of the rice, yet it is a major world exporter.

The majority of the rice acreage farmed in California is by large operators who are diversified in other crops. It was found that 88 percent of California's rice acreage is being farmed by 32 percent of the operators. This presents a difficult situation for policy analysis regarding waste burning legislation since economic impacts by farm size will produce dissimilar results.

There are three rice varieties which predominate in California rice production: S6, M9 and M7. Approximately 47 percent of the planted acreage in 1979 was devoted to short statured rice varieties. It is expected that increasing proportions of rice acreage will be devoted to short statured varieties.

Disposal of rice straw in the major producing rice countries of the world correspond to the prevailing economic climate. Frequently foreign countries will graze livestock on rice straw and stubble, although this form of roughage provides only a maintenance level diet. Rice straw is commonly used for building materials such as for thatched roofs. Other uses include mulch, use in mushroom culture and manufacture of paper and cardboard. In Taiwan rice straw is a valued commodity and is sold to paper manufacturers, mushroom growers, and rope makers.

In California virtually all rice straw is disposed of by burning. This represents a deviance from other rice producing states such as Arkansas, Louisiana, Mississippi, and Texas, where rice straw incorporation into the soil is commonly practiced. The soil and climate conditions and to a lesser extent the variety of rice grown in California are not supportive of rice straw incorporation and subsequent decomposition.

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DRAFT

SOIL SUITABILITY FOR CROP PRODUCTION

Under optimum conditions, resource allocation would enable agricultural land to realize its highest and best use. If alternatives to present utilization are to be identified, careful consideration must be given to the available resources, particularly to those characteristics which show potential as limiting factors. With these parameters established, critical levels for suitability can be defined and acreages could subsequently be catagorized according to their characteristics within the given range. Constraints due to climate or other impeding factors need also be identified and the risks associated with crop production on the acreages involved must be further quantified. Only in light of these constraints can a clear picture of suitability for crop production be presented.

IDENTIFICATION OF THE SUBJECT AREA

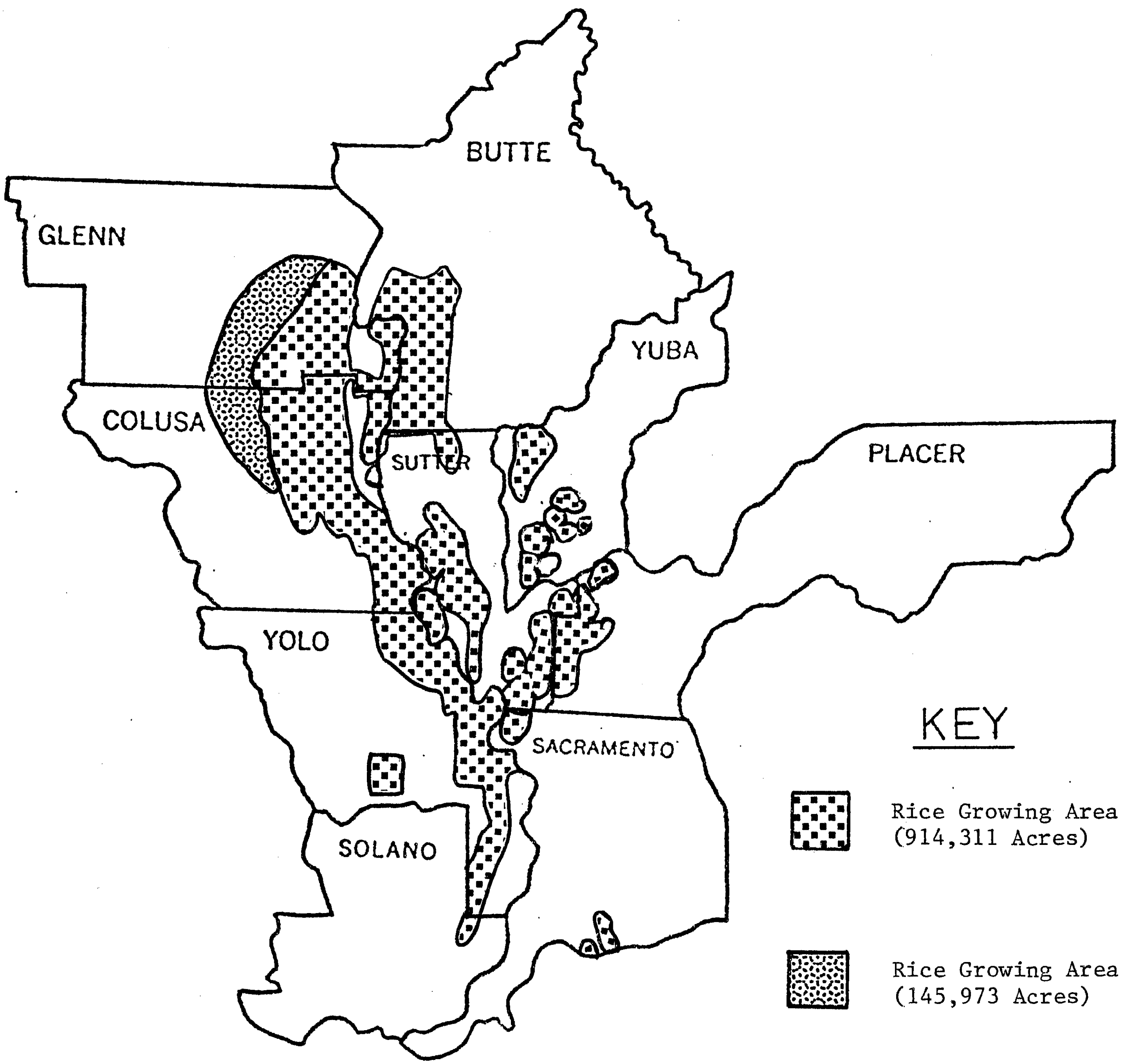
It is imperative that the rice growing areas presented in this study be identified and clearly defined. Included within the rice growing areas are all the acreages producing rice at the present time plus all of the acreages which exhibit soil characteristics capable of producing a normal rice crop. At the present time, virtually all the rice grown in California originates in the Sacramento and San Joaquin Valleys. It is for this reason, and in light of the established markets, that all of the rice growing areas fall withing these two valleys. Figures 3.1 and 3.2 illustrate the rice growing areas for the Sacramento and San Joaquin Valleys respectively, hereafter termed the Central Valley.

It is important to note that the rice growing acreages illustrated and the data presented do not correspond to any singular year, since in any given year a percentage of rice acreage will lie fallow or support an alternate crop or crops. The 1979 California production illustrates this point. Total acreage supporting rice in the State was reported to be 522,000 acres (USDA, 1980). This figure represents only 40 percent of the acreage indicated on the map as supporting or having the potential to produce a normal rice crop.

In order to present the data for rice growing areas on a perennial basis, several sources of information were utilized. Initially, the boundaries and confines of the rice growing area were delineated by utilizing a United States Department of Agriculture survey termed the Wetlands Survey, (Soil Conservation Service, 1973). Additional information pertaining to soil suitability was obtained from California Department of Water Resources surveys. Because these data were county specific and periodically updated they provided a means for affirming the validity of the base map. No discrepancies were encountered among sources. Finally, Copley International Corporation survey data were utilized to expand the subject area. The culmina-

Figure 3.1

SACRAMENTO VALLEY AREAS 1, 2 and 3

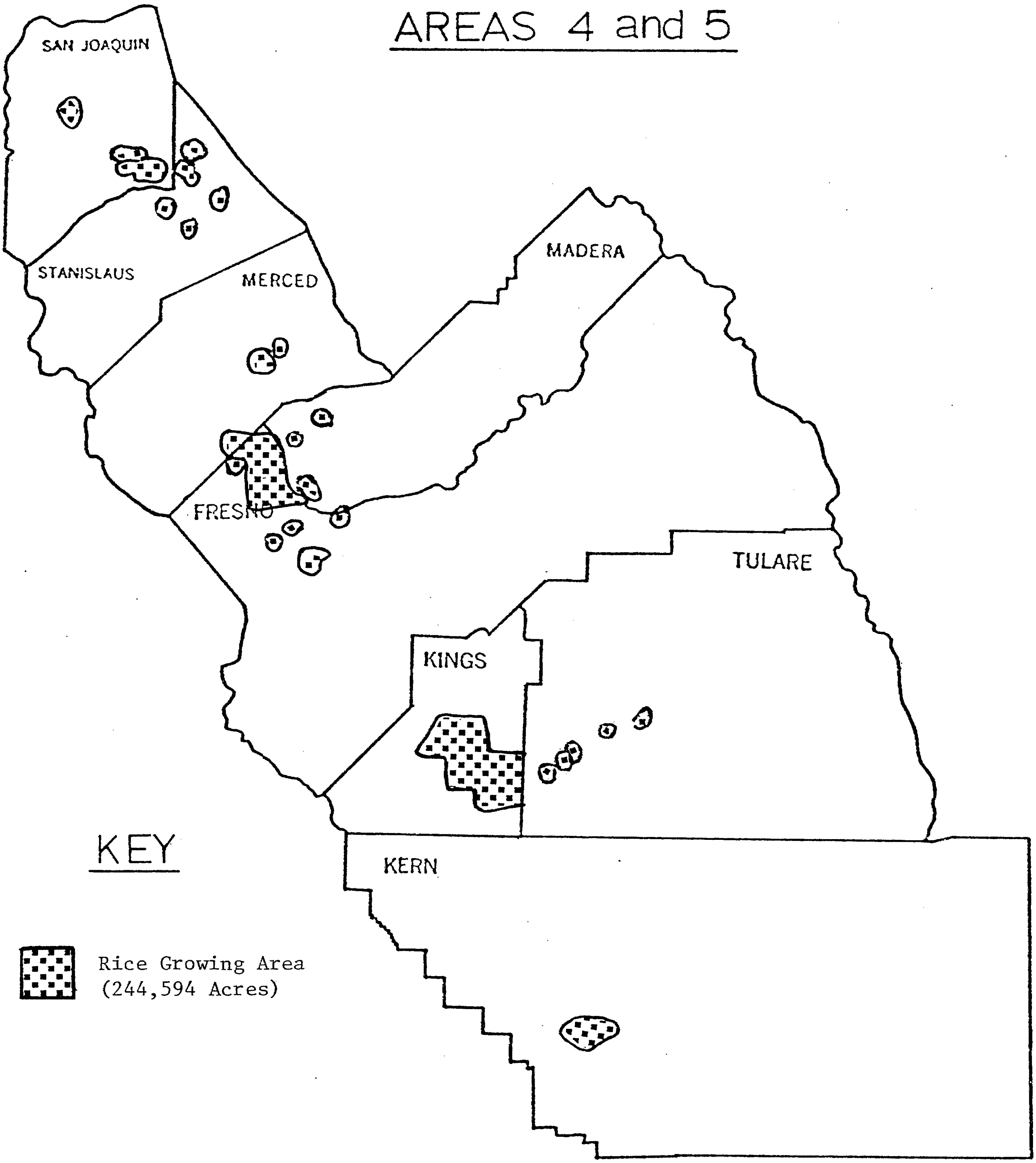


Sources: United States Department of Agriculture, Soil Conservation Service, Berkley, California

Copley International Corporation

Figure 3.2

SAN JOAQUIN VALLEY
AREAS 4 and 5



Sources: United States Department of Agriculture, Soil Conservation Service, Berkeley, California.

Copley International Corporation

tion of this research effort was the production of the previously mentioned maps which define rice growing areas and enumerate their acreages.

SOIL CLASSIFICATION

Prior to determining their suitability for rice or other crops, the soils in the study area must be identified according to certain agronomic considerations. Physical characteristics include surface texture, profile depth, and natural drainage. These physical characteristics will ultimately determine hydrologic soil groups while vegetative soil groups will be distinguished according to specific requirements for crop suitability. Obviously, there will be a range of soil types; these are presented in a supplementary map section. It is the purpose of this study to further identify the range of agronomic considerations and discuss their dissimilarities as well as those subtleties which are common to lending these soils suitable as an aggregate to rice crop production.

Soil Associations

In order to present a general overview of soil characteristics, soil associations were identified and delineated. Detailed tables and maps pertaining to soil associations can be found in the map supplement. A soil association represents at least one major soil series and a minimum of one minor soil series. A specific soil series may occur in several soil associations. Each soil association affords a different potential for general agricultural production and presents different requirements and constraints for proper soil management.

Physical Characteristics

Generally, rice is grown on parcels of land thought to be unsuitable for other crops. Although this statement may be true to an extent, it does not accurately portray the real problems associated with soil classification. Recommendations for land use can only be made after careful consideration has been given to the combination of physical characteristics. Soil textures range from clay soils to sandy soils. Soil profile depth was found to range from three inches to five feet. A look at hydrology indicates that soil conditions can range from permanently saturated to droughty. In light of this tremendous range, an analysis which presents the given acreages in distinct categories has been chosen. With these physical characteristics identified, the soils can be placed in hydrologic and vegetative soil groups and finally classified by their suitability.

Surface Texture. Table 3.1 represents the acreages of the various soil textures found in the rice growing areas. Although there is a wide range of surface textures, clay soils account for 76 percent of the acreage within the subject area. Loam soils comprise an additional 23 percent while silt and sandy soils represent less than 2 percent of the total acreage.

Profile Depth. Table 3.2 shows the acreages for various profile depths throughout the subject area. As expected, a wide range of depths exists; the most shallow are only three inches while other soils are as deep as five feet. The vast

Table 3.1

SURFACE TEXTURE OF RICE SOILS

Location/Acreage	Clays[a]	Loams[b]	Silts and Sands[c]
Sacramento Valley			
AREA 1			
Colusa County	237,744	2,115	3,637
Glenn County	132,392	48,343	493
AREA 2			
Butte County	118,991	76,224	0
Placer County	0	27,482	299
Sutter County	91,859	37,460	3,288
Yuba County	432	33,310	0
AREA 3			
Sacramento County	13,124	1,063	0
Solano County	4,617	0	0
Yolo County	149,362	29,681	0
	748,521	255,678	7,717
San Joaquin Valley			
AREA 4			
Madera County	0	763	0
Merced County	7,041	0	0
San Joaquin County	4,550	11,967	206
Stanislaus County	1,332	3,204	48
AREA 5			
Fresno County	58,851	4,864	0
Kern County	14,598	930	1,063
King County	116,135	7,439	11,790
Tulare County	329	665	0
	202,836	29,814	13,107
	951,357	285,492	20,824

[a] Clay, clay loam and silty clay loam soils.
[b] Loam, silty loam and fine sandy loam soils.
[c] Silt and sand soils.

Sources: United States Department of Agriculture, Soil Conservation Service, Berkeley, California.

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Table 3.2

PROFILE DEPTH OF RICE SOILS

Location/Acreage	Shallow[a]	Moderate[b]	Deep[c]
Sacramento Valley			
AREA 1			
Colusa County	21,190	23,515	224,833
Glenn County	0	49,687	145,231
AREA 2			
Butte County	0	17,516	205,866
Placer County	20,358	5,480	2,989
Sutter County	0	41,740	90,867
Yuba County	0	8,731	25,011
AREA 3			
Sacramento County	1,063	12,859	265
Solano County	2,292	0	2,325
Yolo County	5,712	71,872	108,956
	50,615	231,400	806,343
San Joaquin Valley			
AREA 4			
Madera County	0	0	763
Merced County	0	4,334	2,707
San Joaquin County	0	16,074	764
Stanilaus County	1,330	1,883	1,371
AREA 5			
Fresno County	0	51,880	11,817
Kern County	0	0	10,562
King County	0	133	139,946
Tulare County	0	0	1,030
	1,330	74,304	168,960
	51,945	305,704	975,303

[a]Less than 15 inches of soil.

[b]Between 15 and 40 inches of soil.

[c]Greater than 40 inches of soil.

Sources: United States Department of Agriculture, Soil Conservation Service, Berkeley, California.

Copley International Corporation

majority of the soils found in the rice growing areas are considered deep soils. These deep soils represent 73 percent of the total acreage while soils of moderate depth comprise 23 percent of the total. The remaining 4 percent of the acreage reflects shallow soil depths.

Natural Drainage. Table 3.3 represents the acreages by drainage conditions throughout the subject area. Soils which have poor natural drainage are found on 65 percent of the total acreage for the rice growing areas. Moderate natural drainage conditions were found to represent 8 percent of the total acreage while good drainage conditions prevailed on approximately 28 percent of the remaining acreage.

Soil Groups

Qualities of soils which enable them to support plant growth encompass a multitude of unique combinations of phyical attributes. In order to provide a suitable medium for production, soils must reflect satisfactory hydrologic and vegetative properties. The soils in the subject area must be grouped according to these properties before a determination of suitability for rice or other crops can be made.

Hydrologic Soil Groups. Table 3.4 gives the rice growing acreages identified by hydrologic soil group designations. Group D soils represent 78 percent of the total acreage while Group C soils comprise only 15 percent of the total. Groups B and A approximate 6 and 1 percent of the total, respectively.

Table 3.3

NATURAL DRAINAGE OF RICE SOILS

Location/Acreage	Poor[a]	Moderate[b]	Good[c]
Sacramento Valley			
AREA 1			
Colusa County	186,076	7,346	74,280
Glenn County	73,551	28,197	83,583
AREA 2			
Butte County	138,587	0	56,628
Placer County	0	2,740	25,011
Sutter County	112,582	0	20,025
Yuba County	432	0	33,310
AREA 3			
Sacramento County	13,124	1,063	0
Solano County	4,617	0	0
Yolo County	91,224	45,261	37,685
	620,193	84,607	330,522
San Joaquin Valley			
AREA 4			
Madera County	0	531	232
Merced County	6,543	0	498
San Joaquin County	0	4,550	12,288
Stanislaus County	0	1,229	3,355
AREA 5			
Fresno County	58,715	0	4,982
Kern County	3,189	6,101	1,242
King County	139,847	0	232
Tulare County	1,030	0	0
	209,324	12,411	22,829
	829,517	97,018	353,351

[a]Includes ratings of Very Poor, Somewhat Poor and Poor.

[b]Includes ratings of Moderately Good and Moderate.

[c]Includes ratings of Good, Somewhat Excessive and Excessive.

Sources: United States Department of Agriculture, Soil Conservation Service, Berkeley, California.

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Table 3.4

HYDROLOGIC SOIL GROUPS

	Group A[a]	Group B[b]	Group C[c]	Group D[d]
Sacramento Valley				
AREA 1				
Colusa County	0	3,034	43,244	217,268
Glenn County	493	1,076	65,781	110,595
AREA 2				
Butte County	0	31,546	13,119	147,953
Placer County	299	0	7,124	20,358
Sutter County	0	13,596	6,675	112,018
Yuba County	0	179	8,299	22,491
AREA 3				
Sacramento County	0	0	2,125	12,155
Solano County	0	0	2,292	2,325
Yolo County	0	8,195	35,081	132,604
	792	57,626	183,740	777,767
San Joaquin Valley				
AREA 4				
Madera County	0	763	0	0
Merced County	0	224	1,229	5,317
San Joaquin County	443	206	0	16,074
Stanislaus County	48	334	183	4,019
AREA 5				
Fresno County	0	1,727	3,255	58,715
Kern County	1,063	598	1,860	6,958
King County	11,790	7,306	0	116,268
Tulare County	0	455	478	0
	13,344	11,613	7,005	207,351
	14,136	69,239	190,745	985,118

[a]Soils having high infiltration rates even when thoroughly wetted, consisting chiefly of deep, well to excessively drained sands and/or gravel.

[b]Soils having moderate infiltration rates when thoroughly wetted, consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately coarse textures.

[c]Soils having slow infiltration rates when thoroughly wetted, consisting chiefly of (1) soils with a layer that impedes the downward movement of water or (2) soils with moderately fine to fine texture and a slow infiltration rate.

[d]Soils having very slow infiltration rates when thoroughly wetted, consisting chiefly of (1) clay soils with a high swelling potential; (2) soils with a high permanent water table; (3) soils with claypan or clay layer at or near the surface; and (4) shallow soils over nearly impervious materials.

Sources: United States Department of Agriculture, Soil Conservation Service, Berkeley, California.

Copley International Corporation.

Vegetative Soil Groups. Table 3.5 gives the acreages for the various vegetative soil group designations Specific comparisons are given by the following percentages: Group A, 12 percent; Group B, one percent; Group C, 12 percent; Group D, 10 percent; Group E, 43 percent; Group F, 18 percent; Group G, 4 percent; Group H, zero percent; Group I, zero percent, and Group J, one percent.

Comparison of Sacramento and San Joaquin Valleys

Table 3.6 illustrates the similarities and differences between the soils in the Central Valley. Although these soils are all termed as suitable for rice production, there are important differences which must be identified before specific soils can be termed as suitable for alternate crops or restricted to rice production.

Surface Texture. Clay soils represent 83 percent of the acreage in the San Joaquin Valley and 74 percent of those in the Sacramento Valley. These high clay soils hold water very well and are appropriate for the flood irrigation used in rice production. Loam soils are moderate in texture and are suited to a variety of alternate crops. Loam soils in the Sacramento Valley represent 25 percent of the acreage while 12 percent of the San Joaquin acreages contain loams.

Profile Depth. Under typical conditions, soil depth is not a limiting factor for rice production. However, the variety of alternate crops which can be produced will be restricted to acreages with shallow and moderate profile depths. The Sacramento

Table 3.5

VEGETATIVE SOIL GROUPS

Location/Acreage	Group A[a]	Group B[b]	Group C[c]	Group D[d]	Group E[e]	Group F[f]	Group G[g]	Group H[h]	Group I[i]	Group J[j]
Sacramento Valley										
AREA 1										
Colusa County	26,436	0	41,880	13,916	114,575	65,457	0	0	0	7,274
Glenn County	48,780	3,049	47,628	12,943	60,965	12,586	0	0	0	493
AREA 2										
Butte County	27,102	0	332	0	138,587	0	29,194	0	0	0
Placer County	1,644	299	0	5,480	0	0	20,358	0	0	0
Sutter County	8,283	0	0	11,424	107,368	1,445	0	0	0	3,288
Yuba County	179	0	159	32,912	432	0	0	0	0	0
AREA 3										
Sacramento County	0	0	930	0	12,752	0	598	0	0	0
Solano County	0	0	0	0	4,617	0	0	0	0	0
Yolo County	30,528	2,856	53,740	8,515	81,844	1,499	0	0	0	0
	142,952	6,204	144,669	85,190	521,140	80,987	50,150	0	0	11,055
San Joaquin Valley										
AREA 4										
Madera County	763	0	0	0	0	0	0	0	0	0
Merced County	224	0	0	0	2,659	3,026	249	0	0	0
San Joaquin County	206	443	0	11,524	4,550	0	0	0	0	0
Stanislaus County	266	48	0	0	1,129	0	3,141	0	0	0
AREA 5										
Fresno County	4,982	0	0	29,557	0	29,158	0	0	0	0
Kern County	1,528	1,063	5,712	0	0	2,259	0	0	0	0
King County	104	0	0	0	23,579	116,372	0	0	0	0
Tulare County	0	0	0	0	0	1,030	0	0	0	0
	8,073	1,554	5,712	41,081	31,917	151,845	3,390	0	0	0
	151,025	7,758	150,381	126,271	553,057	232,832	53,540	0	0	11,055

[a] ALL CLIMATICALLY ADAPTED PLANTS SUITED. Soils are deep to very deep, moderately coarse to medium textures, moderately well to well-drained, moderately rapidly to moderately slowly permeable. (Soils in this group can have slight wetness and slight salinity or alkalinity.)

[b] Choice of plants limited by DROUGHTINESS and LOW FERTILITY LEVEL. Soils are coarse to gravelly medium textured, excessively drained, with less than five inches of available water-holding capacity in the root zone.

[c] Choice of plants limited by FINE TEXTURES. Soils are deep to very deep, moderately fine to fine-textured, moderately well-drained, moderately slowly to slowly permeable.

[d] Choice of plants limited by VERY SLOWLY PERMEABLE (CLAYPAN) SUBSOILS. Soils are moderately well-drained, with slow or very slow subsoil permeability.

[e] Choice of plants limited by WETNESS. Soils are imperfectly to very poorly drained. (Drained soil phases will be placed in appropriate group according to their current drainage status. Slight salinity and/or alkalinity may be present.)

[f] Choice of plants limited by SALINITY OR ALKALINITY. Soils are moderately to strongly saline alkali, and usually imperfectly to poorly drained.

[g] Choice of plants limited by DEPTH. Soils are shallow to moderately deep, well-drained, over hardpan, bedrock or other unfractured dense material.

[h] Choice of plants limited by LOW pH. Soils are strongly to extremely acid; pH is less than 5.1.

[i] Choice of plants limited by TOXIC PROPERTIES. Soils are usually moderately to strong serpentine.

[j] Choice of plants depends upon ON-SITE INVESTIGATION. Soils included those in the miscellaneous non-arable category, such as river wash, stoney or rocky upland, etc.

Sources: United States Department of Agriculture, Soil Conservation Service, Berkeley, California.

Copley International Corporation

Table 3.6

COMPARISON OF SACRAMENTO AND SAN JOAQUIN VALLEYS

Surface Texture

Location/Percentage	Clays	Loam	Silts and Sands
Sacramento Valley	74%	25%	1%
San Joaquin Valley	83%	12%	5%

Profile Depth

Location/Percentage	Shallow	Moderate	Deep
Sacramento Valley	5%	21%	74%
San Joaquin Valley	1%	30%	69%

Natural Drainage

Location/Percentage	Poor	Moderate	Good
Sacramento Valley	60%	8%	32%
San Joaquin Valley	86%	5%	9%

Hydrologic Soil Groups

Location/Percentage	Group A	Group B	Group C	Group D
Sacramento Valley	< 1%	6%	18%	76%
San Joaquin Valley	6%	5%	3%	86%

Vegetative Soil Groups

	A	B	C	D	E	F	G	H	I	J
Sacramento Valley	14%	<1%	14%	8%	50%	8%	5%	0%	0%	1%
San Joaquin Valley	3%	1%	2%	17%	13%	63%	1%	0%	0%	0%

Sources: United States Department of Agriculture, Soil Conservation Service
Copley International Corporation

Valley has 26 percent shallow and moderate soil depths while 31 percent of the acreage in the San Joaquin Valley shows these partially limiting soil depths.

Natural Drainage. Many soils with poor natural drainage are ideal for rice crop production. These soils irrigate well and adapt easily to the standing water conditions normally associated with rice growing. Only 60 percent of the soils in the Sacramento Valley exhibit poor drainage characteristics, while 86 percent of the soils found in the San Joaquin Valley show poor natural drainage. Soils which drain well may be better suited to alternate crop production than to supporting rice. The soils with moderate and good drainage comprise 40 percent of the acreage in the Sacramento Valley while only 14 percent of the acreage in the San Joaquin Valley falls into these categories.

Hydrologic Soil Groups. A combination of the previously mentioned physical characteristics was used to place the soils into hydrologic soil groups. Soils found in groups A and B are better suited for alternate crops than those soils found in groups C and D. Furthermore, acreages placed in groups C and D will likely be restricted to rice crop production. Groups A and B represent less than 7 percent of the acreage in the Sacramento Valley and 11 percent of the total acreage in the San Joaquin Valley. Groups C and D, which would likely be restricted to rice, represent 94 percent and 89 percent of their total acreages, respectively.

Vegetative Soil Groups. The ultimate determation of soil suitability for crop production was made from vegetative soil groups. It is within these groups that the greatest differences in the two valleys can be found. Group A soils, which are the most suitable for alternate crops are predominantly found in the Sacramento Valley. The acreage in this group represents 14 percent of the Sacramento Valley soils while only 3 percent of the San Joaquin Valley soils fall into Group A. The majority of high-clay soils, which fall into Group C, are found in the Sacramento Valley which has 14 percent while the San Joaquin Valley has only 2 percent of these clay soils. Group E soils are characterized by wetness and limit the choice of plants to those which adapt to flood irrigation and ponded conditions. Half of the acreage in the Sacramento Valley falls into this group. Another major difference can be found Group F which are those soils in which the choice of plants is limited by salinity. This characteristic would most certainly limit the soils to rice production. Furthermore, low rice yields can only be avoided by utilizing high salinity resistant strains. Only 8 percent of the Sacramento Valley soils fall into Group F, while 63 percent of the soils in the San Joaquin Valley fall into this group. Subtle differences can be found in the remaining vegetative groups shown on Table 3.6.

Soils Most Suitable for Rice

Soils which are best suited for rice growing include those in vegetative groups D, E, and F. These soils are characterized by poor drainage, wetness, and strong salinity or alkalinity. The majority of the soils have drainage and salinity problems due to the presence of subsurface claypans. These claypans inhibit subsoil permeability causing a pooling effect which keeps the soils in a wetted condition and encourages the accumulation of salts below the surface.

These soils can be readily adapted to rice production. The poor drainage conditions facilitate the use of flood irrigation which will minimize water application costs. Specific salinity resistant varieties can be selected under these difficult conditions, and thus, enable the grower to achieve normal yields.

The vast majority of soils in the rice growing area are termed most suitable for rice production. Of the total acreage in the study area, 71 percent of the soils fall into this category. In the San Joaquin Valley, 92 percent of the soils studied are most conducive to rice production, while 66 percent of the Sacramento Valley soils appear in this group.

Soils Most Suitable for Alternate Crops

Soils which are well suited to support alternate crops are identified by vegetative groups A, B, and C. These soils all display rapid drainage characteristics which would make rice irrigating practices unfeasible. Group A soils can support any climatically adapted plants. Group B soils are limited by low fertility but it is assumed that fertilizer application is a prudent soil management consideration for most crops under typical circumstances. All of the soils have slight textural constraints but it is further assumed that sound cultural practice will reasonably alleviate these difficulties.

Of the soils studied, 24 percent of the soil acreage is termed as most suitable for alternate crops. A closer examination of the acreages reveals that these soils are predominantly found in the Sacramento Valley. Only 6 percent of the acreage in the San Joaquin Valley appears in this category while 28 percent of the Sacramento Valley acreage is suitable for alternate crops.

Soils Least Suitable for Rice or Alternate Crops

Soils not normally considered for any agricultural production comprise this category. Soils termed least suitable are those found in vegetative groups G and J. Included in this category are soils appearing over hardpan, bedrock or other unfractured dense material and those miscellaneous non-arables such as river wash or rocky uplands. Final determination of suitability of these areas could only be made following an on-site investigation of the questionable acreage.

Only 5 percent of the total soils in the rice growing areas are considered least suitable for rice or alternate crops. In the Sacramento Valley 6 percent of the acreages fall into this category while 2 percent of the San Joaquin Valley acreages are considered in this group.

CROP SUITABILITY

Soil classification was used to identify and group acreages within the subject area. This information can be further used to establish critical levels of soil quality and group soils according to crop suitability. Virtually any crop can be grown on a given soil barring extraordinary weather conditions; the purpose of this section is to identify those soils which would sustain commercial production of agronomically suitable crops.

Figures 3.3 and 3.4 illustrate the crop suitability for the rice growing areas within the Sacramento and San Joaquin Valleys. These maps identify and delineate those areas most suitable for rice and alternate crops as well as those least suitable for crop production.

Table 3.7 gives the crop suitability for the subject area in tabular form. Acreages for the suitability categories are presented for the individual counties and for the valleys as a whole.

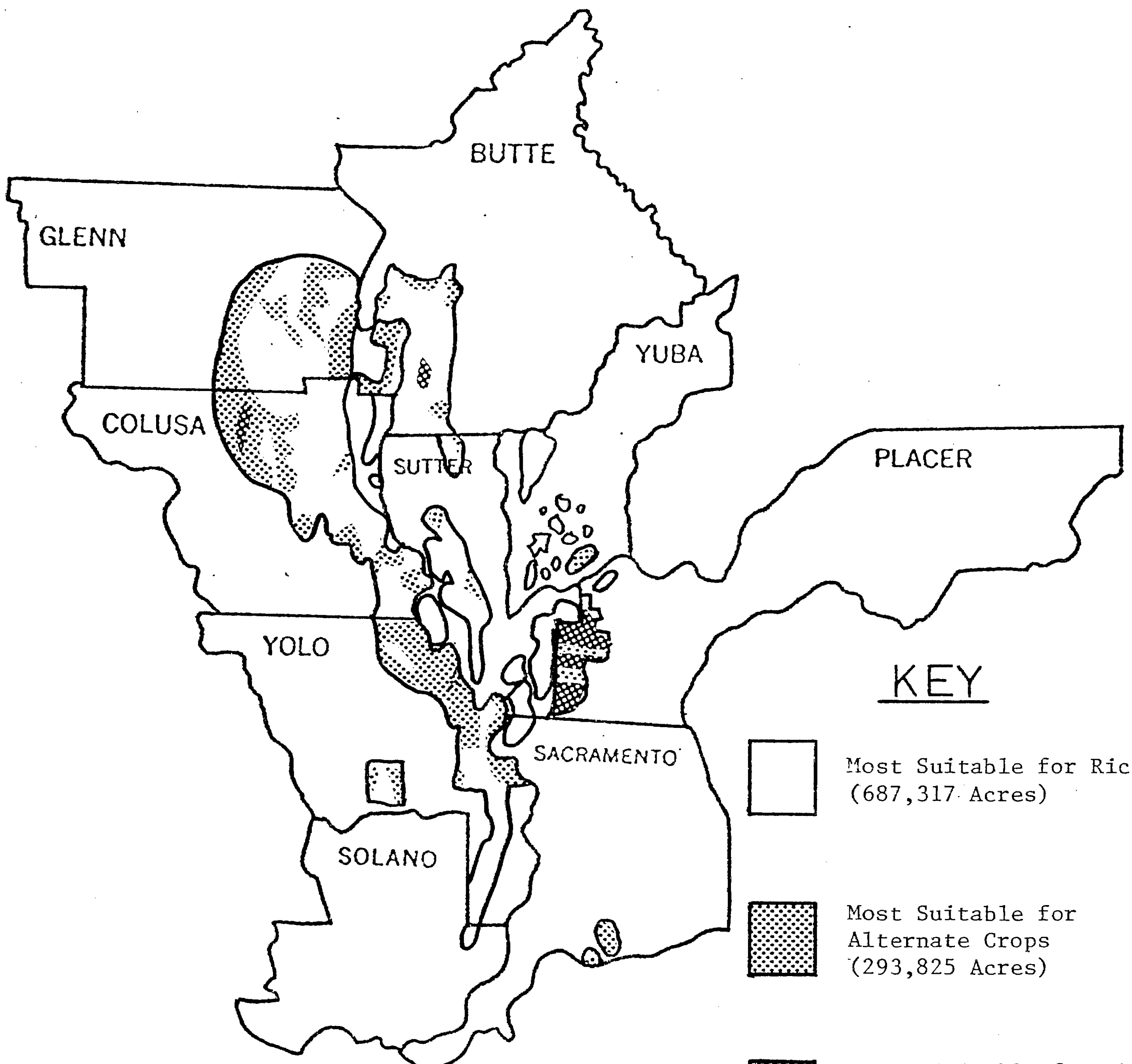
Table 3.8 shows the relative percentages of these crop suitability categories and can be used to further examine differences between the two valleys. The percentages of the total acreage which each suitability group represents are also given in Table 3.8.

Supportive Information

Preliminary empirical data suggests that a majority of the acreage within the subject area would be restricted to rice

Figure 3.3

SACRAMENTO VALLEY
AREAS 1, 2, and 3



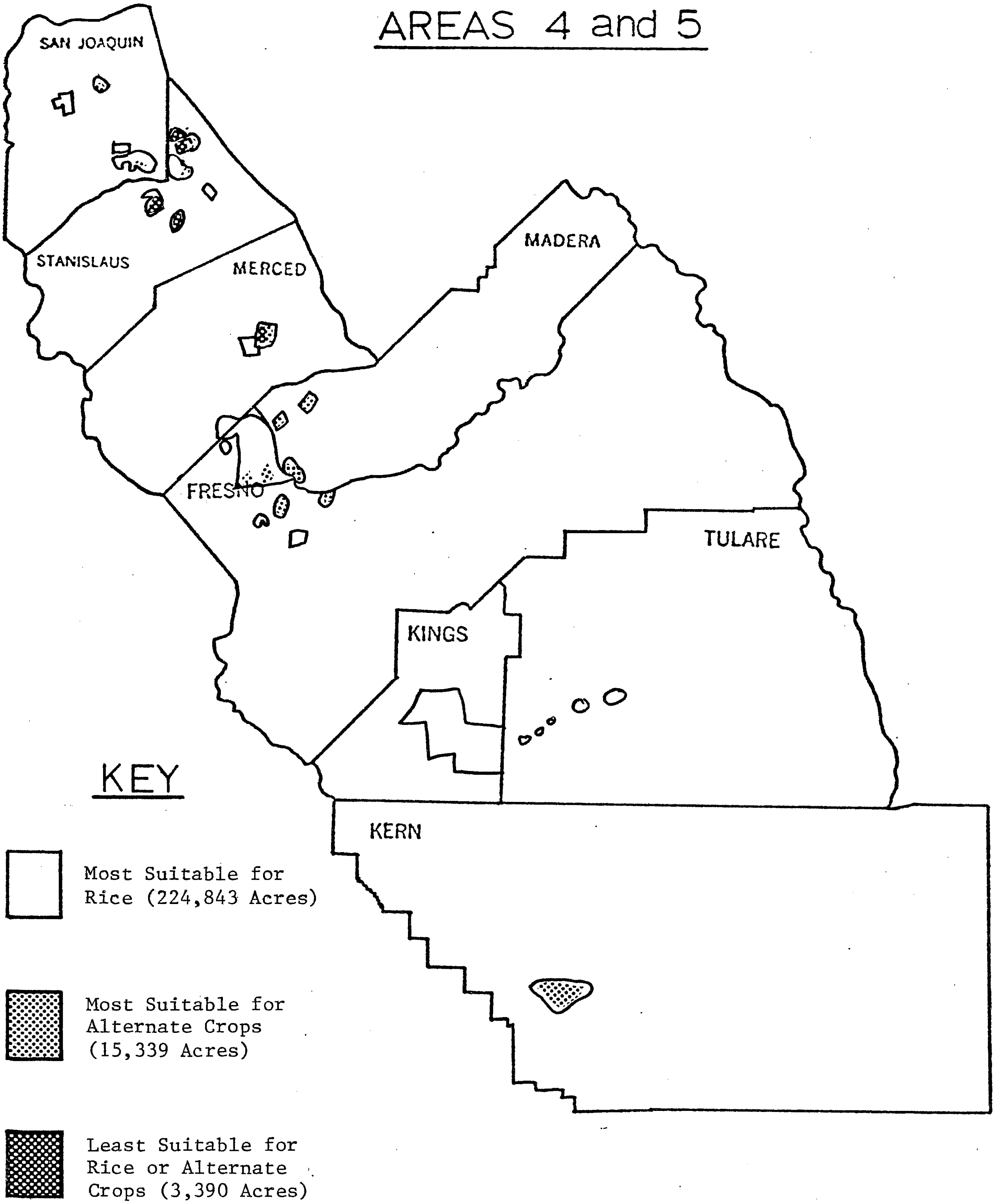
KEY

- Most Suitable for Rice (687,317 Acres)
- Most Suitable for Alternate Crops (293,825 Acres)
- Least Suitable for Rice and Alternate Crops (61,205 Acres)

Sources: United States Department of Agriculture, Soil Conservation Service, Berkeley California
Copley International Corporation

Figure 3.4

SAN JOAQUIN VALLEY
AREAS 4 and 5



Sources: United States Department of Agriculture, Soil Conservation Service, Berkeley, California
Copley International Corporation

Table 3.7

CROP SUITABILITY

Location/Acreage	Most Suitable for Rice	Most Suitable for Alternate Crops	Least Suitable for Rice or Alternate Crops
Sacramento Valley			
AREA 1			
Colusa County	193,948	68,316	7,274
Glenn County	86,494	99,457	493
AREA 2			
Butte County	138,587	27,434	29,194
Placer County	5,480	1,943	20,358
Sutter County	120,237	8,283	3,288
Yuba County	33,344	338	0
AREA 3			
Sacramento County	12,752	930	598
Solano County	4,617	0	0
Yolo County	91,858	87,124	0
	687,317	293,825	61,205
San Joaquin Valley			
AREA 4			
Madera County	0	763	0
Merced County	5,685	224	249
San Joaquin County	16,074	649	0
Stanislaus County	1,129	314	3,141
AREA 5			
Fresno County	58,715	4,982	0
Kern County	2,259	8,303	0
King County	139,951	104	0
Tulare County	1,030	0	0
	224,843	15,339	3,390
TOTAL	912,160	309,164	64,595

Source: United States Department of Agriculture, Soil Conservation Service, Berkeley, California
Copley International Corporation

Table 3.8

CROP SUITABILITY

Location/Acreage	Most Suitable for Rice	Most Suitable for Alternate Crops	Least Suitable for Rice or Alternate Crops
Sacramento Valley	66%	28%	6%
San Joaquin Valley	92%	6%	2%
Total Rice Growing Area	71%	24%	5%

Source: United States Department of Agriculture, Soil Conservation Service, Berkeley California
Copley International Corporation

crop production. Realistically, prudent soil management would preclude the necessity for rotation on these soils with alternate crops. Among the benefits of rotation are the reduction of disease problems, increased soil fertility, and control of weeds and insects, providing the soil would sustain other crops.

In order to fully establish the potential of subject soils in respect to crop suitability a unique combination of checks and balances was utilized. First, crop suitability was analyzed in light of criteria established by the Soil Conservation Service. Second, an extensive survey of rice grower's cropping patterns and related yields was conducted by Copley International Corporation. The results of this survey provide a basis to contrast the empirical findings and justify crop suitability recommendations.

Survey of Rice Growers. Copley International Corporation surveyed farmers throughout the subject area to identify crop rotation plans, crop mixed and approximate yields for alternate crops grown on rice producing acreage. Although the survey information does not permit direct comparisons with the empirical data, it does provide a logical basis for highlighting and contrasting the information taken from Soil Conservation Service reports.

Table 3.9 indicates the percentages of farmers who maintain their fields permanently in rice as well as those who periodically rotate other crops on their rice acreage. Of the farmers surveyed, 64 percent responded that they do not rotate their rice

Table 3.9

CROP ROTATION

Location/Percentage	Farmers Rotating Rice Acreage	Farmers Not Rotating Rice Acreage
Sacramento Valley	37%	63%
San Joaquin Valley	33%	67%
Total Rice Growing Area	36%	64%

Source: Copley International Corporation

acreage while 36 percent indicated that rotation was part of their management practice.

Table 3.10 illustrates the ratio or rice to alternate crops on a percentage basis. For the total rice growing area, 48 percent of the acreage surveyed was presently utilized for rice production; alternate crops account for the other 52 percent of the total acreage. There is a significant difference in the percentage ratios presented for the two valleys. Rice acreage for the Sacramento Valley comprised 52 percent, contrasted with only 29 percent rice acreage in the San Joaquin Valley.

Table 3.11 gives the expected yields for alternate crops grown on rice acreage. Only 3 percent of the farmers surveyed anticipated that their rice land would produce above average yields when supporting alternate crops. The majority of the farmers expected below average yields as evidenced by the 71 percent grower response. A moderate portion of the respondents, i.e., 26 percent, indicated that they would expect normal crop yields. There were no significant inter-valley differences for any of the categories.

SUMMARY

An empirical study of the soils in the rice growing areas was made based on data obtained from the Soil Conservation Service. This data revealed that a relative proportion of soils in both valleys reflected similar surface texture quali-

Table 3.10

CROP MIX[a]

Location/Percentage	Rice	Alternate Crops[b]
Sacramento Valley	52%	48%
San Joaquin Valley	29%	71%
Total Rice Growing Area	48%	52%

[a]Percentage of acreage planted year in which survey was taken.

[b]Alternate crops include: alfalfa, almonds, barley, beans, corn, cotton, milo, oats, prunes, safflower, sugar beets, tomatoes, vine seed, walnuts, wheat, grain, and other crop.

Source: Copley International Corporation

Table 3.11

ALTERNATE CROP YIELDS[a]

Location/Percentage	Expected Yield[b]		
	Below Average	Average	Above Average
Sacramento Valley	72%	25%	3%
San Joaquin Valley	69%	28%	3%
Total Rice Growing Area	71%	26%	3%

[a]Alternate crops include: alfalfa, almonds, barley, beans, corn, cotton, milo, oats, prunes, safflower, sugar beets, tomatoes, vine seed, walnuts, wheat, grain, and other crops.

[b]Estimates made by respondents of survey.

Source: Copley International Corporation

ties and profile characteristics. San Joaquin Valley exhibited poorer drainage characteristics and greater restrictions on crop suitability due to salinity or alkalinity problems. For instance, 63 percent of the rice soils in the San Joaquin Valley is reported to be moderately to strongly alkali. In total, the empirical assessment of the Central Valley soils suggests that 92 percent of the San Joaquin Valley and 66 percent of the Sacramento Valley's rice area is most suitable for rice.

It was assumed that survey data would support these empirical findings. In the Sacramento Valley the survey revealed that 52 percent of the rice acreage is solely used for rice; this supports the empirical findings. In San Joaquin Valley, however, the majority of the rice growing area is used for alternate crops in any given year. Empirically, it was estimated that 92 percent of the southern valley soils were best suited for rice; although, growers reported that actually 72 percent of these soils are devoted to alternate crops.

Rice growers in the San Joaquin Valley report that rice is often grown in rotation with other crops since the large volume of water used in rice culture displaces the alkaline salts in the soil and forces them down through the soil horizon. Subsequent crops can be grown on these temporarily reclaimed soils without the threat of serious yield declines due to salinity. This farm management practice would partially explain the disparity between survey data and the empirical findings. In addition, it is reasonable to assume that much of the San Joaquin Valley soils have been fitted with tile drainage systems and reclaimed by similar leaching practices.

It remains clear that over half of the soils accounted for in the survey area are best suited for rice. In Sacramento Valley, which comprises the majority of rice acreage in California, 63 percent of farmers reportedly do not grow alternate crops on their rice ground. When asked what yields could be expected from alternate crops on these rice soils, 71 percent of California's rice growers reported below average crop yields. If rice growers had no other choice but to grow alternate crops it is estimated that nearly half could compete with other commercial growers from an agronomic standpoint. The impacts would be dissimilar depending on location. For example, Sutter County would have less options than Butte County. (Refer to Table 3.7).

It should be emphasized that soil (and climate) criteria, while very important, do not solely determine the actual farm crop mix. To a large extent, external market factors, availability of support services, as well as individual farmer experience will ultimately constrain the farmer to a select number of crops. It is readily apparent that in Areas 1 and 2 all of the above named factors have contributed to the concentration of rice growing activity at these locations. In the San Joaquin Valley, these same factors have created a separate set of conditions which support the culture of alternate crops in lieu of rice. If soils alone were used for determining crop selection, then the mapped portion of the San Joaquin Valley would be predominantly in rice; however, as the survey makes readily apparent, the majority of acreage in this area is devoted to crops other than rice.

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INCORPORATION OF RICE STRAW

Under optimal conditions, the incorporation of agricultural waste products is undertaken in the absence of duress. However, any decision-making concerning rice straw incorporation by the grower precludes that elimination of waste burning through regulation is imminent. It is expected that rice farmers will not undertake straw incorporation of their own volition as there are additional logistical and economic considerations which are not associated with open-field burning.

Should open-field burning be restricted, rice straw incorporation could then be compared with other technical alternatives for rice straw utilization and disposal. This study presents the technical and economic constraints of such a disposal technique as a possible short-run solution to this complex problem. Further research is needed to identify conditions and procedures under which such an endeavor could prove both technically and economically feasible.

TECHNICAL FEASIBILITY

Rice straw incorporation presents a unique set of logistical and cultural problems. Among these considerations are: soil physical characteristics and suitability, nitrogen nutrition, seedling toxicity, and stem rot incidence and disease severity.

As rice straw incorporation has not been extensively used due to widespread burning, the majority of information pertains to field trials and other testing procedures. It is the purpose of this technical evaluation to identify those areas which could be considered suitable for incorporation and further describe those constraints which ultimately determine the effectiveness of such a technique.

Soil Physical Characteristics

Incorporating rice straw into soils requires both mechanical and biological processes. Mechanical aspects of tillage operations can be severely hampered by difficult soil conditions. Obviously, wet soils will be more difficult to work than dry soils, and sticky, high-clay soils will present greater problems than soils with moderate textures. It is the purpose of this section to further identify those physical characteristics which will enhance or impede rice straw incorporation and subsequently group them as to hydrological soil groups. These hydrological groups will ultimately be utilized to determine soil suitability for incorporation.

Surface Texture. An examination of Table 3.1 reveals that 76 percent of the soils in the rice-growing area are clay soils. When wetted, these clay particles display cohesive and adhesive qualities which are characterized by excessive stickiness. This characteristic will impede the movement of any type of tillage equipment, making the task of incorporation impractical. Tractors, plows and tools repeatedly become clogged and jammed with thick accum-lations of mud and straw which required immediate removal.

Soils with loam surface textures represent 23 percent of the acreage within the subject area. These loams, when adequately drained, should not significantly impede tillage equipment. However, when wetted, these soils reflect characteristics which are very similar to those of clay soils. These wetted loam soils will be more massive than clay soils, applying greater resistance to tillage equipment, although mud accumulation is not as hindering as was the case for clay soils. It is important to note that these loam soils often have clay subsoils. This is to say that should the grower use deep-tillage equipment on wetted soils, the effect would be the same as that with clay soils.

Silt and sand soils present a unique problem for incorporation. Although the soil surface textures present no real problems for tillage equipment; prolonged use of heavy equipment on these soils will cause compaction. This compaction often culminates in the formation of a plowpan, which will significantly alter the drainage characteristics of these soils. Additionally, an unattended plowpan can achieve a density which could prove impervious to root penetration by many plant types.

Profile Depth. Table 3.2 identified soil depth acreages throughout the rice-growing area. Implements used for tillage operations during incorporation have specific soil depth requirements. The minimum plow depth to insure complete burial of the rice straw is eight to ten inches (Burkhardt et.al., 1975). Only 4 percent of the acreage within the subject area have profile depths less than 15 inches. This shallow group designation includes primarily these acreages which have rock layers immediately below the soil surface or those which actually have rock outcroppings.

The remaining 96 percent of the acreage within the rice-growing area represents soils with depths greater than 15 inches. Many of these soils have dense clay subsoil layers which will retard implement movement through the soil and require the tillage operation to expend additional energy to completely incorporate the rice straw. Under deeper tillage conditions, the implements used may break up the dense clay subsoil and, through subsequent mixing, increase the clay content of the surface soil layer. This mixing will alter both the physical characteristics and the tillage requirements for the soils cited.

Natural Drainage. Table 3.3 indicated the acreages with certain drainage rating designations within the rice-growing area. Natural drainage ratings give an indication of the rate at which a soil will dry. Soils with poor natural drainage ratings account for 65 percent of the acreage of rice soils. These soils lose very little water through subsoil percolation and, consequently, they maintain their wetted characteristics for a long period of time.

Soils with moderate and good drainage ratings represent the remaining 35 percent of the acreage of the rice soils. These soils will dry out more quickly than those soils with poor natural drainage. This characteristic will enable these soils to be tilled under a wide variety of operating conditions and are the most readily adapted to incorporation practices.

Hydrologic Soil Groups. Table 3.4 gave the acreages of rice soils in each of four hydrologic soil groups. The soils represented in Group A comprise only one percent of the total. These soils present no major problems for incorporation as they consist of deep, coarse, well-drained soils, having high infiltration rates even when thoroughly wetted.

Soils represented by Group B account for 6 percent of the rice soil acreage. These soils will place minor constraints on the incorporation practices under certain conditions. These soils have moderate infiltration notes when thoroughly wetted and exhibit moderate depth, drainage and textural characteristics.

Soils having slow infiltration rates when thoroughly wetted and having either an impeding layer or a clay subsoil comprise the acreage found in Group C. This acreage represents 15 percent of the rice soils. Group C soils will all place some constraints on incorporation practices. The degree to which these constraints will hinder the operation is dependent on the combination of physical characteristics present and on other site-specific factors.

Group D soils represent the greatest percent of the total acreage (78 percent) and are expected to present the greatest difficulties to incorporation practices. These soils have slow infiltration rates when thoroughly wetted and include: clay soils with a high swelling potential; soils with a high permanent water table; soils with claypans; and shallow soils over bedrock. The severity of these factors will vary with specific locations and be contingent on the combination of other physical characteristics present.

Soil Suitability for Incorporation

Figures 4.1 and 4.2 identify and delineate rice soils according to specific suitability ratings. Table 4.1 gives the corresponding information in tabular form. Three soil suitability ratings were used: least suitable for incorporation, conditionally suitable for incorporation, and most suitable for incorporation. A combination of soil physical characteristics and hydrologic soil groupings were used as criteria for determining the suitability categories and the acreages they represent.

The vast majority of rice soils (82 percent) were termed as least suitable for incorporation. Many of these soils are characterized as having high-clay contents and poor natural drainage. Under optimal weather conditions, these poorly drained soils may prove marginally suitable for incorporation. The remainder of the soils in the least suitable category have very shallow hardpans or underlying rock layers which will make incorporation unfeasible, regardless of climatic conditions.

A modest portion (17 percent) of the acreage within the rice-growing area is termed as conditionally suitable for incorporation. These soils are best described as having antagonistic physical characteristics. For example, a soil with good surface texture but poor drainage due to a deep, impervious layer would be placed in this category. These soils will be suitable for incorporation under ideal weather conditions. Further investigation of the specific soil site would be required to determine the suitability for incorporation under more difficult weather conditions which would hamper the soil's ability to dry prior to tillage.

Less than one percent of the soils studied were termed as most suitable for incorporation. It is expected that these soils will provide an adequate medium for incorporation under all climatic conditions.

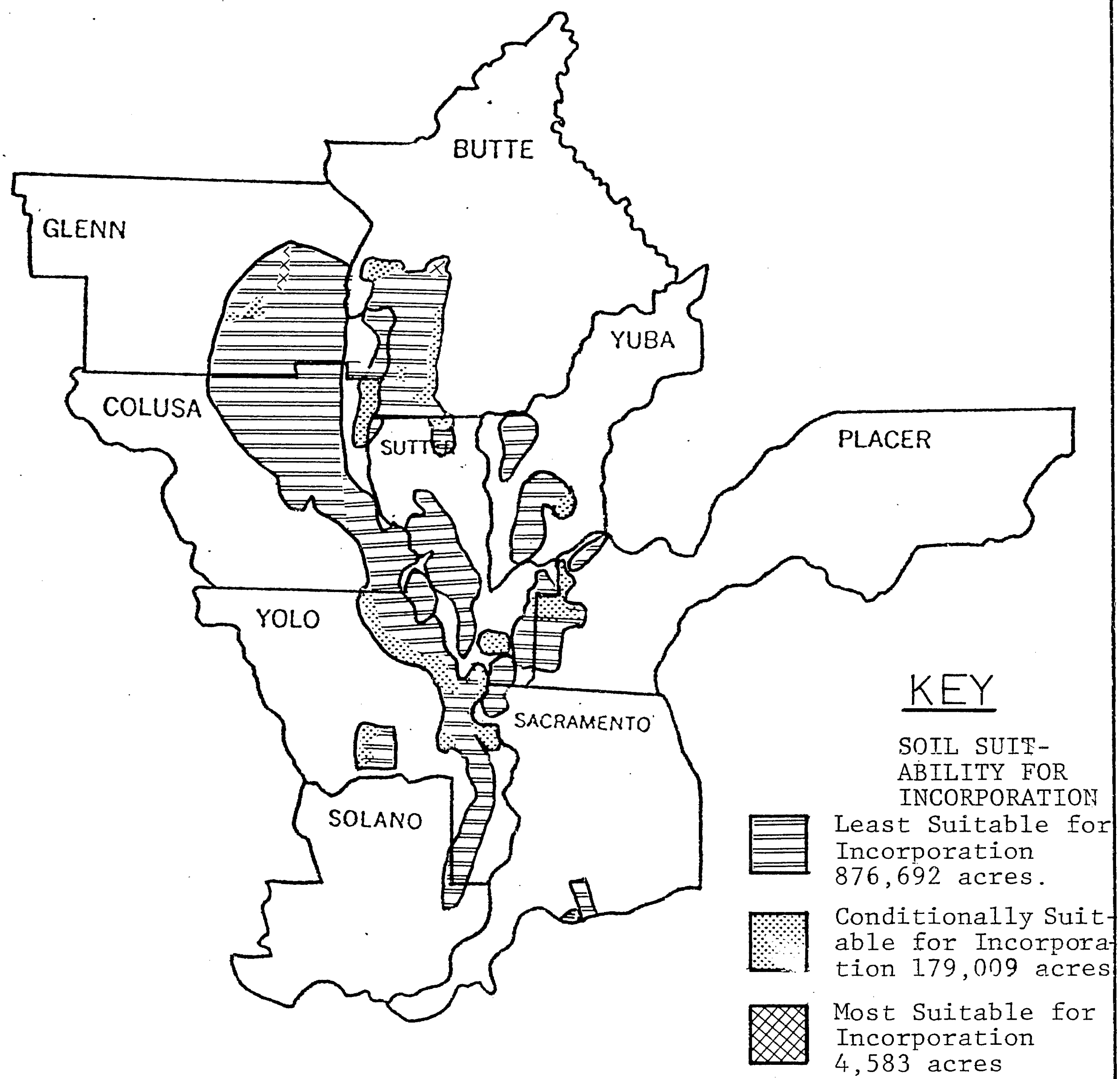
Climatological Variation

Timely incorporation of rice straw is dependent on soil moisture conditions. In the previous section, acreages within the rice-growing area were identified and delineated according to their suitability for incorporation. The suitability determinations were made according to two specific criteria. First, soils were grouped according to their capacity to hold and drain water under normal weather conditions. This provided information as to the ability of the soil to dry out prior to incorporation. Secondly, soils were removed from certain suitability groups and placed in others, following an evaluation of their potentially limiting factors. As these ratings are arrived at, given normal weather conditions, results must be evaluated in light of variations in rainfall.

Temperature. The ambient temperature will affect the rate at which a soil will dry due to evaporation. The following

Figure 4.1

SACRAMENTO VALLEY AREAS 1, 2, and 3

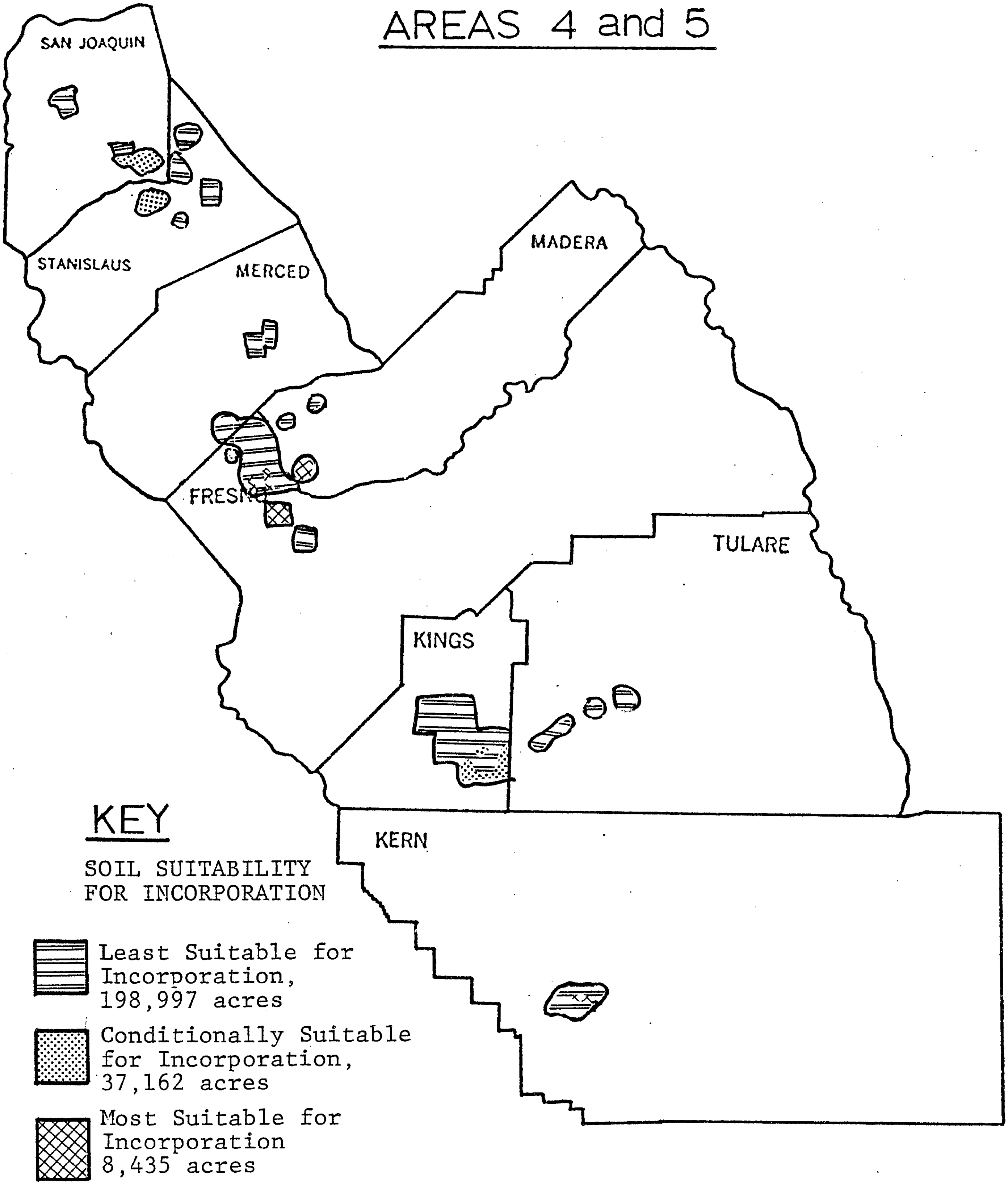


Sources: Soil Conservation Service, General Soil Reports
Copley International Corporation

Figure 4.2

SAN JOAQUIN VALLEY

AREAS 4 and 5



Sources: See Sacramento Valley

Table 4.1

SOIL SUITABILITY FOR INCORPORATION

Location/Acreage	Least Suitable for Incorporation[a]	Conditionally Suitable for Incorporation[b]	Most Suitable for Incorporation
Sacramento Valley			
AREA 1			
Colusa County	257,715	11,823	0
Glenn County	185,054	6,578	3,288
AREA 2			
Butte County	118,991	74,929	1,295
Placer County	5,480	23,347	0
Sutter County	117,895	14,712	0
Yuba County	33,344	398	0
AREA 3			
Sacramento County	14,280	0	0
Solano County	4,617	0	0
Yolo County	139,316	47,224	0
	876,692	179,009	4,583
San Joaquin Valley			
AREA 4			
Madera County	0	0	763
Merced County	7,041	0	0
San Joaquin County	4,550	11,524	764
Stanislaus County	2,226	2,059	299
AREA 5			
Fresno County	58,981	0	4,716
Kern County	8,901	0	1,661
King County	116,268	23,579	232
Tulare County	1,030	0	0
	198,997	37,162	8,435

[a]Soils in Hydrologic Groups C and D, with other severely limiting factors.

[b]Soils in Hydrologic Groups B, C and D, with other moderately limiting factors.

[c]Soils in Hydrologic Groups A and B, with no apparent limiting factors.

Sources: United States Department of Agriculture, Soil Conservation Service, Berkeley, California.
Copley International Corporation

temperature ranges are representative of the rice-growing area:

- Upper Sacramento Valley east - Butte and Yuba Counties (maximum 90.6°F, minimum 58.9°F)
- Upper Sacramento Valley west - Glenn County and northern Colusa County (maximum 89,8°F, minimum 37.6°
- Lower Sacramento Valley - northern Yolo County and Sutter Basin (maximum 90.0°F, minimum 55.6°F)
- Delta and fringe area - Sacramento and San Joaquin Counties (maximum 89.9°F, minimum 53.4°F
- San Joaquin Valley - Fresno and Kern Counties (maximum 92.2°F, minimum 59.2°F)

Source: Agronomy Progress Report, "Summary of 1978 and Milti-Year Statewide Rice Variety Tests," Agricultural Extension Service, University of California, Davis (July, 1979)

As the temperature range for these areas is minimal, it is expected that the relative importance of this factor will be overshadowed by both soil characteristics and rainfall with respect to rice straw incorporation.

Rainfall. Preliminary incorporation practices would begin in the fall, following the traditional rice harvest. The completion of these incorporation practices would take place in the spring, prior to the subsequent planting of the new rice crop. It is for this reason that September, October, April and May have been selected as the critical months for this analysis. Table 4.2 gives the probabilities of various levels of monthly total rainfall for these four critical months. It can be seen that the probability is 27.4 percent that April rainfall will exceed three inches, the level associated with low-yield years.

Table 4.2 considers the months of April, May, September, and October that had rainfall greater than one inch and indicates the chances that weekly totals (as measured in Chico, California) will be greater than one of several given levels. The last week in April and the second week of October seem to have had a greater incidence of high rainfall amounts (above 0.5 inch per week) than might be expected from monthly averages. These two weeks are particularly critical for rice straw incorporation in the Sacramento Valley.

From averages of weekly rainfall totals, Figure 4.3 shows not only the totals but also the estimated availability of hours for field work on rice land (Cervinka et.al., 1975).

Table 4.2

ANALYSIS OF RAINFALL INTENSITY (1913 to 1970)

Rainfall Intensity, In./Mo.	Frequency of Rainfall Intensity for the Month of							
	April		May		September		October	
	Yrs.	%	Yrs.	%	Yrs.	%	Yrs.	%
0 to 1	23	39.8	32	55.1	54	93.2	20	51.8
1 to 2	15	25.9	20	34.6	1	1.7	14	24.2
2 to 3	4	6.9	5	8.6	1	1.7	7	12.1
3 to 4	6	10.3	1	1.7	2	3.4	4	6.8
4 to 5	5	8.6					1	1.7
5 to 6	2	3.4					1	1.7
6 (plus)	3	5.1					1	1.7

Source: (Cervinka, V. et.al., 1975)

Table 4.3

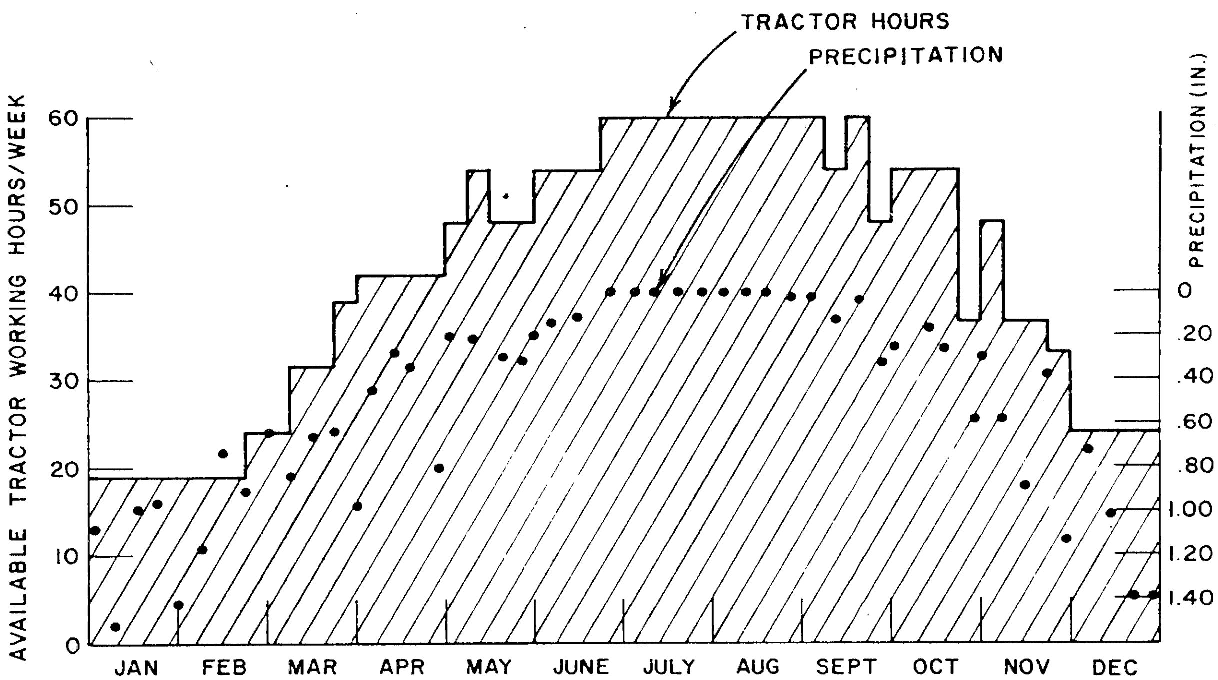
WEEKLY RAINFALL DISTRIBUTION (1913 to 1970)

Month	Week	Number of years when rainfall was greater than 1 inch/month during month in question					
		Rainfall intensity - inches/week					
		0	-.05	-1.0	-1.5	-2.0	2.0+
April	1	9	4	5	6	4	7
(35 years)	2	3	14	11	4	1	2
	3	13	13	4	1	0	4
	4	7	9	6	6	3	4
May	1	8	10	3	1	1	0
(26 years)	2	10	7	4	2	0	0
	3	5	8	6	3	1	0
	4	2	13	2	4	2	0
September	1	4	0	0	0	0	0
(4 years)	2	3	0	0	0	0	1
	3	3	0	0	0	1	0
	4	1	0	1	1	0	1
October	1	15	3	3	2	0	3
(28 years)	2	9	7	4	0	1	5
	3	11	7	3	2	0	0
	4	7	5	2	5	4	3

Source: (Cervinka V. et al., 1975)

Figure 4.3

PRECIPITATION AND TRACTOR WORKING HOURS[a]



[a]Average weekly precipitation (Chico, Calif.) and estimated available tractor working hours per week.

It appears from these tables that rainfall for this time period is low, although it may vary from year to year. In low rainfall years, it is expected that the acreages within the suitability groups will shift toward the most suitable for incorporation grouping. In high rainfall years, the results presented would remain the same, but the soils termed conditionally or least suitable would prove unsuitable for incorporation should this practice be undertaken.

Cultural Considerations

Incorporation of rice straw is known to affect certain cultural practices of rice grain production. For instance, immediately following incorporation, soil microbes start decomposing the rice straw and assimilating soil reserves of nitrogen. This condition is referred to as the mineralization process and results in a nitrogen-deficient condition in the soil. Other aspects of incorporation involve the production and accumulation of organic acids in the soil which may produce a toxic effect on rice seedlings. The effect that rice straw incorporation has on insects and pests is another cultural issue of concern. These three topics are separately discussed in this section. The research findings of various studies are presented in an attempt to summarize the latest information on the cultural aspects of rice straw incorporation.

Nitrogen Nutrition. Once organic matter is introduced into the soil, microorganisms make use of this good supply of energy which promotes a rapid growth of the microbial population. If the organic matter has a small amount of nitrogen in relation to the carbon present, the microorganisms will metabolize other available forms of nitrogen (NH_4^+ or NO_3^-) present in the soil to further the decomposition. Crop residues can be classified according to their ratio of percentage carbon to percentage nitrogen (C:N), which defines the relative quantities of these two elements in the organic material. As a general rule, when organic materials with a C:N ratio of greater than 30 are added to soils, there is immobilization of nitrogen during the initial decomposition process (Tisdale and Nelson, 1975). The C:N ratio will vary depending on the fertility conditions under which the crop is grown. Mature rice straw raised under high fertility conditions could be expected to contain 36.3 percent carbon and .75 percent nitrogen, which corresponds to a C:N ratio of 48:1 (Rao and Mikkelsen, 1976).

Many factors influence nitrogen immobilization as a result of crop residue incorporation. The time required for decomposition to take place depends on the quantity of organic matter added, soil reserves of usable nitrogen, resistance of the material to microbial attack, temperature, and moisture levels in the soil (Tilsdale and Nelson, 1975). These factors have been studied in relation to their effects on rice straw incorporation; both laboratory and field studies have been conducted. The general consensus is that if rice straw is grown under good fertility conditions it can be incorporated into the soil without problems due to nitrogen fertility (Williams, 1968 and 1972; Rao and Mikkelsen, 1976; Broadbent, Telephone Communication, June 1980; Grigarich et.al., 1973). There is no general agreement on this topic, however. Other authors report that rice straw incorporation is troublesome with respect to nitrogen fertility and that yield depressions result regardless of the straw's nitrogen content (Brandon et.al., 1970).

One of the chief factors influencing straw decomposition is the soil moisture. When rice straw is allowed to decompose under aerobic conditions, there is a greater likelihood of nitrogen immobilization. Williams et.al. reports from the literature "that a nitrogen concentration of 1.7 to 1.9 percent (in crop residues) was necessary to avoid immobilization of nitrogen under aerobic conditions, while .45 to .50 percent nitrogen was sufficient under anaerobic conditions" (Williams et.al., 1968). After three separate field trials on Stockton clay soil, Williams determined that rice straw containing higher than .54 percent nitrogen (dry weight basis) would not contribute to nitrogen immobilization in flooded soils (Williams et. al., 1968). It was concluded that under anaerobic conditions less soil nitrogen is utilized by microbes during decomposition.

The timing of incorporation determines the conditions under which the straw will decompose and correspondingly the relative amount of mineralization which occurs prior to plant establishment. Roa and Mikkelsen have firmly established that incubation of the soil for 15 to 30 days before planting reduces the threat of seedling toxicity. Moreover, in laboratory experiments these authors found that, following the proper incubation period, rice seedlings would not develop nitrogen deficiency symptoms (Rao and Mikkelsen, 1976.

Rice growers must commence seed bed preparation activities early in the spring in order to meet planting deadlines in early May.* If time were to be set aside for rice straw incorporation

*Rice growers report that seeding after the first of May results in two days' later crop harvesting, which introduces the risk of crop loss due to rain in the fall.

and the soil incubation period, growers would not have the required amount of field days available for preplant preparation. It is certain that residue incorporation practices would be conducted in the fall, weather permitting.

Studies show that supplemental nitrogen added in the spring (fall incorporation) enhances subsequent rice yields and reduces the loss of nitrogen through immobilization, leaching, and denitrification over fall-applied nitrogen (Brandon et.al., 1970). Table 4.4. below illustrates this point very clearly.

Table 4.4

THE EFFECT OF RATE AND TIME OF NITROGEN APPLICATION ON RICE YIELD

	Time of Nitrogen Application	
Nitrogen Rate	Fall	Spring
lbs/acre	cwt/ac	cwt/ac
0	65.5	69.9**
40	67.0	78.5
80	71.6	80.9*
120	74.6	76.3*
Mean	69.7	76.4

L.S.D.$_{.05}$= Rate of N = 4.2 cwt.
Time of N = 3.0 cwt.
Rate of N x Time of N = 3.0 cwt.
C.V. = 10.03

*Rice lodged before harvest

**Possible green manure response

Source: (Brandon et.al., 1979)

The tabulated yields correspond to the mean of three separate rates of straw application to the soil (0, 3, and 6 tons per acre). Greater response to nitrogen was achieved with spring-applied nitrogen in all cases. At 120 pounds of N per acre, there was a slight advantage with spring-applied nitrogen over the fall treatment. The authors concluded that under such high fertility conditions the variation in yield response during these two periods was not significant and that the high rate of applied nitrogen resulted in "very rank growth, lodging, blanking and depressed grain yields" (Brandon et.al., 1970).

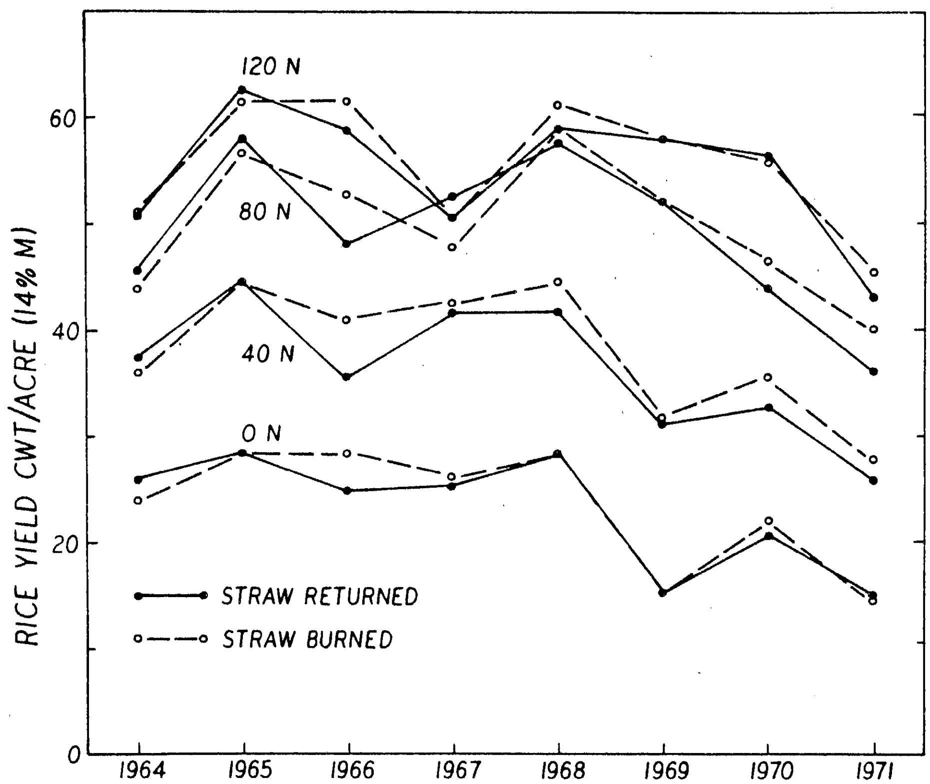
These results correspond to other research findings by Rao and Mikkelsen. In the conclusion of a study entitled Effects of Rice Straw Incorporation on Rice Plant Growth, the authors report "applying fertilizer N at the onset of rice straw decomposition resulted in a greater degree of nitrogen immobilization than applications made after incubation" (Rao and Mikkelsen, 1976).

Although there is no common agreement about rice straw incorporation and its effect on nitrogen immobilization, all the researchers show that crop yields can be increased by supplemental nitrogen following a period of soil/straw incubation. Varying the rates of straw addition in the soil has not been shown to induce nitrogen immobilization except in non-incubated trials (Raos and Mikkelson, 1976). It was reported, however, that at higher straw incorporation rates (six tons per acre) there is a trend toward yield depression on subsequent crops (Brandon et.al., 1979).

The most pronounced effect on nitrogen immobilization arises from the fertility conditions under which the soon-to-be-incorporated crop is grown. Repeatedly, researchers have shown that if rice straw is raised under high fertility conditions incorporation will not suppress subsequent crop yields. In an eight-year study, this point was conclusively demonstrated at the Rice Experiment Station, Biggs, California* (Williams et.al., 1972). The results of that study are shown in graphic form in Figure 4.4.

Figure 4.4

EFFECT OF STRAW TREATMENT AND FERTILIZER ON YIELD OF RICE OVER AN 8-YEAR PERIOD



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*Colusa rice was planted in Stockton clay. The straw and stubble were incorporated by disking and plowing.

Although there is no statistically significant difference between the burning treatment and incorporation, the rice yields (straw production followed by grain yields) varied significantly with fertility conditions. Moreover, there was no observable increase in disease or insect populations in any of the treatments; however, the author points out that such difficulties have been associated with rice residue incorporation (Williams et.al., 1972).

The studies discussed above have elucidated the effects of rice straw incorporation in relation to soil moisture, fertility conditions, time and rate of supplemental nitrogen application, and rates of straw additions to the soil. The experimental conditions discussed involve standard rice varieties on commonly used soil types. Implicit in these studies is the concept of a continuous rice rotation system. The immobilization of nitrogen was not evaluated under non-flooded (aerobic) conditions; therefore, the effects of incorporating rice straw in the fall and planting a non-leguminous, non-flooded spring crop with respect to nitrogen fertility are uncertain. It is likely, however, that supplemental nitrogen could correct any nitrogen deficiency on a subsequent non-flooded crop should this condition occur (Broadbent, Telephone Communication, June 1980). Otherwise, from the standpoint of nitrogen nutrition, the incorporation of rice straw is shown to be satisfactory for most field situations.

Seedling Toxicity. The incorporation of rice straw has been associated with poor rice stands due to seedling toxicity. This situation is brought about by the decomposition of rice straw under reduced soil conditions. The problem is particularly apparent when the rice straw is not thoroughly mixed with the soil. When soils are flooded immediately following incorporation, anaerobic metabolites produce organic acids which are injurious to young rice plants. Laboratory experiments have shown that if 15 to 30 days have elapsed after rice straw incorporation, soils could be flooded without significant amounts of organic acids being produced (Rao and Mikkelsen, 1976). Incubating rice straw in the soil for 15 to 30 days reduces the threat of organic acid toxicity while enhancing plant growth. This growth is precipitated by the reduced level of nitrogen immobilization brought about by the decomposition of organic matter (rice straw) with high carbon to nitrogen (C:N) ratios.

In laboratory experiments designed to measure organic acid concentrations under various amounts of rice straw added to the soil, acetic acid and propionic acid were detected in extracted soil sections (Rao and Mikkelsen, 1976). Other acids known to inhibit plant growth include butryic, lactic and formic acids. Although the toxicity of organic acids depends on the type and quantity present, inhibition of rice plant growth by acids is suggested to be in the order of butyric, propionic formic (Rao and Mikkelsen, 1977).

Root elongation of rice seedlings appears to be most sensitive to acid concentrations and corresponding pH changes in the soil medium (Rao and Mikkelson, 1977). At elevated acid concentrations, nutrient uptake by the seedling roots is reduced. As a consequence, the translocation of energy materials from the rice seed to the leaves and sheath is inhibited. If a proper amount of time has elapsed between straw soil additions and flooding, then seedling toxicity can be avoided.

In a study to determine the effect of rice straw additions on the production of organic acids in a flooded soil, the kind, amount, and rate of organic acid production was observed as a function of rice straw additions equivalent to field application rates of 5.6 and 11.2 tons per hectare* (Roa and Mikkelsen, 1977). The author's summary is most descriptive:

> Only acetic acid was detected in the incubated soil with rice straw added. The amount and peak production of acetic acid increased with the rate of straw added and temperature. Acetic acid concentrations varied between 10.6 and 22.7 μ eg/20 q soil, and the peak production occurred between 15 and 20 days after incubation. Organic acids were not found in sufficient amounts to affect the growth of rice plants grown in soils that were not previously puddled or in a reduced state." (Rao and Mikkelsen, 1977)

The author further reports that organic acid production may have been low since the soil (Sacramento clay) used in the experiment simulated the conditions of soils which are not flooded prior to rice plantings. Also, since the soil was

*Rates are equivalent to 2.26 and 4.05 tons per acre, respectively.

air dried prior to incubation, it took longer for the soil to attain a reduced condition once it was flooded.

In a separate study, the effect of rice straw incorporation on rice plant growth and nutrition was observed under laboratory conditions (Rao and Mikkelsen, 1976). Again, rice straw additions equivalent to field loading rates of 5.6 and 11.2 tons per hectare (.25% and .50% by weight) were used as the basis for measuring organic acid production. Table 4.5 shows the effect straw additions had on organic acid production at various incubation intervals.

Table 4.5

EFFECT OF RATES OF STRAW ADDITION AND DAYS OF INCUBATION ON ORGANIC ACID PRODUCTION

Treatment		Amount of Organic Acid Produced*			
		Acetic Acid			Propionic Acid
No. of Days Incubated	Amounts of Straw Added	7th day	14th day	21st day	21st day
	%	μeq/20 g soil			
0	0	2.15	--	--	--
0	0.25	2.30	--	--	--
0	0.50	2.62	26.53	7.13	7.64
15	0	2.45	--	--	--
15	0.25	0.59	--	--	--
15	0.50	0.05	2.00	--	--
30	0	1.27	--	--	--
30	0.25	1.80	--	--	--
30	0.50	0.05	0.11	--	--

*No butyric acid was detected.

Source: Rao and Mikkelson, 1976

The rate of organic acid production was monitored at seven-day intervals following flooding of the incubated treatments. After the seventh day, only the 0.5 percent straw treatment showed traces of organic acid production. Clearly, the non-incubated treatment resulted in the highest levels of acetic and propionic acid. None of the rice plants showed any symptoms of organic acid toxicity. There were distinct symptoms of nitrogen deficiency observed in the non-incubated trials, however.

These studies confirm that soil incubation (following additions of rice straw is mandatory in order to reduce the threat of organic acid toxicity due to organic acid production. These data show that organic acid toxicity would not be a problem if the proper incubation period is allowed. Soils exhibiting various amounts of clay, silt, loam and sand particles may vary in their oxidation/reduction potential under flooded conditions. Therefore, the results of these experiments cannot be extrapolated to all rice soils. These data are supportive of rice straw incorporation practices and indicate the advantage of early rice straw incorporation before flooding and planting. Ideally, the rice field should be allowed to be fallow for 30 days following incorporation of rice straw.

Algae and Aquatic Invertebrates. A potential disadvantage to rice residue incorporation was believed to exist in relation to increases in algae growth and aquatic invertebrate populations. Decreased yields have been cited due to floating mats of algae.

These mats prevent sunlight from reaching the emerging rice seedlings, thereby lowering plant establishment. Aquatic invertebrates, particularly rice water weevil, have been known to exhibit a variable degree of habitat specificity (Grigarich et.al., 1973). The incorporation of rice straw and stubble alters field ecological conditions and aquatic insect populations are believed to be affected because of it. Rice growers have historically controlled algae and aquatic invertebrates by cultural practices and pesticide application. Studies have tentatively shown that these same practices are effective under rice residue incorporation schemes.

Field experiments have been conducted on algae growth in response to both burning and incorporating residue disposal techniques (Grigarich et.al., 1973). The results of these field experiments indicate that "no significant differences" existed in the burning trials as compared to the incorporation treatments. The authors concluded that longer term trials may be necessary to alter the chemical composition of the rice field soil and thereby provide more comprehensive data on the effect of algae growth due to incorporation of rice residues.

During the same study, field experiments were conducted to determine the effect of rice residue incorporation on aquatic invertebrates (Grigarich et.al., 1973). It was determined that "invertebrate fauna was not materially affected by the burning or tillage management of rice plant residues." Pesticide applications were equally effective on all tillage practices with respect to rice water weevil control. Yield declines were reported with the incorporated treatments but the crop decline could not be attributed to the invertebrate fauna.

Although only a limited amount of research has been conducted on the effects of rice residue incorporation on algae and aquatic invertebrates, the results are supportive of incorporation practices. It is recommended that further research be conducted in this area to involve a broader range of soil and environmental conditions.

Stem Rot Disease in Rice

S.orayzae, commonly known as stem rot of rice, is a fungal pathogen which is spread throughout the Northern California rice-growing districts and, to a very limited extent, in the San Joaquin Valley. It was first observed in California in 1932 at Biggs Rice Research Station (Krause and Webster, 1973). Historically, stem rot of rice has been known to exist since the early 1920's when it was first reported in Arkansas and Louisiana.

The role that stem rot plays in relation to incorporation of rice straw is a critical one. Research points out that incorporation of rice straw in either the fall or the spring results in increases in S.oryzae innoculum, stem rot disease severity, and reductions in yield (Webster and Bockus, 1978). Since there are currently no control measures available to rice growers other than open-field burning, the percentage loss in rice yields attributable to stem rot has a dominant effect on the cultural integrity of rice straw incorporation practices.

In light of these problems, this section will summarize current findings on the incidence and severity of stem rot in California rice-growing districts and determine the feasibility of requiring burning authorization based on critical levels of stem rot in a rice field. Pertinent to these objectives is the mapping of stem rot incidence in California, the classification of rice cultivar susceptibility to stem rot, the identification of critical levels of stem rot which would result in subsequent crop losses and certification methods to be used by a field enforcement inspector.

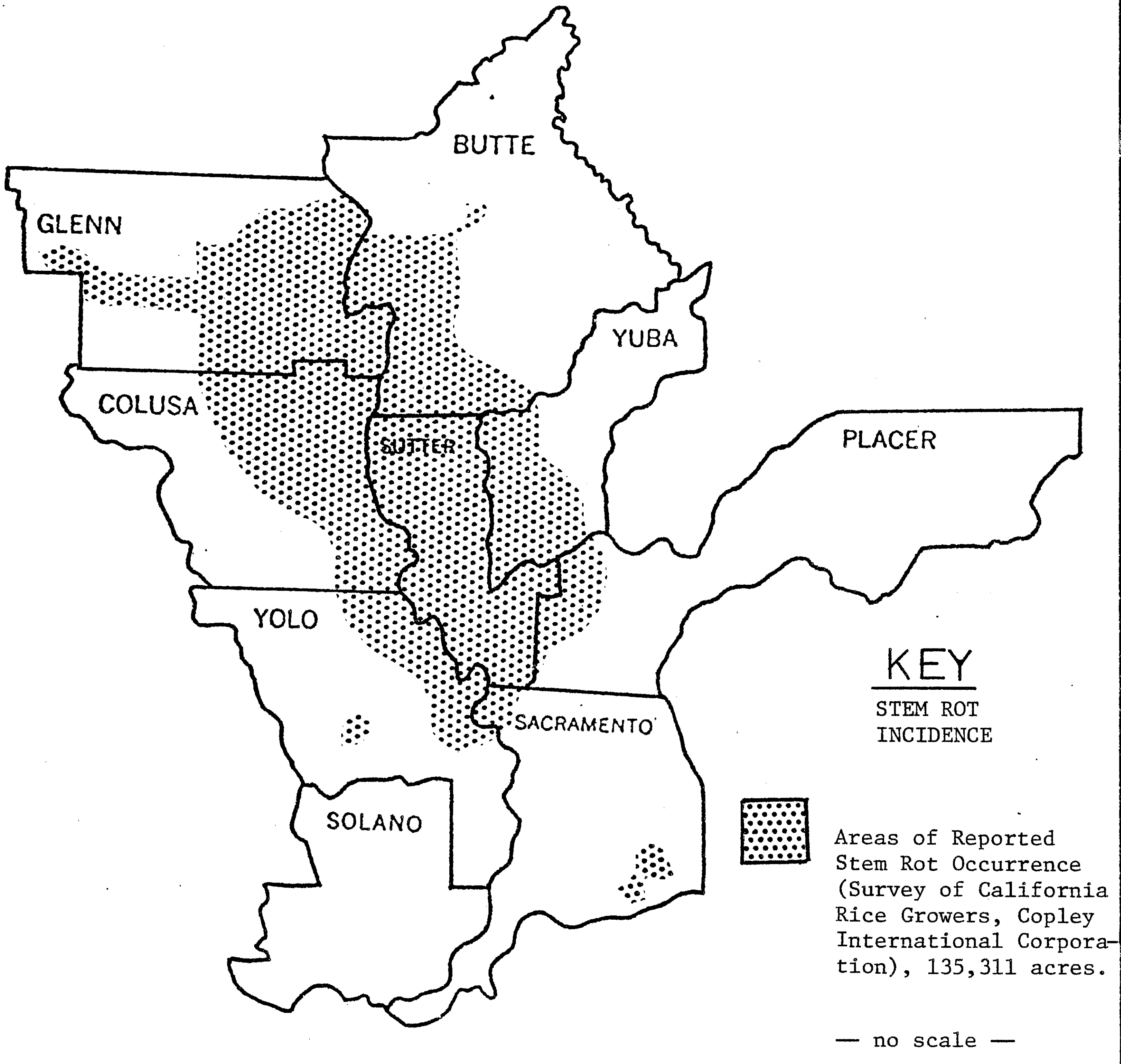
The information used to support the findings in this section comes from three areas. First, Copley International Corporation's (CIC) mail survey of rice growers developed information pertaining to the existing incidence and severity of stem rot in California. This information is presented in graphical, tabular, and map form. Second, a comprehensive review of literature was conducted on stem rot and the findings are contained in this section. Third, CIC conducted both face-to-face and telephone interviews with rice growers, plant pathologists, and civil servants who are involved with disease certification programs.

Incidence and Severity of Stem Rot Disease in California. Of the 289 respondents to CIC's field questionnaire, only 11 percent did not know or could not estimate how much of their acreage was infected by stem rot disease. The majority of the respondents reported that at least a portion of their total acreage used for rice production was infected. Sixty-four (25 percent) of the respondents indicated that none of their acreage was infected with stem rot disease. Figures 4.5, 4.6, 4.7 and 4.8 show the incidence of stem rot disease identified by CIC's field survey.

It is readily apparent that the majority of stem rot occurring in the rice growing districts correspond to the intensity of rice production in these same areas. On a percentage basis though, there is proportionally less stem rot in the San Joaquin Valley. Table 4.6, which shows the percentage of total acreage

Figure 4.5

SACRAMENTO VALLEY AREAS 1, 2, and 3



Source: Copley International Corporation, Survey of California Rice Growers, 1979.

Figure 4.6

STEM ROT SEVERITY - Sacramento Valley

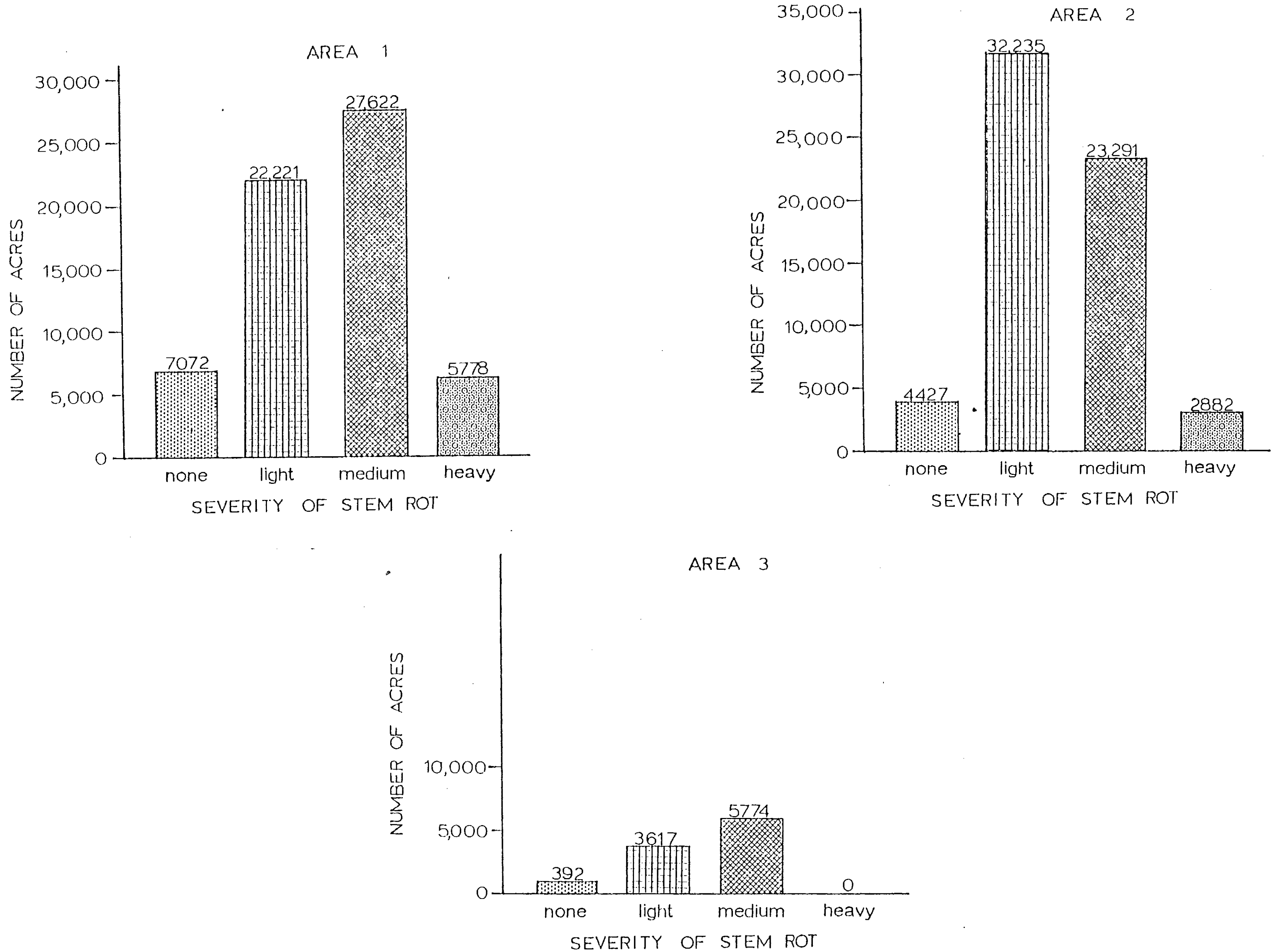


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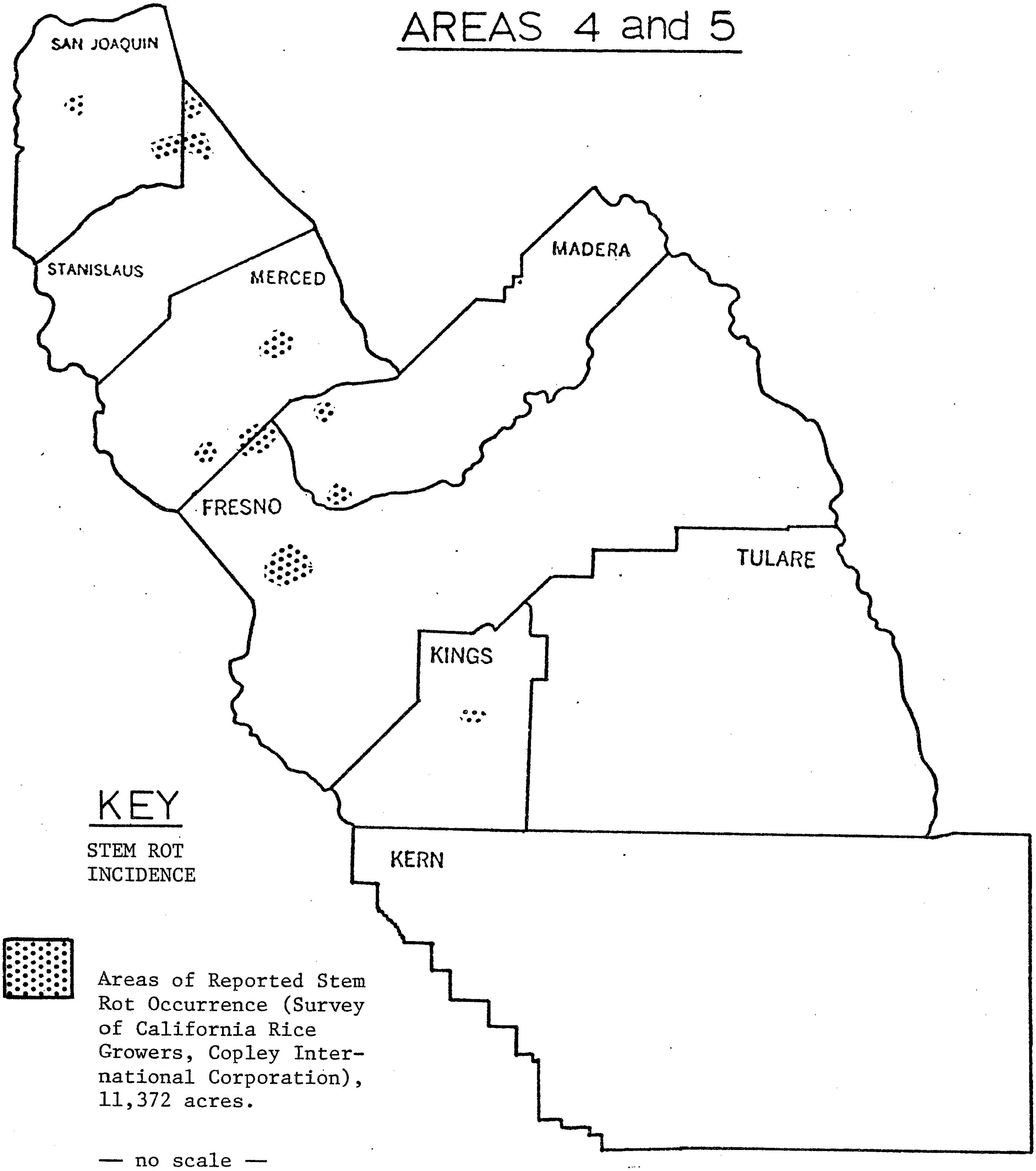
Figure 4.7

SAN JOAQUIN VALLEY
AREAS 4 and 5

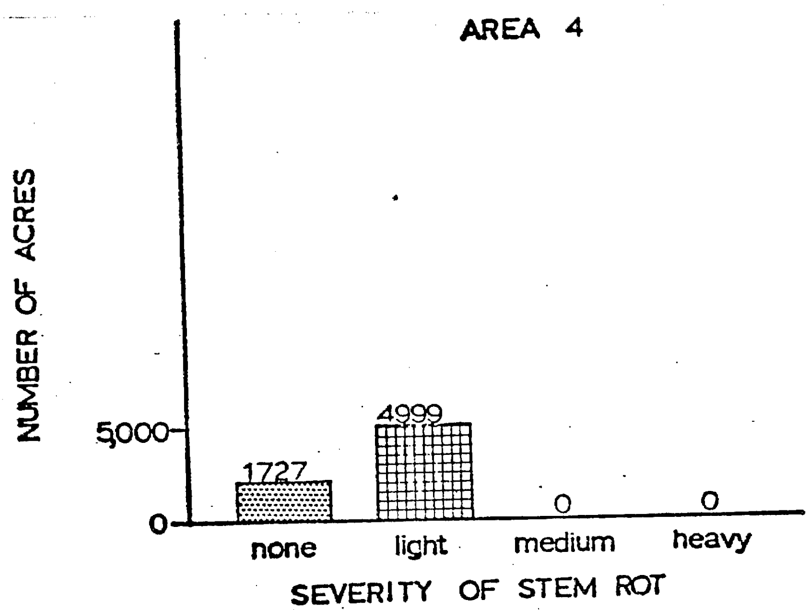


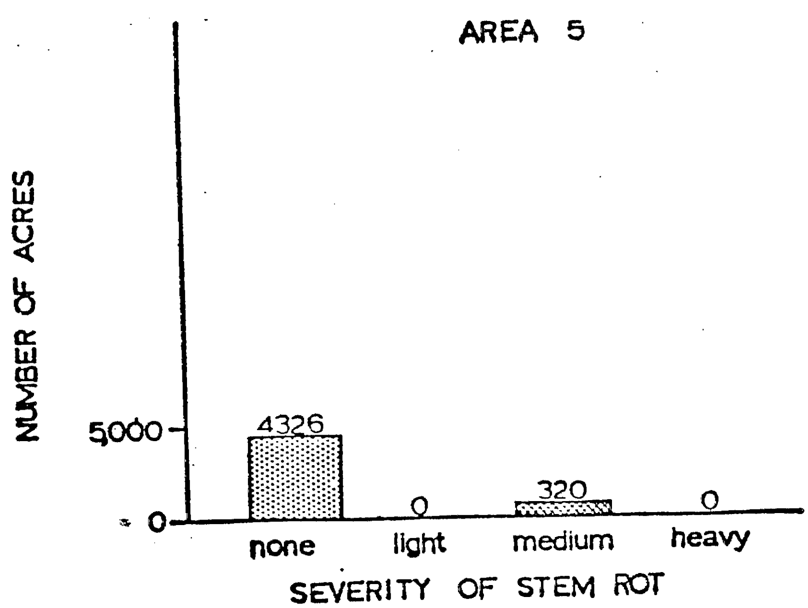
Source: Copley International Corporation, Survey of California Rice Growers, 1979.

Figure 4.8

STEM ROT SEVERITY

San Joaquin Valley





Source: Copley International Corporation, Survey of California Rice Growers, 1979.

Table 4.6

PERCENTAGE OF TOTAL ACREAGE INFECTED WITH STEM ROT[a]

	Percent of Total Acreage						
Location	0%	0-25%	26 - 50%	51 -75%	76 - 99%	100%	Total
Area 1	18% (17)	37% (36)	10% (10)	4% (4)	4% (4)	27% (26)	100% (97)
Area 2	16% (17)	38% (40)	9% (9)	6% (6)	3% (4)	28% (29)	100% (105)
Area 3	22% (4)	28% (5)	11% (2)	6% (1)	--	33% (6)	100% (18)
Sacramento[b] Valley	18% (40)	37% (84)	9% (20)	5% (11)	4% (9)	27% (61)	100% (225)
Area 4	63% (12)	26% (5)	--	--	5% (1)	5% (1)	99% (19)
Area 5	91% (10)	9% (1)	--	--	--	--	100% (10)
San Joaquin Valley	75% (24)	19% (6)	--	--	3% (1)	3% (1)	100% (32)

[a]Numbers in parenthesis () indicate number of survey respondents.

[b]The total number of respondents for each valley are greater than the sum of areas, since several respondents would not disclose their farm location.

Source: Copley International Corporation

affected by stem rot, illustrates this point very clearly. Of the 225 respondents in Sacramento Valley, 18 percent (40 respondents) are not affected by stem rot. Conversely, in the San Joaquin Valley, 24 out of 32 respondents, or 75 percent, are not affected by stem rot. More importantly, of the total respondents in both valleys, 27 percent of Sacramento Valley growers indicated that their entire fields were infected with stem rot disease while only 3 percent in San Joaquin Valley made that same claim.

Assuming an equal distribution of farm sizes (e.g., large and small farms claim the same percentage of total acreage affected by stem rot), these data indicate that at least 24 percent of the total rice acreage in California is completely infected with stem rot disease. Alternatively, it appears that 25 percent of the rice acreage is not affected at all. The remaining 51 percent of farms can be considered to have varying amounts of stem rot, but most have less than 25 percent stem rot incidence.

Clearly, the above discussion shows that stem rot is a common phenomena in California rice culture. The mapping of stem rot incidence indicates that the infected acreage is relatively concentrated in the upper Sacramento Valley. The determination of stem rot incidence does not, however, establish a firm relationship with stem rot severity.

Rice growers were asked to rate the severity of stem rot disease on their affected acreage. The results of this are shown in Table 4.7. These data include the responses of 257 rice growers.

Table 4.7

SEVERITY OF STEM ROT DISEASE IN CALIFORNIA[a]

	Not Affected	Acreage by Severity Rating		
		Heavy	Medium	Light
Area 1	7,072	5,778	27,622	22,221
Area 2	4,427	2,882	23,291	32,235
Area 3	392.	0	5,774	3,617
Total Sacramento Valley	11,891	8,660	56,687	58,073
Area 4	1,727	0	0	4,999
Area 5	4,326	0	320	0
Total San Joaquin Valley	6,053	0	320	4,999
Total Acreage	17,944	8,660	57,007	63,072

[a]The total area surveyed amounts to 146,683 acres.

Source: Copley International Corporation

Approximately 146,683 acres are accounted for in this table, which represents 28 percent of the 1979 harvested rice acreage. Based on grower response, approximately 6 percent of California's stem rot incidence can be attributed to a "heavy" disease severity rating. Thirty-nine percent and 43 percent of the surveyed acreage in California were given "medium" and "light" disease severity ratings, respectively.

Of the affected acreage in San Joaquin Valley, virtually all is considered to be only lightly infected by stem rot. An even larger proportion of the acreage in the southern valley was reported as not having any stem rot problems at all.

It should be noted that in Table 4.6, 25 percent of all growers reported no incidence of stem rot on any of their rice acreage. However, a tabulation of rice acreage and severity rating shows that approximately 12 percent of the total rice acreage is not affected by stem rot. This disparity arises since 75 percent of San Joaquin Valley respondents reported no incidence of stem rot; therefore, the results are naturally skewed towards this population sample. More importantly, this shows that the incidence of stem rot is more widely distributed in the Sacramento Valley than previously indicated.

Given that stem rot exists and the severity of the disease can be qualified, the task remains to associate these data with percentage loss in rice yields on an annual basis.

Rice growers' responses to percentage yield losses resulting from stem rot is tabulated in Table 4.8. The distinction between reported crop losses in Sacramento Valley versus San Joaquin Valley becomes immediately apparent. An overwhelming percentage of growers in the San Joaquin Valley attributed less than 5 percent of crop losses to stem rot disease. Based on the disease severity ratings shown in Table 4.7, San Joaquin growers are relatively unaffected by stem rot in comparison to their northern Californian counterparts. In the Sacramento Valley, for instance, crop losses were almost equally distributed among the 0-5% and 5-10% categories. While only 20 percent of the San Joaquin

Table 4.8

PERCENTAGE LOSS IN RICE YIELDS[a]

Location	Yield Losses					
	0 - 5%	5 - 10%	10 - 15%	15 - 20%	25% or More	Total
Area 1	28% (25)	30% (27)	26% (24)	12% (11)	4% (4)	100% (91)
Area 2	35% (32)	38% (35)	18% (17)	7% (6)	2% (2)	100% (92)
Area 3	31% (5)	31% (5)	38% (6)	--	--	100% (16)
Sacramento Valley	31% (63)	34% (69)	23% (46)	9% (18)	3% (6)	100% (202)
Area 4	85% (11)	8% (1)	8% (1)	--	--	100% (13)
Area 5	67% (4)	--	33% (2)	--	--	100% (6)
San Joaquin Valley	80% (16)	5% (1)	15% (3)			100% (20)

[a]Numbers in parenthesis () indicate number of survey respondents.

Source: Copley International Corporation

Valley growers reported crop losses in excess of 5 percent, nearly 65 percent of Sacramento Valley growers claimed the same distinction.

Approximately 12 percent of Sacramento Valley growers reported yield losses in excess of 15 percent due to stem rot. Assuming an average yield of 60 hundred weight (cwt) per acre for a typical rice farm, these high-yield losses would result in 9 to 15 cwt. of grain per acre being lost due to stem rot. It is unlikely that these rice growers could sustain such yield losses and remain financially solvent for more than a couple of rice-growing seasons.

Statistical Summary of Data. Correlation analysis was conducted on typical respondent rice yields (Question 7A) versus percentage of total acreage affected by stem rot (Question 11). An r^2 value of 0.21 was obtained, which shows that typical rice yields cannot be predicted based on reported incidence of stem rot.* Growers' yields are equally distributed for those who claimed high stem rot incidence, as those yields of growers who reported low stem rot incidence.

Initially, it was assumed that percentage loss in rice yields from stem rot (Question 11b) would be related to respondents' reported typical rice yields (Question 7A). Scattergram and correlation analyses were conducted to confirm this for both the Sacramento and San Joaquin Valleys. The results showed

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*The analysis included 252 observations from growers in both the Sacramento and San Joaquin Valleys.

that percentage loss in rice yields due to stem rot is not suitable for explaining variation in reported typical rice yields. In the aggregate, r^2 values of .024 and .036 were obtained for the northern and southern valley air basins, respectively.

These analyses show that reported incidence of stem rot cannot be used to explain respondent rice yields. No relationship could be established between high incidence of stem rot disease and low respondent rice yields. Moreover, even when growers reported high loss of yields due to stem rot, their reported yields did not reflect this condition.

Growers who reported light disease severity were consistent in reporting low percentage loss in rice yields due to stem rot disease. There was a firmly established relationship of stem-rot-severity response (Question 11a) and percentage loss in rice yields (Question 11b).*

It is important to set these findings in the proper context. These data, for example, apply to cultural conditions existing under a burning situation. Even though the yields of rice growers did not vary as a function of stem rot incidence or reported loss of yields due to stem rot, these data do not predict what would happen if burning were restricted and if incorporation of rice straw burning.

Two things are apparent, however: 1) Rice growers react emotionally to questions on disease severity; and 2) rice yields

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*An r^2 of .33 was calculated with significance at the 99.9 percent level, based on 186 observations for the Sacramento Valley.

throughout the growing areas do not change as a function of reported stem rot incidence. These data do not, by any means, show that stem rot disease does not result in lower yields. There is ample empirical information to prove otherwise. Rather, these survey data show that rice growers react inconsistently in the aggregate and that no relationship can be established between reported stem rot severity and reported typical rice yields.

Effect of Incorporation on Stem Rot Severity. It is acknowledged from the previous discussion that stem rot is perceived to be a serious disease problem by most California rice growers. Even under the conditions of burning, a few growers report yield losses due to stem rot of 25 percent or more. Extensive field studies show that incorporation of rice straw increases disease severity and yield losses more than open-field burning (Grigarick et.al., 1973; Webster, 1974; Webster and Backus, 1978). Should incorporation practices become mandatory, there may be rice growers who cannot meet the compounded financial burden of increased operating costs as a result of incorporation practices and yield decline due to stem rot.

This section will briefly report the research findings of the effects of incorporation on stem rot severity. This information will serve as the basis for establishing suitable tillage practices to reduce the severity of stem rot and identifying the percentage yield declines which could be expected if such tillage practices were initiated.

At various locations throughout the Sacramento Valley, rice residue incorporation trials have been conducted. Private growers as well as the California Cooperative Rice Research Foundation have provided experimental areas on which to measure the effects of incorporation on stem rot disease. Ten years ago, the University of California, Davis initiated field studies on the biological effects of incorporation which spanned four years in duration. These field studies were initially requested by the California Rice Research Board and partially sponsored by the California State Air Resources Board (Grigarick et.al., 1973). A detailed account of the effects of incorporation on stem rot disease over these four years is given in a separate report (Webster, 1974). Additional work in this area involves the examination of sclerotia viability at various soil depths when different tillage practices are employed (Webster et. al., 1976).

The literature consistently reports that incorporation of rice straw enhances inoculum buildup in the soil and leads to increased disease severity on subsequent crops (Webster, 1974; Grigarick et.al., 1973; Webster and Bockus, 1978). Furthermore, it is reported that open-field burning minimizes inoculum build-up and reduces rice grain yield losses over incorporation.

Numerous factors are known to encourage stem rot disease.* As a result of field experiments, it is known that different tillage methods produce widely different effects on inoculum

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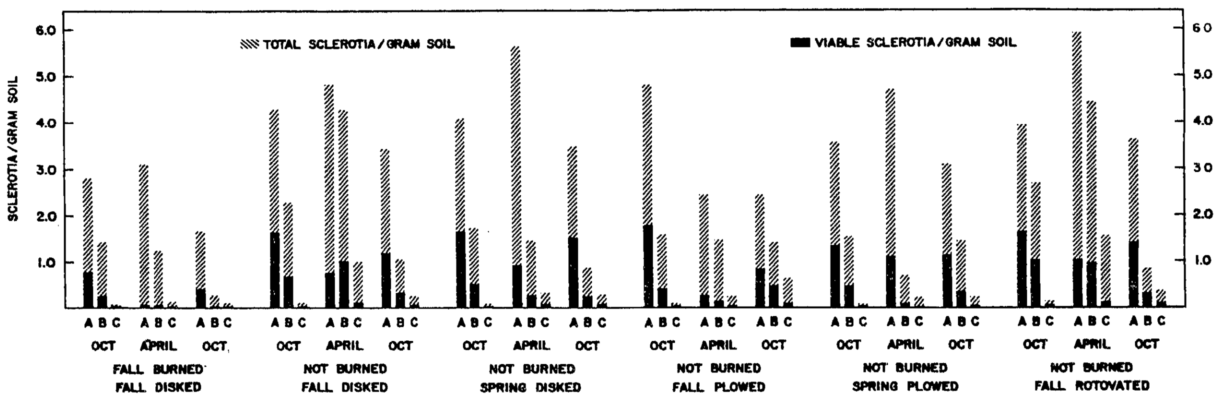
*Among the factors known to have an effect on disease severity, type of tillage, varietal selection, seeding rates, and nitrogen fertilization are the most important.

buildup in the soil and subsequent disease severity. Three types of tillage practices have been given consideration: moldboard plowing, disking, and rotovating. These tillage practices are normally preceded by a straw reduction operation which facilitates incorporation.

Among the tillage methods studied, moldboard plowing treatments have received the most acclaim for minimizing stem rot inoculum levels. "The plowing results in depositing the majority of inoculum at a depth beyond that reached by the implements used to prepare the finished seedbeds" (Webster, et. al., 1976). Figure 4.9 illustrates the relationship of type of tillage to viable sclerotia at various soil depths.

Figure 4.9

EFFECT OF RESIDUE MANAGEMENT ON SCLEROTIA VIABILITY



[A]0-5 cm
[B]5-10 cm
[C]10-20 cm

Note: October 1971 samples taken after harvest, but prior to initial treatments; April 1972 samples taken after all initial treatments, but prior to final seedbed preparation. October 1972 samples taken after harvest of the 1972 crop, but prior to tillage treatments.

Source: (Webster et.al., 1976)

The moldboard plowing treatments show a marked reduction in the number of viable sclerotia at all soil depths when compared to other tillage treatments. Other studies indicate that the decreased viability of sclerotia at greater soil depths may be related to soil moisture conditions and biotic factors (Keim and Webster, 1974; Keim and Webster, 1975).

Regardless of the type of tillage method used for incorporation, if stem rot is present in the field, increases in inoculum levels will result. In field trials with low initial inoculum levels in the soil, incorporation of rice straw has been demonstrated to dramatically increase the number of viable sclerotia after successive incorporations (Webster et.al., 1980). In Table 4.9, the effect of incorporation on stem rot inoculum levels is reported over a four-year period.

In all replications where residue was not burned, inoculum levels were enhanced by incorporation. The moldboard plowing treatment minimized the level of viable sclerotia compared to all other incorporation treatments. However, even moldboard plowing failed to maintain inocolum levels at a constant point as did burning. Lower yields were associated with incorporation of rice straw; however, severe yield reductions did not manifest until the third and fourth year of the experiment (Webster et.al., 1980).

Yield losses attributable to stem rot disease have been experimentally measured to range from 8 to 24 percent (Webster and Bockus, 1978). However, it is unclear what level of yield losses would arise if incorporation were routinely practiced by California rice growers. Shown in Table 4.10 are the results of four years of residue management studies (Webster, 1974). These studies were conducted on rice soils which displayed high

Table 4.9

OBSERVED INOCULUM LEVEL IN TOP 10 CM OF SOIL OF FINISHED SEED BEDS FOR FOUR CONTINUOUS YEARS COMPARING DIFFERENT METHODS OF RICE RESIDUE MANAGEMENT

Treatments	Viable sclerotia per gram soil[1]							
	Year 1		Year 2		Year 3		Year 4	
Burned - fall stubble disked	.05[1]	A	.075	A	.06	A	.06	A
Not burned - fall stubble disked	.07	A	.20	B	.28	B	.29	B
Not burned - fall rotovated	.07	A	.11	A	.26	B	.27	B
Not burned - fall moldboard plowed	.06	A	.18	AB	.22	B	.26	B
Not burned - light fall disk for soil contact[2]	.06	A	.24	B	.34	B	.53	C
Not burned - spring stubble disked	.07	A	.15	AB	.32	B	.47	C

[1]Means of 6 replications with 4 composite samples. Combined from (80-120 89.6-134.4 kg N/ha #N/A) subplots.

[2]Was initiated as a furrowing (fall treatment) for first year. Was changed to fall moldboard plow for second year because residue was unmanageable. Thus increase between Year 1 and Year 2 resulted from residue only partially incorporated in top 1-10 cm of soil during overwintering.

Sig. LSD between years at 5% = .17.

Source: (Webster et.al., 1980)

Table 4.10

MEASURES OF INOCULUM LEVEL, DISEASE SEVERITY AND YIELD UNDER VARIOUS TILLAGE TREATMENTS

	Inoculum Levels Via. scler/100 gr. soil				Disease Rating (1=healthy - 5 severe)				Yield cwt/A. 14%				
Treatments	1970	1971	1972	1973	1970	1971	1972	1973	1970	1971	1972	1973	Average
Burn													
Fall Disc	24	28	26	32	1.72	1.59	1.91	1.77	59.0	54.6	62.6	63.4	59.9
No Burn													
Fall Disc	16	52	55	115	1.84	1.92	2.27	2.10	59.0	50.2	59.6	56.8	56.4
Fall Plow	18	46	47	69	1.69	1.90	2.15	2.11	57.5	50.5	59.0	58.1	56.3
Spring Disc	20	56	62	108	1.97	2.32	2.45	2.29	57.0	50.8	59.2	56.5	55.9
Spring Plow	20	42	47	51	1.99	2.21	2.18	2.02	61.6	49.5	60.8	58.7	57.7
Rotovate	28	48	46	101	1.81	2.02	2.07	2.17	59.0	48.7	59.6	58.6	56.5

Variety = Calrose; all values means of four replicates, each 47' x 530' with separate water systems.

Source: (Webster, 1974)

initial inoculum levels. The variety used in these trials was Calrose, which is known to have substantially less tolerance to stem rot disease than the most tolerant of all California rice cultivars, Colusa (Ferriera and Webster, 1975)

These trials again show that moldboard plowing minimizes inoculum levels and corresponding yield losses.* Over the four years, the fall burn and fall disc treatment averaged 59.9 cwt. per acre of grain. The spring disc treatment, which had the most severe disease rating and lowest grain yields, averaged 55.9 cwt. per acre over the study period. Under these experimental conditions, the total range of yield loss spanned 4 cwt. per acre or approximately 7 percent. In all of the reported tillage treatments, the inoculum levels in the soil built up substantially. These higher inoculum levels are reflected in the yield decline at the end of four years. In contrast to the burning trials where inoculum levels remained fairly constant and yields increased, incorporation of rice straw showed a distinct trend towards yield depression.

The question arises as to whether or not a one-year rotation or fallow year would aid in reducing inoculum levels arising from incorporation practices. Webster reports that one fallow season is not sufficient to minimize stem rot inoculum levels if residue from a previously infected crop is incorporated without burning (Webster, 1974). However, the longevity of sclerotia

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*The tillage treatments were preceded by a straw chopping operation from a cimbine-attached "Alloway Straw Chopper" in the soil under various tillage methods is now known. Studies indicate that a high percentage of sclerotia lose their viability within a relatively short time (Webster et.al., 1976). It is known that sclerotia unattached to residue are "poor competitors in soil" and that they "probably do not contribute to increases in inoculum level" (Webster and Bockus, 1968). As shown in the preceding chapter, it is uncommon for rice growers to rotate out of rice for more than one year, if at all. Therefore, the possibility of reducing the threat of stem rot disease by means of crop rotation is greatly diminished.

Critical Levels of Stem Rot. If the incorporation of rice straw is to be the recommended method for rice straw residue disposal, criteria should be established to allow burning under high stem rot severity conditions. Field observations or laboratory analysis is necessary to "certify" high stem rot severity or sufficiently high inoculum levels in order to warrant open-field burning.

Webster (1974) reports that the extent of inoculum in both the fall and the spring are useful determinants of the next crop's disease condition. Webster succinctly states that:

> Separate studies have shown that correlations between inoculum level, disease severity and yield are very high (r = .9 or higher) and that it is possible to estimate the amount of disease and accompanying losses through a knowledge of the inoculum level that exists in the seed bed in the spring. It has been further shown that there are high correlations between disease severity measured in the fall and the amount of inoculum that will be available in the seed bed in the following spring (r = .8 or higher). (Webster, 1974)

If disease severity could be established in the fall, this would allow enough time for determining the appropriate cultural operation to reduce stem rot severity. Even though accurate estimates of disease severity can be determined in the spring, this would not aid in determining a burn or no-burn situation. Since spring measurement of inoculum levels is based on the amount of viable sclerotia in a seed bed, this method assumes that residue disposal has already taken place.

Symptoms of stem rot disease are most evident on plants nearing maturity (Krause and Webster, 1973). Depending on the time a particular plant is infected, the disease symptoms could range from no symptoms at all to lesions on leaf sheaths (inner and outer) or to a severely infected tiller with mycelium and sclerotia present. Webster reports that disease severity in the fall can be determined just prior to draining fields in preparation for harvest or up until the grain is ready for harvest (20 percent moisture content) (Webster et.al., 1980; Krause and Webster, 1972). Following harvest, it is likely that a determination of disease severity could be made, although the determination would be more difficult since the frequency of plants which failed to produce panicles could not be evaluated. Also, after harvest the straw may be windrowed and partly embedded in the soil, which would preclude observation of a large portion of the straw and stubble.

Since the disease severity advances with time, plants observed immediately before harvest would naturally reflect more severity than plants observed just prior to draining the fields. An advantage of this type of disease certification is that inspectors would have three to four weeks during which stem rot severity could be assessed (Cooperative Extension, Calendar of Rice Operations for Colusa, Glenn and Yolo Counties, 1975).

A disease certification program based on plant analysis could be implemented by one or a combination fo two methods--visual and laboratory analysis. The pros and cons of each of these methods need to be elaborated.

A visual determination of stem rot severity would require sampling at various locations in a rice field. Disease severity of each field could be rated according to the index already established in Krause and Webster* (1973). This would require little prior knowledge of plant pathology on behalf of the inspector. A hand lens may be used to identify lesions or other signs of infection such as mycelium and sclerotia. To determine the percent of the field that is infected, as many samples as possible using a grid-type design should be taken. An inspector with a strong agricultural background would be able to make such a determination quickly. With this method, it is difficult to establish rigid criterion levels of disease severity, yet it is inexpensive and can be done efficiently.

A laboratory analysis would require collection of leaf and stem samples for each form under investigation. These plant

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*A description of the index is included in Appendix.

samples would be analyzed to determine the level of infestation and the rate of plant retardation. Multiple samples would be required in order to determine percent of field infected. The advantage of this approach is that an accurate determination of both the presence and type of infestation can be made. Anyone can collect the sample plants, and the results can be obtained quickly. This method is expensive; costs range from $40 (if sent to a lab) to $100 (if lab makes the collection). The results would not indicate viability of the sclerotia, however, which is very important.

Alternatively, if soil testing is employed, results can take up to two weeks. Analysis would cost $70 to $80 for an average size farm or $140 if the lab is required to collect the soil samples. Multiple samples would be required and the results would include: 1) sclerotia per gram of dry soil; and 2) percent viability.

In order to obtain burning authorization based on disease severity, any one or a combination of the methodologies would be suitable. Reports of disease severity could be coordinated with local Air Pollution Control Districts (APCD's) who ultimately would be responsible for burning authorization. If disease severity was reported to be below a critical level, burning would not be allowed.

It would be inappropriate to suggest critical disease severity ratings which could be used for burning authorization, based on the information obtained during the course of this study. As reported in the literature: "Correlations between inoculum level, disease severity and yield are very high," yet these data are not published at the level of detail required to establish critical disease severity ratings. Dr. Webster reports that: "A preliminary report of the quantitative relationships between inoculum level, disease severity, and yield has been presented. A detailed analysis of these and numerous other data will appear elsewhere" (Webster et.al., 1980). Once this information is published, ratings of disease severity can be reasonably extrapolated to establish critical levels at which incorporation becomes severely limiting in terms of crop production.

The level of detail available in the literature is insufficient for establishing a relationship between disease severity in the fall and the subsequent crop's yield losses. Presently, the data suggests that disease severity ratings greater than about 2.2 (refer to Appendix B for details on the ratings system) correspond to yield losses of about 10 percent. Survey data indicate that a 10-percent yield loss represents one standard deviation of reported "typical rice yields" (Question 7A) for Sacramento Valley rice growers.* It is calculated that only 16 percent of the rice growers in the Sacramento Valley experienced rice yield losses of greater than 10 percent. In addition, researchers claim that, under experimental conditions, it is dif-

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*The mean reported rice yield for Sacramento Valley is 59.1 cwt./acre, with a standard deviation of 5.96 cwt./acre. An analysis of kurtosis and skewness shows that the sample population (241 observations) is evenly distributed with a median rice yield of 59.8 cwt./acre.

ficult to justify yield responses within 10 percent of the mean* (Broadbent, 1980). Therefore, a 10-percent yield loss due to stem rot would be the lower limit for burning authorization. Expected yield losses (due to stem rot) greater than 10 percent should be sufficient to warrant the open-field, waste burning of rice straw.

Stem Rot-Resistant Rice Varieties. It is known that certain rice varieties exhibit degrees of tolerance to the fungal pathogen, *Sclerotium oryzae*. In general, researchers state that medium-and late-maturing rice varieties exhibit greater disease resistance than the early varieties (Ferreira and Webster, 1975; Amin, 1975). These resistance characteristics appear to be inherited, and researchers are hopeful that these traits can be genetically passed along in order to develop stem rot disease resistant cultivars.

At the present time, there are no known cultivars completely tolerant of inoculum of *S. oryzae*. Of the California varieties, the latest published data show that Colusa is the least susceptible and Earlirose the most susceptible to stem rot disease** (Ferreira and Webster, 1975).

In Table 4.11, the relative degree of stem rot resistance is shown for ten United States varieties. The data provided in the table are a result of studies conducted under greenhouse

*That is, yields within a control group will normally vary within plus or minus (±) 10 percent of the mean.

**There is no published data on S6, N9, N7 or M5 California rice varieties.

conditions and 16-hour (day length) photo periods. Six different strains (isolates) of S. oryzae were used to inoculate the rice plants. Each strain of S. oryzae varied in its degree of virulence. All the rice plants were inoculated with 150-mg mixture of the isolates.

Table 4.11

THE STEM-ROT DISEASE REACTION OF 10 RICE CULTIVARS AFTER INOCULATION WITH A MIXTURE OF SIX ISOLATES OF SCLEROTIUM ORYZAE

Cultivar	Number of Plants	Disease Index[a]	Standard Deviation of the Mean
Italica Livorno	25	4.71	.31
Tedoriwase	21	4.26	.56
Bluebelle	21	4.20	.25
Szegedi Szakallas	25	4.16	.50
Earlirose	25	3.75	.49
Calrose	11	3.71	.46
Norin 8	12	3.46	.22
Norin 48	11	3.38	.40
Taichung 122	21	3.24	.23
Colusa	25	3.13	.31
LSD (P = 0.01) = .29)			

[a]Disease index is that of Krause and Webster, 1973, which is based upon categories 1-5; (i) healthy, no symptoms or signs of disease; (ii) lightly infected, symptoms on outer leaf sheath only; (iii) mildly infected with discoloration of, and sclerotia in, the inner leaf sheath, culm green and healthy; (iv) moderately infected, slight to mild discoloration of the culm, interior of the culm healthy; (v) severely infected, culms infected internally, either collapsed or not.

Source: (Ferreira and Webster, 1975)

These data confirm erlier field studies (Krause and Webster, 1973) and observations during commercial rice production that Colusa offers greater disease resistance to stem rot than other varieties tested. Five years earlier in 1970, the susceptibility of six rice cultivars to *S. oryzae* were tested at three different fields, each with varying levels of inoculum (Krause and Webster, 1973). The results of this field study are shown in Table 4.12.

Table 4.12

SUSCEPTIBILITY OF SIX RICE CULTIVARS TO SCLEROTIUM ORYZAE AS TESTED IN THREE DIFFERENT FIELDS EACH WITH DIFFERENT INOCULUM LEVELS[a]

Cultivar	Field 1[b] Disease Index	Field 2[b] Disease Index	Field 3[b] Disease Index	Greenhouse 1970 Disease Index Nonwounded
Earlirose[a]	4.20 a[c]	3.69 a	1.44 a	4.75 a
Caloro	3.89 b	2.95 b	1.19 a	4.12 b
Kokohoe Rose	3.70 b[c]	3.01 b	1.38 a	4.30 b
CSM-3	3.58 c	2.86 b	1.28 a	4.14 b
Calrose	3.53 c	2.80 b	1.21 a	4.05 b
Colusa	3.15 d	2.83 b	1.16 a	3.60 c

[a]A Randomized complete design replicated four times.
[b]Field 1, 412 vs/p; Field 2, 38 vs/p; Field 3, 10 vs/p.
[c]All figures in a given measurement followed by the same letter do not differ significantly at the 5% level in Fields 1, 2, and 3; greenhouse data at the 1% level.

Source: (Krause and Webster, 1973)

The three separate disease indexes reflect field conditions at various stem rot inoculum levels. With the exception of field two, Colusa showed the least susceptibility to stem rot disease in the field and greenhouse trials. Earlirose, in all cases, appeared to be the most susceptible.

Other studies report rice cultivar resistance to stem rot disease (Amin, 1975). It is well documented that rice cultivars exhibit relative tolerances to stem rot disease; yet the genetic processes which produce this disease-resistant condition are not fully understood. Researchers have tentatively concluded that resistance traits are "quantitatively" inherited (Ferreira and Webster, 1975). That is, the progeny of a disease-resistant and non disease-resistant cultivar cross will exhibit a blend of the parents' characteristics. The results of these inheritability experiments offer encouragement to plant geneticists for breeding desirable cultivars tolerant to stem rot disease.

Other important work indicates that the use of rice seedlings to test disease reactions between rice cultivars will be beneficial in plant breeding programs (Ferreira and Webster, 1976). Rice seedlings have proven to be very valuable for screening stem rot resistance in rice cultivars. The rice seedlings reflect disease symptoms earlier than more mature plants and are affected more severely.

Chemical Control. Research has shown that triphenyltin hydroxide (TPTH), more commonly called Du-ter, is effective in reducing stem rot disease and improving yields under commercial field operating conditions. It is uncertain, though, whether this chemical will be registered for use in California rice fields.

The timing of application of Du-ter is critical if effective control of stem rot is to be obtained. The most severe symptoms of stem rot are a result of infection at early stages of the rice plants' development. Du-ter should be applied during the fourth to sixth week after seedling emergence. Experiments have shown that rice is most susceptible to stem rot infection between the tillering and internode elongation stages of the plant's development. A single application during the mid-tillering stage of TPTH at the rate of .99 lbs per acre (1.12 Kg./ha) is shown to result in significant reductions of disease severity with corresponding yield increases ranging from 6 to 25 percent (Jackson et.al., 1977).

Table 4.13 shows the results of 1976 trials with Du-ter at five separate locations in Butte County (Jackson et.al., 1977). In four out of five trials, stem rot disease was controlled and yields were increased over the non-treated plots. The unreported trial was discarded because the Du-ter could not be administered correctly due to mechanical difficulties.

Table 4.13

DISEASE INDICES AND YIELDS OF TRIPHENYLTIN HYDROXIDE (TPTH) TREATED AND NON-TREATED STEM ROT OF RICE PLOTS IN BUTTE COUNTY, CALIFORNIA, 1976

			Disease Index[a]		Yield		
Cultivar	Site	TPTH	Mid-Season	End of Season	kg/ha	lbs/ac	% Treated Over Nontreated
CS-M5	1	Treated[6]	1.02	1.03	9038	8043	9
		Nontreated	1.23	1.60	8235	7329	
	2	Treated	1.03	1.03	8312	7398	6
		Nontreated	1.30	1.75	7832	6970	
CS-S6	3	Treated	1.08	1.13	9202	8189	25
		Nontreated	1.79	2.11	6860	6105	
	4	Treated	1.12	1.17	8705	7747	24
		Nontreated	1.76	1.92	6651	5919	

[a]Disease Index: 1 = healthy, 5 = most severe; see text for details.
[b]Treated Plots (2-hectare) received TPTH at rate of 1.12 kg/ha (a.i.) at the midtillering stage.

Source: (Jackson et.al., 1977)

Clearly, the results show a marked reduction in the disease index and corresponding yield increases. When Du-ter is applied in all cases, the disease index increased substantially for the nontreated trials while inoculum treated levels in the trials either remained the same or increased slightly over the testing period. Yield increases were highest for those trials which showed correspondingly high disease indexes over their nontreated counterparts. For instance, at Site 3 the nontreated plot showed the highest end-of-season disease index, and its treated counterpart resulted in the greatest percentage yield increase. The most pronounced effects of stem rot disease control are seen in incidences of high potential disease severity.

The California State Department of Food and Agriculture has petitioned the Federal Environmental Protection Agency (EPA) to allow the use of Du-ter under special emergency situations. The petition was submitted for the second time in April, 1980. If the petition is accepted by the EPA, the State Food and Agriculture Department would be authorized to permit the use of Du-ter under Section 18 of Federal Insecticide, Fungicide, and Rodenticide Act. The county agricultural commissioner's offices would be responsible for ensuring that the emergency uses of Du-ter are justified and in compliance with EPA regulations.

The registration of new pesticides is a lengthy and involved procedure. A spokesperson from Thompson-Hayword Company estimated that the screening process for Du-ter will take six to seven years through the EPA. If petitioned by the State of

California under Section 18, the EPA may authorize the use of Du-ter in less than six months.

The State Department of Food and Agriculture recognizes that the long-term environmental effects of Du-ter are not known and that in some cases its use may be counterproductive to the goals of existing Department of Health programs. State officials report that the use of Du-ter may compromise the effectiveness of mosquito abatement programs already in existence in the State.

In the Sacramento Valley, mosquito abatement districts are responsible for introducing mosquito fish (Gambusia affinis) into rice paddies during the early portion of the rice growing season. After rice growers have established the water level in their rice checks and the temperature of the water is stabilized, the mosquito fish are introduced into the fields. By the time mosquito larvae become abundant, the mosquito fish population is high enough to serve as an effective control against the insects. The timing of application of Du-ter, however, would directly conflict with the biological control of mosquitoes offered by Gambusia affinis.

If Du-ter was applied while the mosquito fish were present, the fish would be eradicated. The mosquito fish could not be reintroduced into the rice fields for approximately three weeks (Butte County Mosquito Abatement District, 1980). At this late date, it would no longer be feasible to stock the rice checks with the quantity of mosquito fish required for successful control of mosquitoes.

In addition to being toxic to mosquito fish, Du-ter is very active on algae and on vertibrate and invertebrate animal species. There is concern that Du-ter would reduce the population of natural predators which are beneficial to man. There is no advantage in using Du-ter other than for stem rot disease; however, it does seem to eradicate most other plant pests at the time of its application.

While the effects of Du-ter for reducing stem rot disease are well established, it is too early to determine its value as a commercial fungicide. The EPA has yet to authorize its use in California, even for emergency applications. If Du-ter does become acceptable for use under Section 18, then close observation of its ecological effects need to be made before recommendations for its wide-scale use can be made.

It should be added that the social costs of using a pesticide are often unknown until its detrimental effects have already become manifest. And it is likely that, as far as environmental issues are concerned, emotions in both the public and private sectors would run high if Du-ter was viewed as an alternative controller of stem rot disease in lieu of burning. Given that the objective of business is to maximize profits, the rice grower will employ the most economic means available to solve his technological problems. Hence, it may be that, from an economic point of view, the most prudent application of Du-ter would be in conjunction with the field burning of rice straw.