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PROJECT TITLE: Monitoring Rice Growers' Straw Management Practices

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OBJECTIVES AND EXPERIMENTS CONDUCTED BY LOCATION TO ACCOMPLISH OBJECTIVES:

General objectives were to 1) learn from grower experience by systematically monitoring their straw management practices; 2) supplement ongoing controlled variable straw management research underway currently at two sites. Both current year and three year summary data are presented.

1. **Field site selection**. We closely monitored thirty fields in 1995/96, collecting a full set of data, and did disease ratings on an additional eighteen fields. In the three years of the project, we made observations on a total of 126 fields. We chose fields based on a) straw management method; b) geographic location, to include fields throughout the Sacramento Valley; c) soil characteristics; d) willingness of growers to cooperate.

2. **Data collected.** We established study sites in the thirty fields in 1995/96, and collected straw management, soil, straw decomposition, crop performance, and cost data. Over three year study, we collected similar data on 93 fields. Study sites were small, representative areas of commercial fields.

Management: Number of years field incorporated, harvest method, straw variety, straw management system (rainfed, irrigated, flooded, burned), chopping (type, number of times), tillage (chisel, disc, plow, rollers, etc.), material application (water, fertilizer, microbials, manures).
Soil physio-chemical properties: Saturation paste %, pH, EC, Ca, Mg, Na, SAR, CEC, Organic C, sand %, silt %, clay %, total N.

Straw data: Percent straw cover after completion of fall straw management, and again in the final spring seed bed; straw decomposition during fall, winter and spring, and during the following crop season; winter water management (1995-96 only).

Rice straw decomposition. Estimated by loss of straw from mesh bags placed in fields at the start of the straw management cycle. Bags contained flail chopped M-202 straw from the current season which was oven dried for determination of net straw weight prior to placement in the field. Four replicate samples were recovered at seven sample dates at each location during the fall-winter-spring period. The last bag was removed just prior to spring ground work, then all bags for each site were replaced in the same fields and recovered in a similar fashion during the crop season, with the last bag coming out at the start of harvest. Bags were washed free of soil in a Calgon solution and oven dried prior to weighing to determine straw loss.

Weather variables: From CIMIS stations

Crop performance: In the following crop, variety planted, plant population, N, P, S in leaf blade at panicle initiation, disease ratings, field yield.

Cost information: By interview, data on farm size, ownership, straw practices, rice acreage, equipment type, horsepower, age, cost basis, labor, material inputs, etc. Twenty-six costs sheets were prepared for 1995/96 and a total of eighty-three in the three years of the study.

SUMMARY OF 1996 RESEARCH (MAJOR ACCOMPLISHMENTS) BY OBJECTIVE:

1. **Management.** Tables 1 and 2 present summary data for the various management systems observed in each of the three years of the study and multi year data.

It was convenient and informative to catagorize straw management into three major systems, although within each there was great variability in respect to tillage, chopping, water management and application of materials. **"Rainfed"** includes all those project fields which depended strictly on stored soil moisture and winter rainfall. **"Irrigated"** includes those systems which had one or more fall irrigations applied, but in which the water was not retained in a flooded condition for more than a month. **"Flooded"** includes all fields which had ponded water retained for most of the fall and winter straw decomposition season. We did not study burned fields in this project. This selection of fields is not intended to represent a statistically valid cross section of what the industry is doing as a whole. Far more fields would have been needed, so care should be taken if one wishes to extrapolate. However, these fields do represent a range of activities that are real life examples of grower activities, hence can provide valid insights.

Table 1.

Years of incorporation. This gives the average number of years that fields have had their straw incorporated. Understandably, with each passing year, the number is larger. Flooded fields have consistently been under this management practice longer than for other systems. Several of our cooperators were early adopters of this technique. They express a higher degree of satisfaction with flooding than do growers using other systems, hence tend to stay with it.

Straw variety. The varieties represented in our project were somewhat proportional to their general usage. For example, in the 1995 variety survey conducted by the Rice Experiment Station, M-202 was planted on 63.9% of the acres, M-201 on 6.6 %, and M-204 on 12.4%.

Table 2.
Chopping. Of all fields studied, 68.6% were chopped and was fairly constant over years. Use of chopping tended to increase over years in flooded systems as growers substituted this practices for rolling or discing. Flail choppers were most popular, used on 36% of the fields, with combine mounted, forage and rotary choppers at 17.1, 12.4 and 2.9%, respectively.

Chiseling. Of tillage methods observed in this study, chiseling was least popular, used on 17.3% of the fields, and in all three systems about equally. One pass was most common. Chopping greatly improves the action of chiseling in respect to soil/straw contact.

Discing. Discing was the most popular tillage method to incorporate straw, used on 48.5% of the fields. Of the disced fields, 62% had one pass, 32% two passes, and 6% three passes. Sixty-one percent of the rainfed, 75% of the irrigated and 26% of the flooded fields were disced. The term "discs" includes heavy stubble discs and lighter types meant for final seedbed work. In practice, stubble discs are more effective because of their heavier weight and greater clearance between blades, and between blades and frame. Lighter discs tend to plug more and do not penetrate hard soils very well. All discs are benefitted by chopping the straw, but successful incorporation of unchopped straw is possible with stubble discs. However, we have observed disc penetration problems when the straw is chopped close to the ground and interwoven. Correct adjustment of discs to ensure they remain level and track correctly is important to prevent formation of straw piles in the field.

Plowing. Not shown in Table 2, plowing was used on only 5% of the fields. While it effectively covers the straw, growers are reluctant to plow because of higher cost, impacts on levelness of fields, slower speed, and the potential to bring up adverse (e.g. alkaline) subsoil. However, some growers are using plowing every third or fourth year to combat disease.

Dry rolling. Some growers use dry rolling to press straw against the soil after discing in non-flooded systems, or before flooding in some flooded systems. However, only 12% of the fields in our study were dry rolled, about two thirds of them in the rainfed systems.

Wet rolling (cage rollers). This practice is used to press rice straw into flooded soil, and was used on 43% of the flooded systems. Those fields not wet rolled may be disced, chiseled, chopped or have combinations of these practices. A few growers who flood do not use any other operation, although this is rare. Cage rollers vary in their effects, mainly related to their weight. Heavy rollers tend to bury the straw, while lighter rollers press the straw into the mud. The latter tend to leave a pronounced mat over the soil in the spring which insulates the soil, slowing drying.

Table 1. Field number, years of incorporation and straw variety in project fields, 1994-96, by major straw management method and year.

	Rainfed				Irrigated				Flooded			
	'94	'95	'96	All	'94	'95	'96	All	'94	'95	'96	All
Number of fields observed	18	11	7	36	1	5	7	14	19	16	15	50
Years incorporated, average	1.2	2.6	2.7	1.5	*1.0	1.6	2.1	*2.1	1.8	3.0	3.2	2.5
Straw variety, % of fields:												
M-202	50	70	84	61	0	80	43	54	58	76	71	68
M-201	15	0	16	11	100	0	0	8	11	0	0	4
M-204	15	0	0	8	0	0	0	0	16	18	12	15
M-401	0	10	0	3	0	0	0	0	5	6	12	8
Kokuhorose	5	0	0	3	0	0	0	0	5	0	0	2
Akitakomachi	0	10	0	3	0	0	28	15	0	0	6	8
Sweet rice	10	10	0	8	0	20	28	23	0	0	0	0
Valencia	5	0	0	3	0	0	0	0	0	0	0	0

* One field with 30 year history of incorporation not included in averages.

Table 2. Straw tillage, rolling and chopping implements, by method and year.

	Rainfed				Irrigated				Flooded			
	'94	'95	'96	All	'94	'95	'96	All	'94	'95	'96	All
Chopper type and percent of fields in project by straw management method and year.												
None	15	27	30	24	0	20	14	15	50	38	31	41
Combine chopper	20	18	10	18	0	0	14	8	23	13	19	19
Rotary chopper	10	9	0	8	0	0	0	0	0	0	0	0
Flail chopper	25	9	30	24	0	80	57	62	23	50	50	39
Forage chopper	30	36	0	26	100	0	14	15	8	0	0	2
Chiseling, percent of fields by straw management method and year.												
None	75	100	70	78	0	100	43	67	94	81	94	90
One time	15	0	30	16	0	0	57	33	0	23	6	8
Two times	10	0	0	5	0	0	0	0	6	0	0	2
Discing, percent of fields by straw management method and year.												
None	45	22	0	31	0	42	0	23	88	75	23	73
One time	40	22	43	37	100	29	0	23	12	25	23	27
Two times	15	44	29	26	0	29	100	46	0	0	0	0
Three times	0	11	29	9	0	0	0	0	0	0	0	0
Dry rolling, percent of fields dry rolled, by straw management method and year.												
None	71	86	80	76	100	78	100	85	81	100	100	94
One time	29	14	20	24	0	22	0	15	19	0	0	6
Wet rolling, percent of fields wet rolled, by straw management method and year.												
None	100	100	100	100	100	100	100	100	56	31	41	43
One time	0	0	0	0	0	0	0	0	31	50	59	47
Two times	0	0	0	0	0	0	0	0	13	19	0	10

2. Soil Properties.

Table 3 presents average and range of soil physical and chemical analysis for samples drawn from the study site.

Table 3. Soil physical and chemical characteristics in study sites, mean and range of values.			
	Mean	Minimum	Maximum
Saturation paste, %	50.2	28	76
pH	5.6	4.5	7.2
EC, mmhos/cm²	0.49	.16	4.11
Ca, meq/l	1.5	0.1	15.6
Mg, meq/l	1.3	0.1	18.6
Na, meq/l	1.8	0.44	21.5
SAR	1.7	1.0	8.0
CEC, meq/l	25.4	0.7	47.5
Organic C, %	1.2	0.5	2.3
Sand, %	29.7	5.0	64.0
Silt, %	44.9	27.0	68.0
Clay%	25.4	5.0	59.0

Relationships of this data to straw decomposition and occurrence and severity of disease are discussed in subsequent sections.

3. Rice Straw Decomposition

The mesh bag technique is an index, not a direct measure of straw decomposition. It provides relative values, not absolute values. The degree to which it correlates to actual decomposition has not been adequately studied. Preliminary data from two separate efforts to look at this relationship suggest that mesh bags correspond somewhat to actual straw decomposition of straw in the soil. However, the correlation in the study we did, R=.631, was not statistically significant. In this and a related study, mesh bags discriminated between large treatment effects but did not reveal small differences. Because we were consistent in our method throughout, we are confident our numbers reflect real treatment differences.

Figure 1 shows average annual straw decomposition for all systems for the period from incorporation to spring ground work. The pattern of decomposition is similar in each year, but differs in amount. The reasons for the annual differences are related to climate and management. Climatic and management effects on straw decomposition are discussed separately below. Annual differences are primarily associated with the initial period, from fall until spring groundwork began. Subsequent decomposition of straw in the planted crop (not shown in Fig. 1)proceeded at

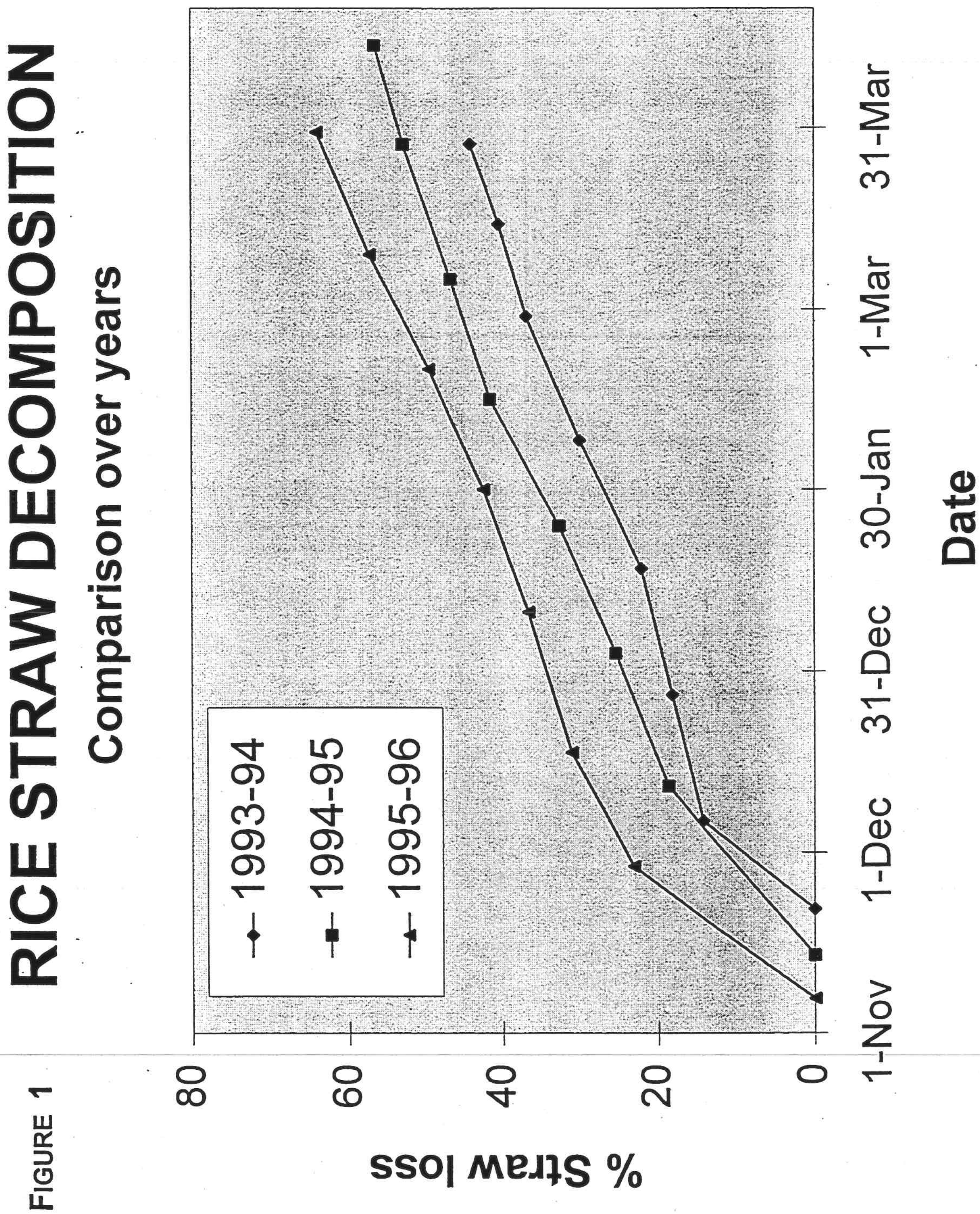

RICE STRAW DECOMPOSITION
Comparison over years
1993-94
1994-95
1995-96
% Straw loss
0
20
40
60
80
1-Nov
1-Dec
31-Dec
30-Jan
1-Mar
31-Mar
Date

FIGURE 1

a similar rate and to a similar total amount across all systems.

Table 3 gives average annual straw decomposition by major management method and time of the yearly decomposition cycle.

Table 3. Average annual straw decomposition, by major method at the end of the fall-winter-spring period (Fall) and at harvest time of the following crop (Crop).

	Rainfed			Irrigated			Flooded			Mean		
Time	**93/94**	**94/95**	**95/96**	**93/94**	**94/95**	**95/96**	**93/94**	**94/95**	**95/96**	**93/94**	**94/95**	**95/96**
Fall	36.7	51.1	56.1	33.0	54.2	63.1	46.9	59.1	68.2	41.0	55.8	65.6
Crop	84.3	89.3	84.7	87.5	89.0	84.7	82.6	87.4	84.1	83.7	88.3	84.6

Straw decomposition during the fall period increased annually for each of the three systems. Within each system, decomposition was consistently greater in the flooded system and lowest in the rainfed system, with irrigated systems intermediate. The reasons for the observed differences are explored below.

Climate effects on straw decomposition. Heat and moisture are prerequisites for straw decomposition. We evaluated temperature differences by summing heat units above 40° F for five locations in the Sacramento Valley, for each of the three years. The data is presented in Table 4 for the period Oct. 1 to April 1, approximately the time frame for the fall-spring straw decomposition period.

Table 4. Annual heat unit accumulation above 40° F for Sacramento Valley locations, for two periods, Oct. 1 to Jan 1 (labeled Jan 1) , and Oct. 1 to April 1 (labeled Apr 1).

Year	1993-94		1994-95		1995-96		Location average	
Location	Jan. 1	Apr. 1	Jan. 1	Apr. 1	Jan. 1	Apr. 1	Jan. 1	Apr. 1
Colusa	1259	2291	1003	2089	1567	2703	1276	2361
Nicolaus	1204	2117	975	2032	1477	2537	1219	2229
Sacramento	1333	2375	1092	2210	1333	2212	1253	2266
Willows	1480	2501	1146	2120	1478	2461	1368	2361
Durham	1329	2368	1018	2097	1597	2716	1315	2394
Year average	1321	2330	1047	2110	1490	2526	1286	2322

Heat unit accumulation varied greatly among years and locations. The winter of 1994-95 was coldest, while 1995-96 was warmest of the three years. Durham, Willows and Colusa tended to be warmer, while Nicolaus and Sacramento were cooler. A greater number of heat units were typically accumulated in the first half of the decomposition period (Oct. 1-Jan 1) than in the second half (Jan 1-April 1.) To the extent that heat is a limiting factor in straw decomposition, the most important thing these data suggest is that there is a potential advantage to incorporating straw as early as possible to take advantage of the warmer fall weather. Some confirmation of this is that the earlier the straw was incorporated, the greater the decomposition in the spring (R=.57***). An evaluation of the data shows that the duration of the decomposition period is mainly influenced by when the process began rather than when it ended. We have not yet evaluated if there is a significant correlation of location with straw decomposition.

Rainfall (Table 5) varied among years. The first year of the study was notably dry and decomposition rates were low in rainfed systems in the driest areas. One example of this effect was in several fields near I-5 on the Westside that were very shallow incorporated, permitting rapid drying between rain events. Decomposition in these fields was 20-22% compared to the average of 36.7% for rainfed systems in that year. Combined with a late start for many fields, we believe the dry weather contributed to the low decomposition rates in fields dependent on winter rainfall. Flooded fields were not subject to this moisture constraint and responded mainly to prevailing temperatures and management factors. In contrast, the following two years were markedly wetter and decomposition rates increased, suggesting that growers can expect better results in wetter years, other factors being equal.

Table 5. Annual rainfall for Sacramento Valley locations, for two periods, Oct. 1 to Jan 1, and Oct. 1 to April 1, inches.

Year	1993-94		1994-95		1995-96		Location average	
Location	Jan. 1	Apr. 1	Jan. 1	Apr. 1	Jan. 1	Apr.1	Jan. 1	Apr. 1
Colusa	3.75	5.03	7.97	27.46	4.5	9.4	5.41	13.96
Nicolaus	5.77	6.38	8.59	19.88	5.83	--	6.73	--
Sacramento	3.9	5.32	3.74	11.66	5.7	9.54	4.45	8.84
Willows	1.16	2.31	2.24	25.87	4.04	--	2.48	--
Durham	3.87	7.86	9.22	15.93	7.5	12.68	6.86	12.16
Year average	3.75	5.38	6.35	20.16	5.51	10.54	5.19	11.65

Tillage and soil effects on straw decomposition. Numerous factors working together determine the rate and amount of straw decomposition in a given location. No single factor is wholly responsible, although some may be more important than others. Our approach was to evaluate single factor correlations of tillage and soil factors with straw decomposition in the spring, by major management method. The correlation of linear correlation (r) and level of significance (p) of straw decomposition with tillage and soil factors are presented in Table 6, for each of the three major straw management systems and all systems combined.

Table 6. Correlation (r) and significance (p) of straw decomposition with tillage and soil variables, by major management system. Tillage and soil variables not included and cells with ns mean there was no significant correlation of the variable at the .05 level with straw decomposition.

System	Rainfed, n=34		Irrigated n=13		Flooded n=47		All Systems n=94	
Variable	r	p	r	p	r	p	r	p
Years incorporated	.407	.017	ns	ns	.282	.055	.318	.002
# discings	.375	.029	ns	ns	.374	.010	ns	ns
% silt	ns	ns	ns	ns	.307	.036	.305	.003
% clay	ns	ns	ns	ns	-.311	.033	ns	ns
Duration of incorporation period	.655	.000	.722	.005	.658	.001	.570	.001

Few factors were significantly correlated with straw decomposition, and most of them had low values. Duration of exposure of the straw to the soil was positively related in all management systems and had the highest correlation value, suggesting that growers can best help themselves by starting straw decomposition early, regardless of system used. The number of years in a row that a field was incorporated was positively but weakly correlated with straw decomposition in rainfed and flooded systems. This suggests that repeated incorporation has a small beneficial affect on decompostion. The number of discings was positively correlated in both rainfed and flooded systems, suggesting that the degree of straw-soil mixing is beneficial. Clay content was negatively correlated with straw decomposition in flooded fields, while silt content was positively correlated. This suggests that clay texture soils inhibit decomposition in flooded fields, which is possibly related to low oxygen levels compared to coarser soils.

Chopping. Straw was chopped on 88% of rainfed fields, 69% of irrigated fields, and 53% of flooded fields, or 68% of all fields. However, because our mesh bag technique uses chopped straw, we cannot measure the impact of chopping on decomposition in the field. Our field observations suggest that chopping clearly helps tillage implements mix the straw and soil better and is therefore appropriate for growers to do.

4. Impacts of Straw Management on Following Rice Crop Performance

Table 7 provides mean performance indicators in the rice crop in the year following the incorporation of straw. There were insufficient fields with irrigated straw in the study in 1994 for meaningful data.

Table 7. Field performance indicators, by major straw management method and year.

	Rainfed				Irrigated				Flooded			
	'94	'95	'96	Mean	'94	'95	'96	Mean	'94	'95	'96	Mean
Straw cover final seedbed, %	20.6	19.0	14.8	19.0	-	7.5	10.7	10.6	24.8	26.5	11.5	19.4
Plant population, #/ft²	41.9	29.4	29.8	36.9	-	35.3	25.7	31.2	45.1	35.1	27.1	34.9
Leaf N @ PI, %	3.56	2.84	3.06	3.28	-	3.24	3.32	3.19	3.43	3.33	3.19	3.31
Leaf P @ PI, %	0.33	0.29	0.26	0.31	-	0.27	0.27	0.27	0.31	0.28	0.30	0.30
Leaf S @ PI, ppm	2966	2366	2644	2753	-	2403	2308	2321	2777	2520	2479	2590
SPAD meter reading	39.4	37.7	40.9	39.1	-	39.1	40.4	39.0	38.7	39.9	42.0	40.1
Yield, cwt/ac	84.3	77.7	81.0	81.7	-	81.8	73.2	78.3	85.3	79.6	78.1	81.0

Straw cover in final seedbed This measurement is suggestive of how well straw was incorporated in the final preparation of the seedbed and may relate to potential stand problems in the young crop. For example, floating straw accumulating on the downwind side of the field and on high spots can suppress plant growth. In one case, we measured an affected area equal to about one percent of the field where plants were completely absent. The mean for irrigated fields was lower than for other systems, but we have no explanation for this difference.. Mean seedbed straw from 1994 to 1996 for rainfed and flooded systems decreased over years and may be related to greater straw decomposition in these years coupled with better seedbed preparation intended to bury straw more effectively..

Plant population Mean plant population was not different among methods, but differed among years. In no case were stands low enough to be considered a problem, with the exception of discrete areas where straw accumulated in dense mats.

Straw related factors that could influence stand establishment include algae and gas. Many growers have reported increases in algae since starting straw incorporation, and tend to use more copper sulfate as a result. 1996 was a particularly severe algae year, mostly because of hot weather occurring during early stand establishment in many fields. Controlled tests to determine the individual contribution of straw management to algae incidents have not been conducted. Our impression is that straw on the seedbed does increase algae somewhat, but has not, with the exception of 1996, contributed measurably to stand loss. Many growers have likewise reported more incidents of gas bubbling from fields when the walk them during early stand establishment. However, we have no evidence that this gas formation is causing crop damage, except in corners or edges where straw accumulates.

Leaf nutrient levels Mean leaf N was not different among methods or years. SPAD meter readings differed among years. Leaf P and S was lower in irrigated fields. The limited number of irrigated fields, several of which were in a common soil type which is known to have low native P and S, may have biased the data. No clear trend emerged in the data to suggest that rice crop nutrient levels were influenced by method of straw management, and all the data are within normal parameters for healthy rice. Fertilizer applications compensated for potential differences. While this does not address the question of whether or not fields with straw should be fertilized differently than burned fields, it does suggest the situation can be managed.

Commentary from growers suggests that nutrient requirements have not been increased by straw incorporation. In fact, some growers feel that they can reduce N rates slightly.

Yield. Average field yields did not differ among methods, but differed over years within the flooded method only. In all but irrigated fields for 1996, yields in the project fields were above statewide average for the year. Maintaining field yields while incorporating rice straw is one of the growers' biggest concerns. Based on reported yields of project fields, we are unable to detect a large general yield reduction in California rice fields that is clearly attributable to straw management. However, rice farms vary greatly in their ability to withstand yield loss, even of small magnitude. Farms with high costs are the most vulnerable to even small scale yield reductions.

In individual instances, identifiable problems that are definitely linked to straw management are probably reducing crop yields by some unquantified amount. For example, many growers are reporting increased disease which they feel is damaging their rice. In the past two seasons average yields in California have been down dramatically and many question to what extent straw is responsible. Evidence suggests that disease levels are higher, and since this is related to straw management, there is undoubtedly some impact on yield. To what extent low yields are a direct effect of straw or weather or both is a matter of conjecture.

5. Disease Monitoring

We monitored disease levels in each of the study fields by randomly selecting 100 stems in the area immediately around the study site. We also evaluated disease levels in additional fields by collecting 200 stems from throughout the basin that is nearest to the center of the field. We scored severity and incidence for both stemrot and aggregate sheathspot.The majority of the fields in this study were evaluated only one or two years because of changes in straw management. However, we have disease data for each of the three years for six fields. Therefore, one needs to be cautious about interpreting this data. We believe this data has some value in establishing both a baseline of disease levels across a broad array of situations, and provides some insights about the trend of disease severity and incidence. Table 8 contains results of disease levels, sorted by year and management method.

Stemrot severity levels in the sample fields were higher in 1995 and 1996 compared to 1994. Other disease indices were not statistically different, although stemrot incidence in particular trended upward over time. We found no significant relationship of straw management method to the various indices of disease.

Table 9 gives significant correlations of disease indices with soil chemical and physical factors. Those not included did not correlate significantly.

Table 8. Disease index means, by year and method.							
	Year Means			Method Means			Grand Mean
	1994	1995	1996	Rainfed	Irrigated	Flooded	Year x Method
Stemrot severity*	1.30 a	1.64 b	1.90 b	1.64	1.42	1.60	1.69
Stemrot incidence	18.9	29.2	32.6	31.9	22.2	24.0	28.6
AgSS severity	21.9	20.1	24.0	18.6	17.2	23.0	22.2
AgSS incidence	64.3	59.1	68.0	58.3	52.9	67.0	64.2

* Means followed by different letters are significantly different at the 95% confidence level.

Table 9. Correlation and significance of disease indices with soil factors, n=91								
	Stemrot Severity		Stemrot Incidence		AgSS Severity		AgSS Incidence	
	R	P	R	P	R	P	R	P
S/P %,	.254	.031			-.297	.011	-.299	.038
pH					-.356	.002	-.493	.001
EC, mmhos/cm					-.258	.029	-.308	.002
Mg, meq/l					-.232	.053	-.226	.008
Na/meq/l							-.398	.001
SAR							-.412	.001
CEC	.340.	003	.287	.014			-.364	.002
Sand, %							.267	.020
Clay, %	.261	.024					-.266	.021

Correlations with individual soil components were in general small, and are only indicators for further study. However, they collectively provide evidence that the two diseases respond to soil characteristics differently. For example, stemrot levels correlated positively to factors suggestive of heavy soil--saturation paste, CEC and clay content. Conversely, aggregate sheathspot levels responded in the opposite manner to the same factors plus SAR and its components (Na, Mg, EC). In addition, aggregate sheath spot was negatively related to pH, suggesting that acid soils may have more of this disease than alkaline soils.

An important question is, "What happens to disease over years when straw is incorporated every year?" Data in Table 8 shows an increase in stemrot severity over time. In addition, aggregate sheathspot incidence and severity correlated positively with the number of years fields had straw incorporated., r= .355** and .306,** respectively. However, there was a negative correlation of stemrot incidence and severity with years of incorporation, r= -.226** and -.243*, respectively. These results are ambivalent, so we must look at data from the same fields over time. We had six fields in our study from which we collected disease data for three years in a row. Results are in Table 10.

Table 10. Disease levels over time with consecutive years of straw incorporation.

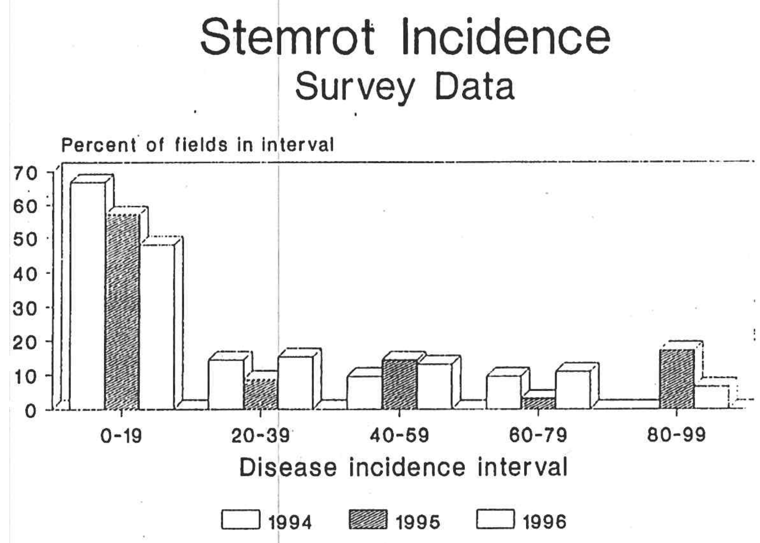
	Stemrot incidence, %			Stemrot severity, 1-5			AgSS incidence, %			AgSS severity, %		
Grower #	1994	1995	1996	1994	1995	1996	1994	1995	1996	1994	1995	1996
1	2	0	10.5	1.00	1.00	1.24	100	97	98	63	40	44
2	0	2	8	1.00	1.00	1.21	83	98	96	28	35	45
3	0	1	1	1.00	1.00	1.02	77	90	94	28	38	36
4	15	5	10	1.20	1.10	1.18	51	86	95	31	30	26
5	17	14	8.5	1.30	1.20	1.23	84	80	85	27	31	36
6	75	86	89	2.10	3.00	2.70	15	10	84	23	31	11
Annual mean	**18.2**	**18.0**	**21.2**	**1.27**	**1.38**	**1.43**	**68.3**	**76.8**	**92.0**	**33.3**	**34.2**	**33.0**

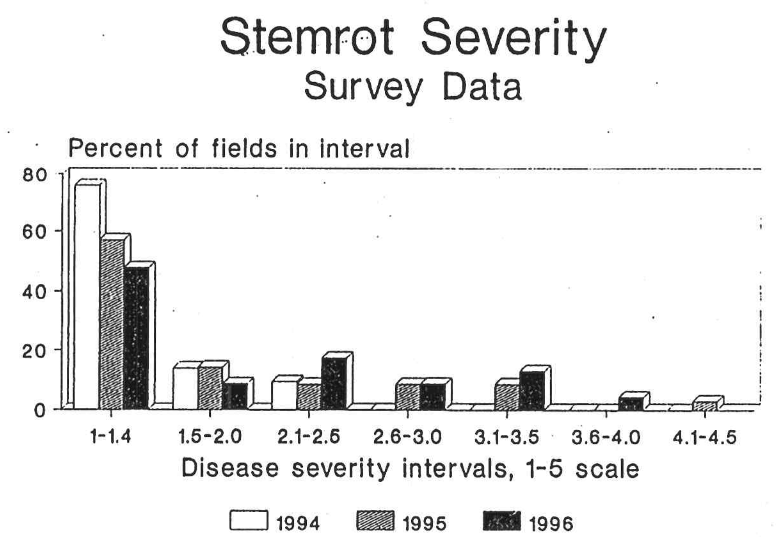
Mean incidence and severity for either disease did not significantly increase among these six fields over time. The trend, however, for both stemrot severity and aggregate sheathspot incidence is for disease indices to increase with more years in straw. More paired comparisons would be needed to confirm this statistically. There are fourteen fields in our project for which we have disease data for two years, 1995 and 1996. Mean aggregate sheathspot incidence significantly increased during that time. As with the three year means, there is also a trend for stemrot severity to increase although the means of the two years are not significantly different. Stemrot incidence and aggregate sheathspot severity remained relatively constant over time.

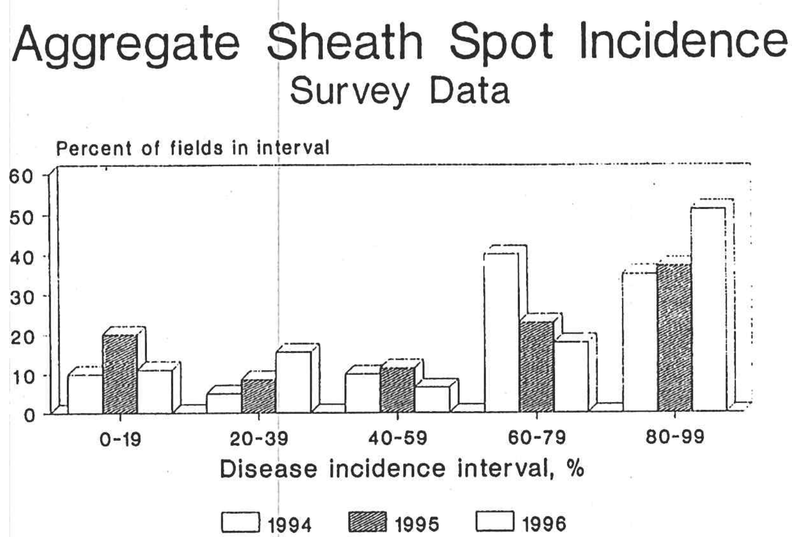
Stemrot and aggregate sheath spot compete with each other for infection sites so that if one is high, the other is often low. This is consistent with the aggregate pattern we observed in the 102 project fields for which we have disease data, and with previous work. The correlation of incidence of both diseases and severity of both diseases is -.488 and -.346, respectively. While these correlations are highly significant, they are relatively low. We do have examples in our study of fields with high levels of both stemrot and aggregate sheath spot. One cannot rely on the presence of one disease to control the other, although there is some competition present.

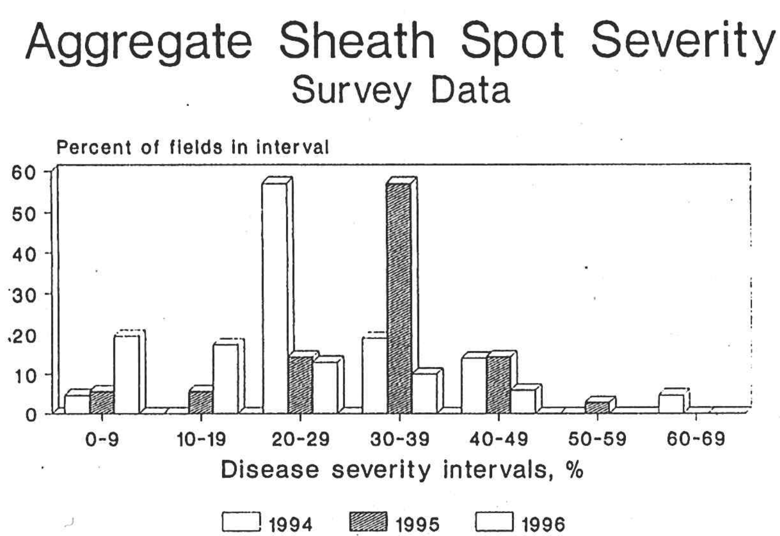
Figure 2 gives the distribution of disease indices in the 102 survey fields over time. The distribution of the two diseases is very different, with about 55% of fields having an incidence of

FIGURE 2









1994, 21 fields
1995, 35 fields
1996, 46 fields

stemrot below 20%, while about 65% of fields had an aggregate sheathspot incidence over 60%. This suggests that stemrot tends to be less severe in the average field, but affects a few fields very severely. In contrast, aggregate sheathspot is more widespread. The distribution of severity of stemrot is similar to incidence, with about 60% of fields at a low level, and the balance spread among greater severity levels. About half the fields have an intermediate aggregate sheathspot severity level, with the remainder equally divided above and below this.

6. Costs of Straw Management

Table 11. Mean straw management costs, by major management method and year, summary of data from 1993/94 to 1995/96

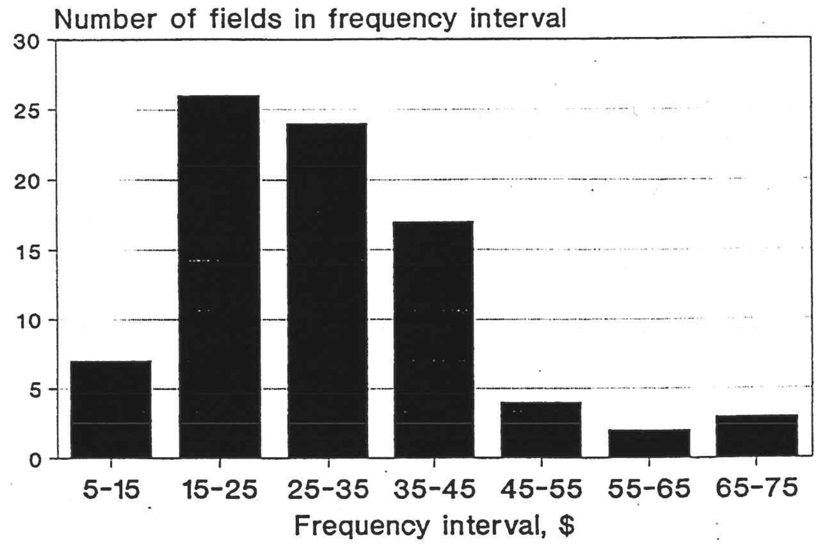
	METHOD			YEAR			
FALL COSTS	**Rainfed n=30**	**Irrigated n=10**	**Flooded n=43**	**1993/94 n=31**	**1994/95 n=26**	**1995/96 n=26**	**MEAN n=83**
Labor time, hours/ac	.37	.69	.50	.47	.48	.49	.48
Labor cost, $/ac	4.02	7.16	4.75	4.58	4.79	5.00	4.78
Fuel, lube, repairs, $/ac	7.38	7.63	4.98	6.48	6.58	5.37	6.16
Materials, $/ac	1.95	9.86	11.27	5.41	10.20	7.63	7.61
Custom/rent/ $/ac	12.49	7.52	10.22	11.01	9.67	11.40	10.71
TOTAL POSTHARVEST COSTS, $/AC	25.84	32.17	31.21	27.48	31.24	29.40	29.26
Interest on operating capital @ 11.61%, $/ac	.60	1.11	.18	.59	.12	.60	.44
TOTAL OPERATING COSTS, $/AC	26.44	33.28	31.38	28.07	31.36	30.00	29.70
Total cash overhead (taxes, insurance), $/ac	.44	1.03	.29	.23	.71	.40	.43
TOTAL CASH COSTS, $/AC	26.84	34.31	31.68	28.26	32.07	30.40	30.13
TOTAL NON-CASH OVERHEAD (dep. & int.) $/AC	6.53	11.70	4.69	7.25	7.00	4.10	6.18
GRAND TOTAL, $/AC	**33.37**	**46.01**	**36.36**	**35.55**	**39.07**	**34.50**	**36.31**
SPRING COSTS, $/AC (included in total)	4.12	.00	5.73	4.98	4.04	4.16	4.43

Total cash costs are markedly similar across methods and years. The most variable of the components of cash costs is material, which is mainly the cost of water, in both irrigated and flooded systems. The average cost of water in irrigated and flooded systems was $9.22 and 9.96/ac, respectively. Additional materials used included manure, biological additives (supposed to breakdown straw) and fall fertilizer. Figure 3 shows that about 81% of the fields had cash costs in a range of $15 to 45/ac, 8% less than $15/ac and 11% over $45. The costs in the more expensive fields were associated with using expensive custom chopping operations, use of manure, and high cost of additional spring ground work when fall decomposition was inadequate.

Noncash overhead contributed an average of 17% to the total costs. Eighty six percent of the fields had overhead expenses of less than $10/ac (Fig. 3). Fields with higher overhead costs were associated with purchase of expensive new equipment (eg. forage chopper) which was not used

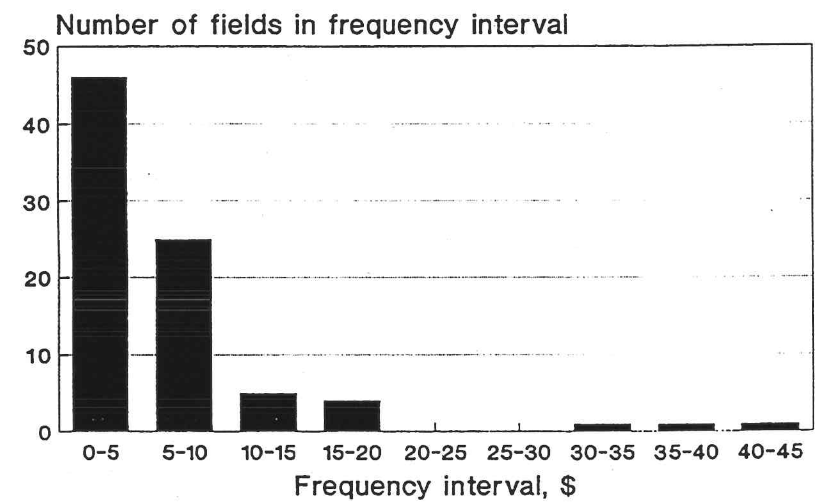
FIGURE 3

TOTAL CASH COST

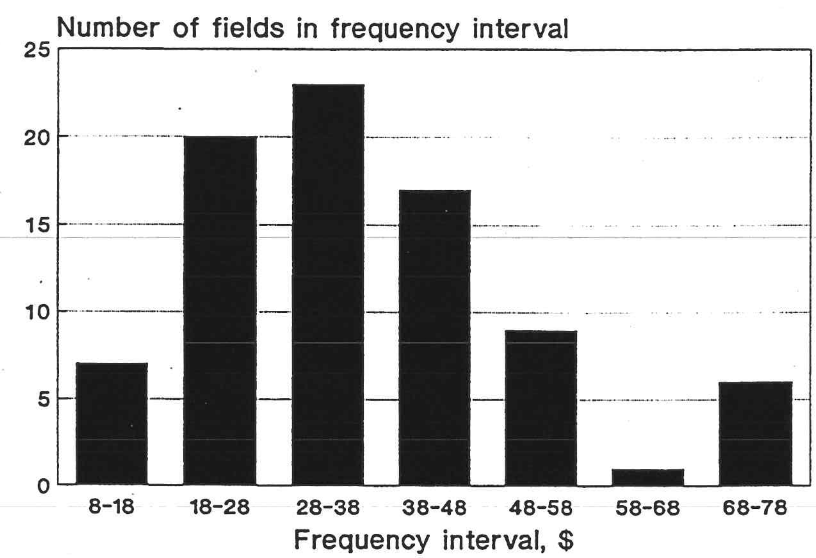


NON-CASH OVERHEAD COSTS

Depreciation & Interest



TOTAL COSTS



on sufficient acres to lower the cost.

Total cost were greatest in irrigated systems and least in rainfed. Irrigated systems spent more on water, labor and equipment while flooded systems spent more on water and custom opertions. Rainfed systems spent the most on custom operations. Expenses did not differ significantly over years. Sixty percent of the fields had a total cost between $18 and $48/ac (Fig. 3). Total costs are a combination of fall costs, and spring costs that are considered by the grower to be above the normal required.

There was no correlation between cost of straw management and the amount of acres farmed. However, smaller scale farms are less able to purchase straw management equipment, such as choppers, because they cannot spread the cost over enough acres to justify the expense. They must either hire contract work or themselves become a contractor, which some are doing. Larger farms can more directly support equipment purchases.

There was no correlation between the cost of managing straw and how well it worked, as measured by straw decomposition. This suggests that growers should seek a least cost, minimal approach to straw management and avoid the temptation to do extra tillage operations which do not appear to improve straw decomposition.

The components of the spring costs are included in the "Grand Total", but are also given separately in Table 11, in the last row. Average spring costs added $4.43/ac, with 90% of the fields incurring a spring cost of less than $15/ac, and 72% less than $5/ac. Seventy-one percent of the cooperators indicated they had no additional costs in the spring related to straw management.

Our cost analysis does not include the impact of yield reductions due to straw related problems. As noted before, yield impacts can and do occur. However, we have no way to incorporate these changes in our cost analysis.

7. Water Management

How much water is used for winter flooding is of great interest because of the many competing uses for water. From the rice industry perspective, winter flooding is a beneficial use because it provides an effective means of managing straw. Conservation groups also promote this practice because it increases the acreage of wetland habitat during the winter months. In contrast, there are concerns about how this may affect migrating fish, loss of stored water in a drought, and potential contributions to localized flooding in the Sacramento Valley in very wet winters. There is no systematic, annual measurement of how much water is being used for rice straw decomposition. In 1994-95, two independent studies determined either 120,000 or 140,000 acres of harvested rice fields were flooded. To our knowledge, this has not been reported in 1995-96.

During our interviews with growers and observation of fields, we collected data pertaining to individual sites, which is presented in Table 13. In respect to water depth, no specific or consistent practice is used. Some growers attempt to capture all water by putting more boards in the irrigation boxes, so their depth varies greatly, according to rainfall. Others maintain a continuous flow and target a given level. Depths are kept shallow initially, 3-5", to accomodate rolling, but usually rise afterward. There is also some sensitivity to the needs of waterfowl which vary widely in their water depth preference. Most growers flood from November to February, and have fields drained by early March.

Table 13. Winter water management in 1995/96.

Field ID	Flood Date	Water amount	Management	Comments
31	10/5/95	Grower estimate: 1.5 af/ac	Continuous flood	Flooded for hunting
54	10/13/95	Not measured	Irrigated	
36	10/14/95	1/4 af/ac	Irrigated,	
5	10/15/9	Not available	Continuous flood	Maintained 6-8", more after rain
70	10/23/95	Not available	Continuous flood	Maintained 6", deeper after rain
84	10/25/95	Not measured	Continuous flood	Estimate, 4-5" across all checks
17	10/25/95	Slightly over 2 af/ac	Continuous flood	
48	10/25.95	1 af/ac	Always wet, depth varied greatly	Tried to maintain 3-4"
73	10/26/95	Grower estimate, 2 af/ac	Filled to 8-10", shut off	Boards left in
39	10/27/95	1 af/ac		1/2-3/4 af to flood, 2"' desired depth
13	10/29/95	1.5 af/ac		Always wet, depth varied
55	10/30/95		Continuous flood	Drain water repumped to field
63	11/1/95	Not available	Continuous flood	Flood for hunting, 4-5" desired depth
67	11/6/95	1.25 af/ac	Continuous flood	
4	11/6/95		Contiunous flood	Grower est.: High spots 3-4", low 7-8"
30	11/6/95	Not measured	Irrigated, shut off.	No boards to hold water
53	11110/95	Not measured	Continuous flood	Flooded for hunting
28	11/10/95	Not measured	Continuous flood	Tried to maintain 5"
29	11/11/95	Not measured	Continuous flood	Flooded for hunting
59	11/14/95	Not measured	Continuous flood	For hunting, estimate 8" depth aveage
82	11/20/95	2.1 af/ac	Continuous flood until 1/196	For hunting
56	11/26/95		Irrigated	
47		Rain only	Non-flood	Boards in to catch rain
72		Rain only	Non-flood	Boards in to catch rain

In-field measurement of water use was beyond the scope of this project. The entire matter of water use for winter flooding is deserving of a thorough study by water experts who understand rice straw management systems and who would be given access to the necessary information from water purveyors. Some instrumented measurements should also be done. Otherwise, this will remain a matter of conjecture rather than a firm basis for policy

PUBLICATIONS AND REPORTS (1996)

Williams, J F, S R Goldman-Smith, S R Scardaci, and J E Hill. "Monitoring Rice Straw Management Practices in California," 26th Rice Technical Working Group, February, 1996. San Antonio, TX. Abstract and oral presentation.

Williams, J F and S R Goldman-Smith. Interim Report, "Monitoring Rice Straw Management Practices." To The Nature Conservancy and the Heller Foundation, June, 1996.

Williams, J F and S R Goldman-Smith."Monitoring Rice Growers Straw Management Practices: A Progress Report." Rice Field Day, Rice Experiment Station, August 28, 1996. Abstract and poster.

CONCISE GENERAL SUMMARY OF RESULTS:

Incorporation of rice straw is accomplished using three general methods which are differentiated mainly by water management. A grower's decision to use a particular system is determined mostly by cost and availability of water and involvement in waterfowl management and enhancement. Within each system great variety exists regarding the tools used to incorporate straw and the order in which they are used. Data strongly support the conclusion that flooded systems are more effective in decomposing straw and have the additional benefit of creating winter wetland habitat. Consequently, more growers use flooded straw management than other methods. Preferred tillage method was by discing, usually a stubble disc, while chisels and plows were less often used. Over two thirds of fields were chopped prior to other operations. The relationship of chopping to straw decomposition has not been extablished, but is is clear that chopping augments straw management, and is a recommended practice for many systems. This may lead to more complete decomposition.

Data also show that average fall-spring straw decomposition increased each year of the study for all systems. The reasons for this appear to be mostly related to annual differences in rainfall and prevailing temperatures and certain management practices, the most important of which is earliness in doing fall incorporation. In general, multiple tillage operations did not increase decomposition, while repeat years of incorporation did. Some data are suggestive that fine texture soils somewhat impede decomposition compared to coarser texture soils. Straw remaining in the spring continued to decompose under the subsequent crop, with about 85% total decomposition over the full year cycle. In-crop decomposition did not differ by method or year.

Several factors that can potentially reduce crop yields were identified, including straw mat affects on stand density, algae, gas formation, and nutrient effects. However, in most cases these were well-managed by the growers and did not noticably impact average crop performance. Individual fields, however, were affected by one or more of these problems mid performance may have suffered. Disease, including stemrot and aggregate sheathspot, emerged as the primary straw-related problem that can potentially reduce crop yield. The preponderance of our data support the conclusion that average stemrot severity and aggregate sheathspot incidence increased over the three years of our study. Distribution of disease indices among project fields suggests that they differ greatly in their incidence, with mean incidence of stemrot and aggregate sheathspot at 29% and 64%, respectively, over all project fields and years. Several soil factors--salinity, pH, alkaline elements, SAR, CEC, clay %-- are negatively related to aggregate sheathspot occurrence. Stemrot severity was positively related to factors indicative of heavy soils, saturation paste percent, cation exchange capacity and clay content.

A primary concern of rice growers is the cost of straw management which is not compensated with extra income. It is an expense borne by the existing yield, so they are naturally very concerned about increasing costs with the possibility of yield simultaneously decreasing due to disease. Average total costs for all systems and years was $36.31/ac, most of which is incurred in the fall. This includes an average of $4.43/ac for additional expense in the spring caused by straw. Costs ranged from $7.70 to $76.54/ac, with 60% of the fields incurring an expense between $18 and $48/ac. Cost and farm size did not correlate, suggesting that farm scale is not a factor in determining expense. Nor did cost correlate with straw decomposition, suggesting that growers should be very cautious about straw work that does not improve results. To some extent, practices to promote cost effective straw decomposition may be contrary to practices that promote disease control. If increased disease levels demand action, growers may have to spend more money on straw work, such as plowing periodically, to bury sclerotia.

Water usage for winter flooding was not in the scope of this project. However, general information on how growers are managing their water, including depths, is presented. Water is generally kept at a depth 3-8". Little measurement of water use is done, so mostly estimates were provided, and ranged from 1 af/ac to 2.1 af/ac. Rainfall is a significant portion of total supply.

A thorough study of water use for straw decomposition is needed to determine diversion, Et, percolation and net use amounts. Currently, our knowledge of the subject is inadequate. Some instrumented field sites should provide useful site specific information on the components of infield water use. In addition, data on winter water delivery by purveyors is a primary information source to establish overall system requirements. Such a study should also include evaluation of drain water returning to the system. A methodology to annually determine the acreage of winter flooding is also needed. This could provide the basis for important policy decisions on winter water use