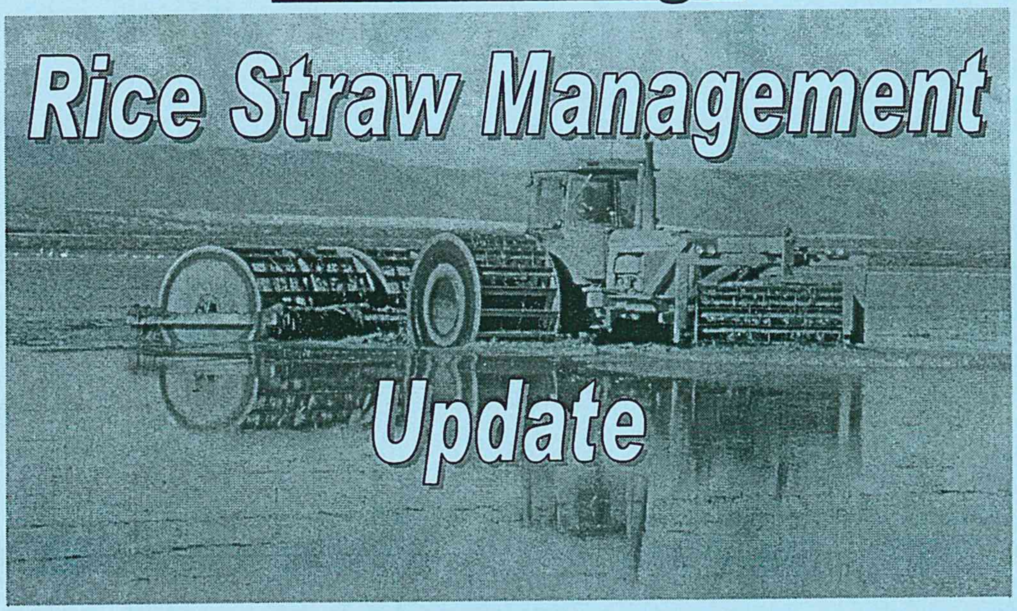
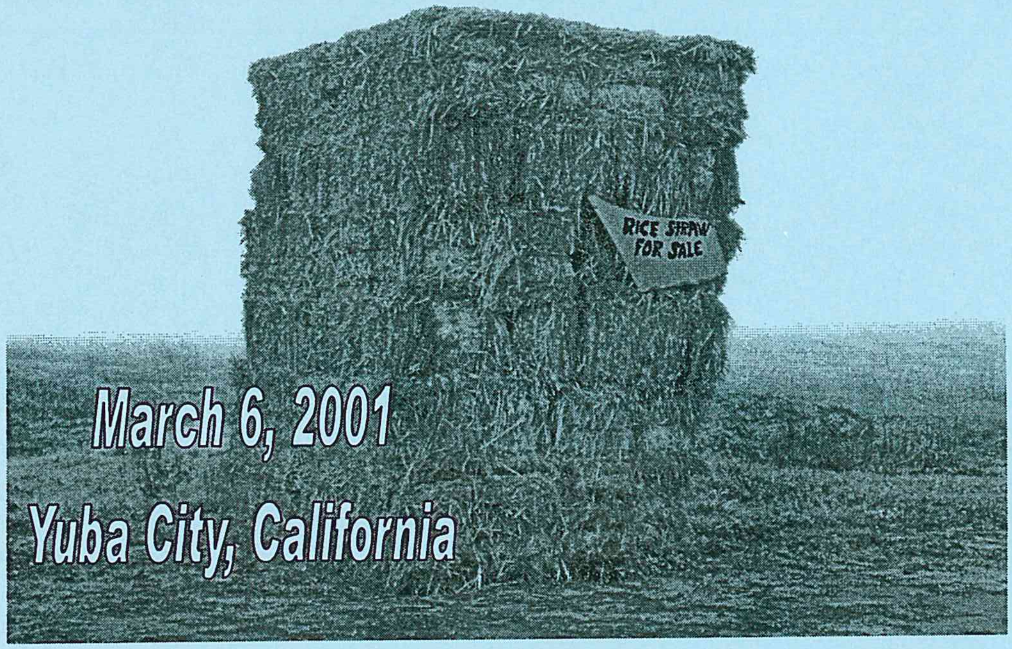
Proceedings

Rice Straw Management Update





March 6, 2001

Yuba City, California

Sponsored by

The UC-DANR Workgroup

The UC Rice Straw Harvesting & Handling Project

With support from the

California Rice Commission

&

The Rice Producers of California

Rice Straw Management in California

As the 1991 legislation that began the phasedown of rice straw burning in the Sacramento Valley nears full implementation, it is appropriate to summarize University of California straw management research. Major research projects are underway on the two primary straw disposal alternatives, soil incorporation and utilization. The meeting featured presentations on the crop production impacts of various in-field straw management methods in the first session. In the second session, results of studies on harvesting and handling were reviewed.

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Impacts on Crop Production

Harvesting and Handling Rice Straw

Meeting organized by

Jack Williams, UC Cooperative Extension, Sutter/Yuba, Placer & Sacramento CountiesCass Mutters, UC Cooperative Extension, Butte & Glenn CountiesBryan Jenkins, Department of Biological and Agricultural Engineering, UC Davis

Soil quality and C sequestration

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California rice farmers produce some of the highest yields in the world as a result of a fine-tuned fertilizer, pest and thermal residue management strategies developed over many decades of experimentation by growers and university and federal researchers. Thermal residue management, or open-field burning, is an old agricultural practice that has been shown to sustain production in cropping systems. It is thought that burning destroys weed seeds and disease spores that over winter in the rotting rice straw. This is especially important in cropping systems where monoculture is practiced, as is common in California, because of the opportunity to select resistant pests over many years of growing the same crop.

As population growth and urban expansion continue to accelerate in California, rice growers have been pressured to reexamine their rice straw management strategies because of air pollution concerns associated with open-field burning practices. Alternative rice residue management practices that incorporate rice straw into paddy soils and winter flooding are currently being adopted in California due to the legislative restriction of open-field burning mandated by the California Rice Straw Burning Reduction Act (AB 1378, 1991). Since these population pressures are occurring through the world, California provides an example of the direction of the future rice industry.

One common alternative practice is to flail the rice straw and soil-incorporate by chisel plowing. This is thought to accelerate the decomposition of the straw to reduce the incidence of disease and problems with spring seedbed preparation. These changes in rice residue management are more expensive and impact the bottom line of rice growers. For example, open-field burning cost growers about $3 an acre compared to about $37 an acre for incorporation and winter flooding (S. Blank and co-workers, University of California-Davis). It remains to be seen whether the additional winter water use is sustainable under future urban pressure and limited water supply in California.

The positive side of straw incorporation is the enhancement of soil quality through building of soil organic matter. Many studies have shown that soil organic is a key indicator of good soil quality. Increased soil organic matter is associated with positive changes in nutrient availability. With these changes soil physical and biological properties are normally enhanced. For example, increased soil organic matter improves soil tilth making it easier to work the soil. Biological properties, such as the size of the microbial biomass, are also improved and lead to a more active and available supply of soil nutrients. Another positive aspect of building soil organic matter is the concept of soil carbon sequestration. Soil carbon sequestration is a term that defines the build up of soil organic matter. However, its usage is not to maintain soil fertility, rather to define a mechanism to store carbon in the soil to mitigate the "Greenhouse or Climate Change" effect from rising carbon dioxide levels as a result of industrial activity. In principle, cropping systems would be managed to create soil carbon through increased biomass production leading to more plant litter to transform into soil organic matter. Post burning rice residue management practices, such as straw incorporation and winter flooding, are viable management practices to increase soil carbon or organic matter. The significance of this practice is that the United States congress is considering providing payments to farmers who change management practices to sequester soil carbon. This type of language may appear in the next Farm Bill. Therefore, demonstrating that rice growers can sequester soil C is of critical importance to assure that rice growers receive these types of payments.

Changes in agronomic practices that impact yield or show positive gains in soil carbon or organic matter often take up to 10 years before they are realized. Furthermore, the impact on long-term soil fertility and rice yield is uncertain during the transition period where changes in management occur. Some of these uncertainties include the incidence of weeds and pests, which can be related to soil nitrogen availability. The impact of long-term rice straw incorporation is also of concern in light of results from the International Rice Research Institute in the Philippines: Stagnant rice production has been attributed to changes in nitrogen availability as a result of the massive amounts of straw produced by triple cropping and of continuous flooding. These changes may alter the sustainability of rice production unless producers are able to adequately manage for nitrogen in soil with continuous flooding and incorporated rice residues. This is especially true for California growers who winter flood their fields to enhance rice decomposition. Therefore, the long-term effect of rice residue incorporation on soil nitrogen availability and pest occurrence has yet to be fully evaluated in California and other parts of the world.

As a result of these changes, a cooperation between the California Rice Research Board, University of California Davis, Ducks Unlimited and the California Energy Commission was formed to develop long-term experimental sites to assess the sustainability of alternative rice residue management practices. The California Energy Commission was interested in ways to cut fuel usage under alternative rice residue management. The most intensively studied site is on Steve Dennis' ranch in Maxwell, in the heart of California rice-growing country. The site was established in 1993 to compare open-field burning with alternative rice residue management. The implementation of residue incorporation with winter flooding has been found to reduce straw waste for seedbed preparation and provide needed habitat for migratory waterfowl. In addition, though no significant change in total soil C has been noticed, stable carbon pools in the incorporated/winter-flooded plots have steadily and significantly increased. This is an important demonstration that rice growers can sequester soil carbon through a change in residue management.

The implementation of residue incorporation with winter flooding has been found to reduce straw waste for seedbed preparation and to provide needed habitat for migratory waterfowl. Other benefits of straw incorporation include the enhancement of soil quality through increases in soil organic matter. Storage of soil carbon will become important to mitigate global warming through the removal and farmers may get paid to so in the provisions of the upcoming new Farm Bill. However, these benefits need to be weighed against potential yield-limiting factors associated with the in field management of rice residues.

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Managing Rice Straw: Research Shows Many Advantages of Winter Flooding

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Rice Straw Management Update
March 6, 2001
Yuba City, CA

Introduction

Rice straw management is an important part of rice production. As with any crop residue, the method the producer uses to manage the straw after harvest has significant impacts on soil fertility as well as potentially significant environmental impacts. Burning the rice straw has been the most common method employed for straw disposal in the past. However, air quality concerns have resulted in dramatic reductions in the amount of rice straw burning allowed in California. Currently only 25% of the acreage in rice may be burned, with further reduction an ongoing possibility. Recent research has demonstrated that winter flooding is an excellent management alternative that can enhance soil fertility and provide significant environmental benefits.

Beginning in 1993 scientists from the University of California Division of Agriculture and Natural Resources with funding from the California Energy Commission, Ducks Unlimited and the Rice Research Board, began a long-term study to investigate different methods of managing the rice straw problem. The methods of disposal included four techniques: burning, incorporation, rolling, and baling and removing the straw. Each of these methods was compared with and without winter flooding, totaling eight different methods. The different techniques and impacts on soil fertility and several environmental impacts are summarized in Table 1.

Table 1. Impacts of rice straw disposal methods

#	Disposal Method	Fertility	Air Quality	Soil Carbon Sequestration	Waterfowl
1	Burn	-	-	-	-
2	Incorporate	+	o	+	-
3	Roll	+	o	+	-
4	Bale & Remove	-	o	-	-
5	Burn & Flood	-	-	-	+
6	Incorporate & Flood	+	o	+	+
7	Roll & Flood	+	o	+	+
8	Bale/remove & Flood	-	o	-	+

+ positive impact - negative impact o no impact

Incorporation or rolling combined with winter flooding were shown to result in the fastest straw decomposition rates and most significant improvements in soil fertility. After five years nitrogen fertilizer requirements are reduced. Air quality impacts are minimized compared to burning for all the non-burn options. Carbon storage in the soil is enhanced by incorporation and rolling as compared to burning or bale/remove. Because winter flooding enhances decomposition of the straw, incorporation costs are lower than when the straw is incorporated without winter flooding. Finally waterfowl on the Pacific Flyway benefit in all cases where winter flooding is practiced. In an interesting twist to the research it was determined that the foraging of the wildfowl enhances straw breakdown. The mechanism for this enhancement in breakdown is not well understood, but it is thought to be related to additional mixing of the rice straw with the soil caused by the foraging activity.

Effects on Yield

One of the major concerns of growers regarding the incorporation of rice straw is the possibility that the straw will tie up available nitrogen and increase the need for chemical fertilizer and/or reduce yields. Surprisingly, the long-term study has shown that incorporation actually increases the fertility of the fields over the long-term. The nitrogen in rice straw ranges between 75 and 90lbs/acre and the amount of potassium is around 100lbs /acre. When rice straw is burned the nitrogen is lost. Most of the nitrogen and potassium are also lost when the straw is baled and removed from the field. Hence only incorporation with or without winter flooding provides benefits in fertility. Figure 1 shows the overall results for rice yield after 7 seasons of management under the eight different methods. This graph represents the yield results with uniform nitrogen input. Overall, yield was not significantly different for all treatments.

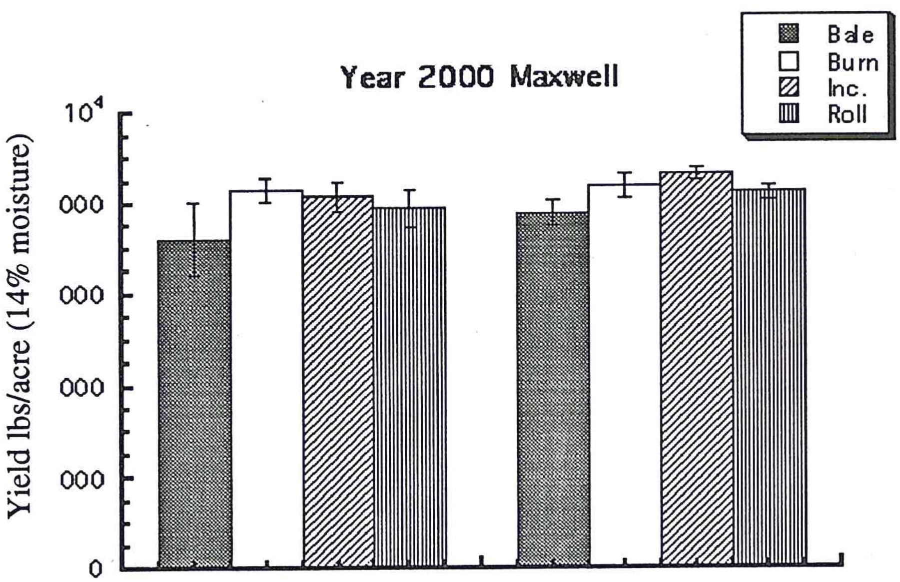

Figure 1. Yield of rice grain Maxwel 2000, after 7 seasons of alternative straw management practices.

Comparing the effects of winter flooding on soil fertility the research shows that the level of nitrogen available to the rice crop in the spring is significantly higher for fields that experience winter flooding. Yet the yield improvement under winter flooding is not statistically significant. This is thought to be due to the fact that the amount of nitrogen being applied is already reaching the maximum amount needed by the crop. To determine if this was the case, studies were conducted using progressively increasing levels of nitrogen on fields where the rice straw was either burned or incorporated.

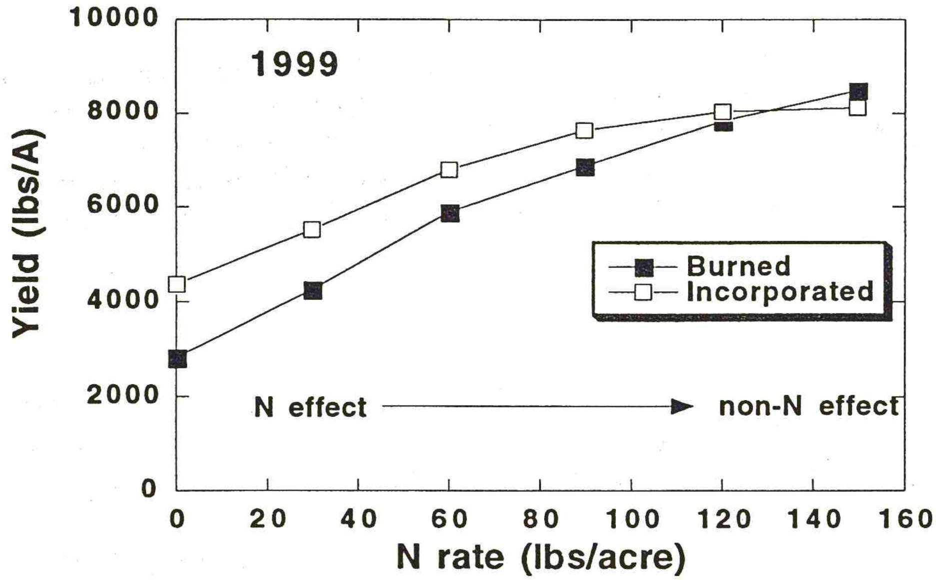

Figure 2. Impact of burning and straw incorporation on grain yield as affected by rate of nitrogen fertilizer application.

To realize the benefit from winter flooding the producer needs to actually reduce the amount of fertilizer applied. After five years of incorporating rice straw, nitrogen application rates can be decreased by about 25 lbs per acre as compared to fields where the straw is not incorporated. The data in Figure 2 seem to indicate that something other than nitrogen availability may affect the yield potential of the rice crop when straw is incorporated. The most likely cause is additional competition from weeds or losses due to pests and diseases.

Weeds: Mixed Findings

Examining the effects of the various practices on weeds showed that incorporation tended to increase the prevalence of grassy weeds, particularly water grass. However, this effect is significantly decreased when the fields are flooded during the winter (Figure 3).

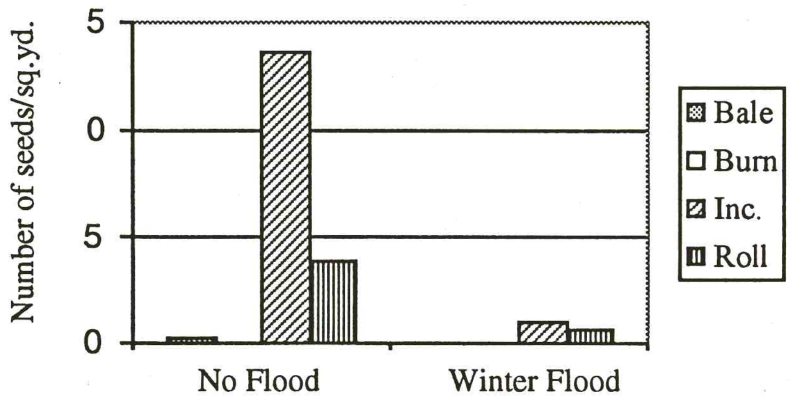

Figure 3. Incidence of water grass at Maxwell after 6 years of alternate straw management practices.

Once again winter flooding demonstrates significant benefits whether the field is burned or not. In this case burning followed by winter flooding produces the least water grass, as does straw baling and removal. Incorporation without flooding leaves the most water grass seeds, followed by rolling without flooding. For both the incorporate/winter flood and roll/winter flood the number of water grass seeds per square yard of soil was significantly reduced.

The mechanism for this decrease in water grass has been shown to be in part due to the foraging of the waterfowl in the winter flooded fields. Figure 4 compares the incidence of grassy and broadleaf weeds in flooded fields where birds were allowed to forage compared to plots from which birds were excluded. All fields were treated with herbicides for weed control.

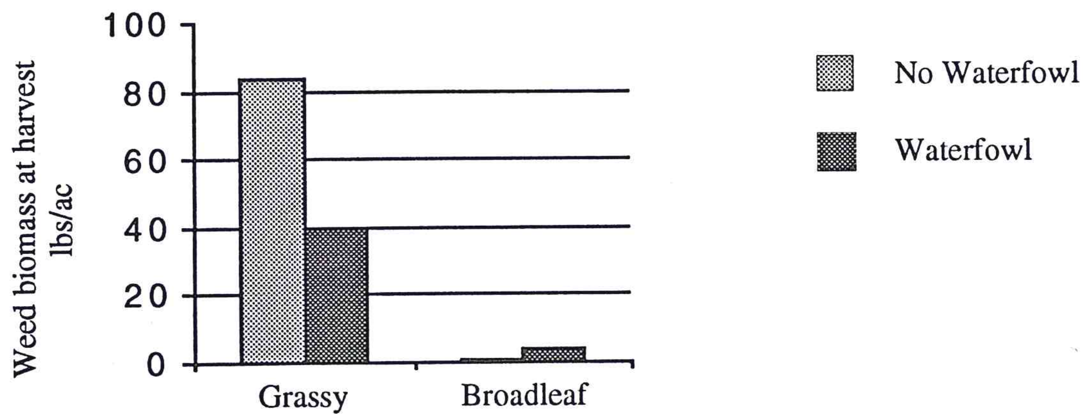

Figure 4. The effect of waterfowl on weed seeds across selected Sacramento Valley rice fields.

If one cannot burn, and decides not to bale due to the cost and negative effects on fertility, then incorporation with winter flooding is the superior remaining method in terms of weed control.

There are also benefits with respect to controlling insect pests and disease. Rice water weevil causes significant damage to rice fields and must be controlled using pesticides. Research has demonstrated rice weevil damage is significantly less of a problem in fields that experience winter flooding. The resultant potential reduction in pesticide use means cost savings for the producer and a benefit to the environment. Stem rot causes significant yield losses in affected rice fields. Recent studies show that winter flooding reduces the occurrence of stem rot.

Methane vs. CO_2 and PM5/10 Production

One question raised by researchers in this long-term study was the possibility that anaerobic decomposition in the winter flooded fields might lead to the formation of methane, an important greenhouse gas. A research project examining methane production showed that methane was produced in all of the winter flooded treatments, with significantly more methane produced when the residue is incorporated or rolled compared to burned or baled. Burning, however, contributes large amounts of CO_2 that is also a greenhouse gas. Burning also produces large quantities of PM5 and PM10 particles that are serious human health hazards.

Incorporation or rolling also provides a benefit through the accumulation of carbon or soil organic matter. To help reduce the amount of greenhouse gasses in the atmosphere it has been suggested that producers be paid for the amount of carbon they return to the soil. Farmers would be compensated for soil carbon storage in the form of carbon credits. This policy, if implemented, could enhance farm income.

Looking at All the Benefits and Costs

When all of the benefits are considered winter flooding appears to be a real win-win practice for the farmer and the environment. Flooded fields experienced enhanced decomposition resulting in lower cost incorporation compared to fields that were not flooded. Less nitrogen can be applied to fields where the straw has been incorporated and the field flooded, resulting in reduced production costs and lessening the potential for water pollution. The impacts of two significant pests, rice water weevil and stem rot are also reduced, possibly reducing the need for pesticides. As compared to burning, winter flooding reduces the production of pollutants known to cause smog. Finally, ducks and geese on the Pacific Flyway benefit significantly from the wetlands created. The major disadvantage to incorporation of rice straw is the increase in weed pressure as compared to burning. This effect is minimized by winter flooding.

Recommended Methods for Winter Flooding

Based on the practical experience of the researchers and producers involved in the study the following method is recommended. After the rice is harvested the stubble should be rolled or disced to increase the contact between the stubble and the soil. Fields harvested with a stripper header must be processed by either chopping or disking as waterfowl avoid fields with tall stubble.

Following rolling or discing, the field is flooded with four to six inches of water through late march. The field is then drained. Tillage and planting follow as normal except that after five years of winter flooding with incorporation fertilizer application can be reduced by about 25 lbs per acre.

Conclusion: Truly a Win-Win Solution

Because the costs of air pollution, nitrate pollution, habitat loss, and water pollution are not paid for by the farmer, there may be significant societal benefits to encouraging producers to use winter flooding. Other policy options which could help producers choose winter flooding would be to subsidize the cost of water used for this purpose, or provide other credits for the use of this procedure.

Winter flooding of rice fields appears to be an example of how long-term research can lead to farming systems which continue to produce at high levels with reduced negative impacts on the environment. Farm advisors and producers involved in the study have found winter flooding to be a viable, cost effective and environmentally beneficial method of solving the rice straw disposal problem.

Effects of various methods of straw management on *Sclerotium oryzae* inoculum, stemrot severity, and yield of rice in California.

R. K. Webster, and N.A Cintas, Department of Plant Pathology, University of California, Davis.

Summary

Under continuous rice cropping, open field burning has been the primary means of rice residue disposal and of minimizing the carry over inoculum of *Sclerotium oryzae*, the cause of stem rot of rice. The phase down of open field burning in California has necessitated the need to develope alternatives to burning. In 1993 a continuous year experiment was initiated in Colusa County to evaluate the effects of alternative residue management strategies on overwintering sclerotia of *S. oryzae*, stem rot incidence and severity, and yield. Treatments were arranged in a split plot design with winter flooding and winter non-flooding as the main plots, and fall incorporation of the straw residue, rolling of the straw to enhance soil contact, baling and removal of residue, and fall burning as the sub-plots. *S. oryzae* inoculum and disease severity were significantly lower and yield was significantly higher in five out of six years in the winter-flooded main plots compared to the winter non flooded main plots. Over the duration of the trial, *S. oryzae* inoculum was consistently lower in burn sub-plots when compared to all other sub-plots. No consistent differences in disease incidence and severity or yield occurred in the sub-plots, although average yield over the six years was highest in burn sub-plots when compared to all other sub-plots. Average yield in the flooded main plots was 9006 pounds per acre compared to 8548 in the non-flooded mainplots. The results suggest that fall incorporation of straw and residue followed by winter flooding is the best alternative to burning for stem rot management.

Introduction

Stem rot, caused by the fungus *Sclerotium oryzae* Catt., is a serious disease of rice world-wide (17,23) including California (12,14,30,31). The sclerotia produced by the fungus serve as primary inoculum by floating on the water and infecting rice stems at the waterline (2,9,23,31). Sclerotia form abundantly in infected tissues as the rice plant nears maturity and continue to form in crop debris (31).

The most effective means of managing stem rot in California has been by burning infested rice residue left in the field after harvest to minimize overwintering inoculum. Legislation has required a reduction in agricultural burning in the Sacramento Valley Air Basin (3), so that by the year 2000 permitted burns will be allowed if justified on only 25 % of rice acreage planted. A recent stay on the mandated phase down was passed by the state legislature to allow more time to find alternatives to burning rice straw for disease and residue management (4). As burning becomes more and more limited, alternative residue and disease management strategies are needed.

Likely alternatives to burning include: rolling to increase soil contact of residue, incorporation, and baling/removing of residue. Winter flooding combined with these alternatives has been used with the assumption that it helps increase the decomposition of the residue. Rolling the residue increases its contact with the soil, which enhances its access to microorganisms for decomposition. Incorporation increases contact between residue and soil even more, which in turn facilitates decomposition (21). Baling and removal of rice straw is intended to remove residue, inoculum, and substrate for further inoculum production. Winter flooding is attractive as a means of enhancing decomposition and providing habitat for waterfowl in rice paddies during the winter.

Previous studies have shown that maintaining or fluctuating soil moisture results in a reduction of sclerotial viability (11). Straw incorporation by means of moldboard plowing has been shown to reduce the total number of sclerotia by burying them and rendering them unavailable to float to the surface of flooded paddies in the spring and cause infection as the rice emerges from the flood water (9,29). Straw incorporation, when compared to no-tillage, also resulted in fewer viable sclerotia in the seedbed (9) likely due to dislodging sclerotia from the residue, increasing their contact with the soil and enhanced mortality through microbial activity. *S. oryzae* sclerotia which are in contact with soil have a half-life of 1.9 years (1). Baling and removal of rice straw has been reported to be nearly as effective as burning for reducing overwintering inoculum (2,28).

The objective of this study was to determine potential alternatives to open field burning of residue (with or without winter flooding) under continuous rice cropping.

Materials and Methods

Field design. A 74-acre field trial in Colusa County was established in the fall of 1993, followed by the first crop of rice grown in 1994. The trial was arranged in a split plot design. The main plots were winter flooding and winter non-flooding with subplots of fall burning, fall baling and removing, fall incorporation of rice residue or fall rolling to enhance soil contact. Subplots were 1.9 acres. Each subplot practice was completed in the fall as soon as possible after harvest. All straw management treatments were completed prior to winter flooding except for the flood/roll subplot, which was cage rolled with 3-5 inches of standing water. Winter flooded main plots were flooded in late October or early November and drained in late February or early March of each year. Each subplot was established with a separate irrigation system to prevent movement of inoculum between subplots. Treatments were replicated four times and cultivar M-202 was planted each season. All other cultural practices employed at the site were typical of standard rice production systems used in California, including water-seeding (7).

Soil sampling. Soil samples were collected from the prepared seedbeds in the spring just prior to flooding. The soil type at the site is Willows Clay Moderate Alkaline (8). Due to the large size of the subplots, each subplot was split into three sections for sampling. Within each section, a "W" pattern was walked. Along this "W" 10-12 soil samples were taken with a garden trowel from the upper two inches of the seedbed, where the inoculum that causes disease lies (25,26). Soil samples collected along the "W" were combined as a composite sample and, when necessary, air-dried before processing. All soil samples were ground in a soil grinder (Iler Improved, The Fen Machine Co., Cleveland, Ohio) that was adjusted for a minimum clearance of 2 mm. Sclerotia from the soil samples were then retrieved using the procedure developed by Krause and Webster (13) with the following modifications: 1) the filtrate in the Buchner funnel was surface disinfestated with a solution of 8 ml commercial bleach (5.25% sodium hypochlorite) and 92 ml water (followed by three rinses with deionized water), and 2) sclerotia were placed on water agar plates amended with 100 PPM chlorotetracycline.

Plant Sampling. Plant samples were collected annually from 1994-1999. Samples were collected near rice maturity, when the field was being drained for harvest. Tillers were cut below the water line (and above the roots) from approximately the same areas where the soil samples were collected. Ten to twelve samples of at least 10 tillers were collected along a "W" path within each subplot section. For each section of the subplot, over 100 tillers were collected for disease evaluation. Plant samples were rated for disease by the method developed by Krause and Webster (14), i.e. healthy and infected tillers were divided into five categories based on the amount of disease: (i) = healthy, no symptoms; (ii) = slightly infected with symptoms and sclerotia on the outer leaf sheaths only; (iii) = mildly infected with discoloration of the inner leaf sheaths, 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. The disease index is then calculated:

$$\text{Disease Severity} = \frac{1(H^n)+2(L^n)+3(M^n)+4(M^{*n})+5(S^n)}{\text{Total number of tillers examined}}$$

Where H^n = number of healthy tillers, L^n = number of lightly infected tillers, M^n = number of mildly infected tillers, M^{*n} = number of moderately infected tillers, and S^n = number of severely infected tillers. A rating of 1 indicates a sample of all healthy tillers, and a rating of 5 indicates a sample with all severely infected tillers. Data for each subplot was averaged before proceeding with analyses.

Panicle weights. To determine the relationship between the disease severity rating and yield, over 10,000 panicles were collected in both 1996 and 1997. Individual tillers were rated for disease severity and weight of the panicle from each tiller was determined. After tillers were rated for disease severity, all panicles within each severity class were clipped from the stems and dried individually in a drying oven at 65°C until no weight loss from day to day was measurable. Panicles were then weighed to determine their dry weight.

Yield determination. Yields of paddy rice, at 14% moisture, were determined for each plot each year. Each season the majority of each subplot was harvested (minus microplots within). In 1997, however, the yield was determined from a 570 foot long by 32 foot wide (twice the width of the harvester header) section harvested in two strips through the center of each subplot.

Statistical analysis. Split plot analysis of variance was performed using SAS (SAS Institute Inc., Cary, NC) to determine differences in sclerotial levels, disease levels, and yield between main plots and subplots and the interactions between main and subplot treatments. Least significant difference analysis was used for mean separation.

For the panicle weight per tiller data sets, correlation and regression analyses were performed using SAS REG and CORR procedures to determine the relationship between yield and disease severity.

Results

Inoculum levels. After the initial year of the trial, there were significantly fewer viable sclerotia recovered per gram of soil each year in the winter flooded plots compared to the winter non-flooded plots (Table. 1). Significantly fewer viable sclerotia were recovered from the burned subplots each year of the trial compared to all other subplots (Table 1). Significantly greater viable sclerotia were recovered from the rolled subplots each year compared to all other subplots (Table 1).

After the initial year of the trial, interactions between residue management and winter flooding management were significant in regards to the number of viable sclerotia per gram of soil ($P \leq 0.05$) (Table 1).

Disease incidence and severity. In 5 out of 6 years there was a significant reduction in disease severity in the winter flooded plots compared to the winter non-flooded plots (Table 2).

However, there were no consistent differences in stem rot severity between straw management subplots over the six years of the trial (Table 2). Interactions between residue management and winter flooding management and their effect on disease incidence and severity were significant only in 1996 with a Pr>F value of 0.0372 ($P \leq 0.05$)

Yield. In every year except 1997, yield was significantly higher in the winter flooded plots compared to the winter non-flooded plots (Table 2). There were no consistent differences in yield between straw management subplots over the six years of the trial (Table 2). Burn subplot yields were highest in 3 of the six years and averaged highest overall for the duration of the trial. Interactions between residue management and winter flooding management and their effect on yield were not significant.

Individual panicle weight versus disease severity. The Pearson correlation coefficient between stem rot severity and panicle weight in 1997 was determined to be -0.60 (P=0.0001, n=135). As stem rot severity increased from healthy through various ratings to severe, there was a significant reduction in total weight of the panicles with a significant negative correlation. The relationship between disease severity levels measured and reduction in yield in 1997 is shown in Fig. 1. The severity-yeild relationship was well described by a linear regression model as indicated by a highly significant coefficient of determination (r^2) of 0.36 (P=0.0001, n=135).

Discussion

Fall incorporation of residue followed by winter flooding resulted in a decrease in stem rot severity as well as an increase in yield, suggesting that winter flooding is a viable management strategy for stem rot of rice.

The average number of viable sclerotia per gram of soil in the first year of the trial was 1.43. Burning reduced the number of viable sclerotia per gram of soil to 0.33 by 1999. Past reports have shown burning maintains or decreases levels of viable sclerotia per gram soil, while unburned plots resulted in increasing numbers of viable sclerotia (29,31). Significant interactions between main plot and subplot treatments for the number of viable sclerotia suggest that winter flooding of plots may have influenced inoculum levels differently depending on the straw management treatment. Specifically, burning rice residue effectively reduced inoculum whether the plots were flooded in the winter or not, but all other straw management treatments resulted in significantly lower inoculum levels in plots that had also been flooded in the winter.

In past studies on stem rot in California, inoculum levels and disease severities varied. At a Butte County rice field studied in the late 1970s, inoculum levels ranging from 0.24 to 1.15 viable sclerotia per gram of soil resulted in stem rot severities of 1.59 to 2.45 (30). At a Sutter County site sampled in the early 1990s, similar levels of 0.26 viable sclerotia per gram of soil resulted in stem rot severities averaging about 2.7 (25). The cultivar grown in this study, M-202, has greater tolerance to stem rot than the cultivars grown in the earlier studies. The mean sclerotial density at the Colusa site exceeded 0.6 viable sclerotia per gram. The resulting severities were on average closer to a rating of 3. When looking for rice lines resistant to stem rot, the more resistant cultivars not only showed a reduction in stem rot severity, but also in sclerotial production (18). Sites with different sclerotial densities may have similar levels of stem rot severities due to the tolerance of the cultivar grown.

According to Kiem and Webster, alternate wetting and drying of *S. oryzae* sclerotia in rice soils reduced sclerotial viability (11), which supports the results of our study where winter flooding resulted in a reduced number of viable sclerotia per gram of soil from 1.35, in the initial year of the trial, to 0.51 by 1999. It is possible that the total number of sclerotia recovered was lower in the winter-flooded treatments because the flood water enhanced the rate of decomposition of the sclerotia. The rate of rice straw decomposition increased when the soil was moderately moist (60% moisture) compared to soils with low or high moisture, 30 or 150%, respectively (15,18). As temperature increased, the rate of rice straw decomposition also increased (15,18). Thus, it is not surprising that as temperature and moisture increased, rice straw decomposition also increased (15,20). Winter flooding may aid in the decomposition of sclerotia because the winter flooded paddies are usually wet longer after draining in the spring as the temperature increases. It is also possible that sclerotial decomposition was encouraged by the microflora populations in the winter flooded treatments. Cartwright found differences in fungal microflora on stem rot sclerotia between different rice residue management systems (5). Such microflora differences, which were both fungal and bacterial, may explain some of the differences in sclerotial viability observed. Also, the flooding of stubble in November may have diminished the carbon availability in the residue for further sclerotial production.

Shahajahan found significant positive correlation between *S. oryzae* inoculum and stem rot severity (22). Webster et al reported that when inoculum levels exceeded 0.6 viable sclerotia per gram of soil the linear correlation between inoculum and disease severity was lost (27). This conclusion is consistent with our results in this study where straw management subplots most often showed no significant differences in disease incidence and severity despite significant differences in inoculum levels. In almost all soil samples from the trial, levels of viable sclerotia per gram of soil recovered exceeded 0.6 with the exception of the burned subplots, (Table 1).

The lack of significant difference in yield as a result of disease occurring from high inoculum levels (above 0.6 sclerotia per gram soil) in some of the straw management treatments, may be explained by the relationship observed between disease severity and panicle weight (6). Panicle weight was known to decrease with increased stem rot severity (6,27) and this was verified in the present study. If particular plots showed final disease severities of 2 and 4, we would expect yield differences between these plots. Most of the disease severity ratings averaged about 3, without much variability. Since inoculum in some treatments was almost always above 0.6, the disease severity ratings and yield reductions due to disease may not be expected to vary significantly between all treatments. However, each year there was a significant difference in disease severity between the flooded and non-flooded mainplots and a significant difference in yield between the flooded and non-flooded mainplots with the exception of 1997. In that year the harvest method differed and the entire study received two applications of Quadris to minimize the threat of Blast disease.

Past reports show that as nitrogen fertilization is increased, stem rot severity also increases (10). Past reports also show that once the amount of nitrogen fertilizer applied provides for maximum yield response, no further increase in yield are obtained with further increases in nitrogen (24). On the other hand, it has been generally observed that stem rot severity is favored by nitrogen fertilization above that required for maximum yield response (10,17,22). Preliminary results of other studies at the experimental site have shown that native nitrogen levels have increased in the subplots where residue has been incorporated. Since all plots received the same fertilization rate throughout the study the incorporated plots contain higher nitrogen levels available to the plants than those where straw and stubble are burned or removed. Thus disease severity could be higher in these plots due to nitrogen effects and an abundance of inoculum. (Table 2) In either event, it appears that disease severity in most of the plots is occurring at a level typical for this disease under inoculum levels and cultural factors that are occurring in the different treatments.

Each year the entire 1.9-acre subplots were harvested to obtain the yield data presented, except in 1997 when only a section through the center of each plot was harvested. A probable explanation for the higher and more uniform yields in all treatments in 1997 is that harvested strips through the center of the subplots eliminated effects of levees separating the subplots. Other exceptions likely contributing to the higher and more uniform yields in 1997 were a more aggressive use of herbicides due to the buildup of weeds in incorporated and rolled subplots. Also, rice blast disease was found for the first time in California in 1996. Because of the large investment in time and expense in the continuous year trial, two applications of Quadris fungicide were applied during the 1997 season to reduce the potential impact of rice blast on the outcome of the study. The disease severity and yield data (Table 1) for the 1997 season suggest the fungicide applications contributed to lower stem rot severity during the 1997 season. This could have been expected since Quadris is also considered effective in controlling stem rot as well as aggregate sheath spot of rice which occurs at a low level at the experimental site.

In conclusion, if burning is not an option, fall incorporation of residue followed by winter flooding appears to be the best alternative at present to rice straw burning for residue disposal and the management of stem rot of rice. Unfortunately the additional tillage costs of incorporation and the costs of the water are considerably higher than fall burning for disposal of the residue and management of disease. If burning is not an option, fields could be disked and then flooded in the winter for stem rot management. Baling and removal of straw addresses the residue disposal and disease inoculum problem but again the costs are significant, alternate uses for the straw have been slow in development and Potassium deficiency has been observed on some soils after 2 or 3 years of straw removal. In our view, the noted increase in weeds and levels of disease and lower yields in the rolled subplots precludes the rolling option.

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Table 1. Effects of winter flooding and various residue management treatments on *Sclerotium oryzae* inoculum

	Viable sclerotia per gram soil[a]						
	1994	**1995**	**1996**	**1997**	**1998**	**1999**	**Mean**
Main Plots							
Flood	1.35	0.98	0.94	0.78	0.77	0.51	0.88
Non flood	1.52	1.68	1.51	2.05	2.21	1.58	1.76
LSD[b]	NS[c]	0.2999	0.2139	0.4571	0.3052	0.2935	
Sub plots							
Burn	1.03	0.63	0.62	0.52	0.60	0.33	0.62
Incorporate	1.48	1.15	1.33	1.36	1.42	0.93	1.27
Bale	1.30	1.20	1.23	1.35	1.68	0.96	1.12
Roll	1.91	1.86	1.73	2.43	2.26	1.97	2.02
LSD	0.4384	0.4241	0.3024	0.6465	0.4317	0.415	
Main x Sub[d]	0.0761	0.2136	0.0024*	0.0278*	0.0027*	0.0016*	

[a] Soil samples were collected from prepared seedbeds.
[b] LSD = least significant difference at $P \leq 0.05$.
[c] NS = not significant.
[d] Pr>F values for main x sub plot interaction, * = significant at $P \leq 0.05$.

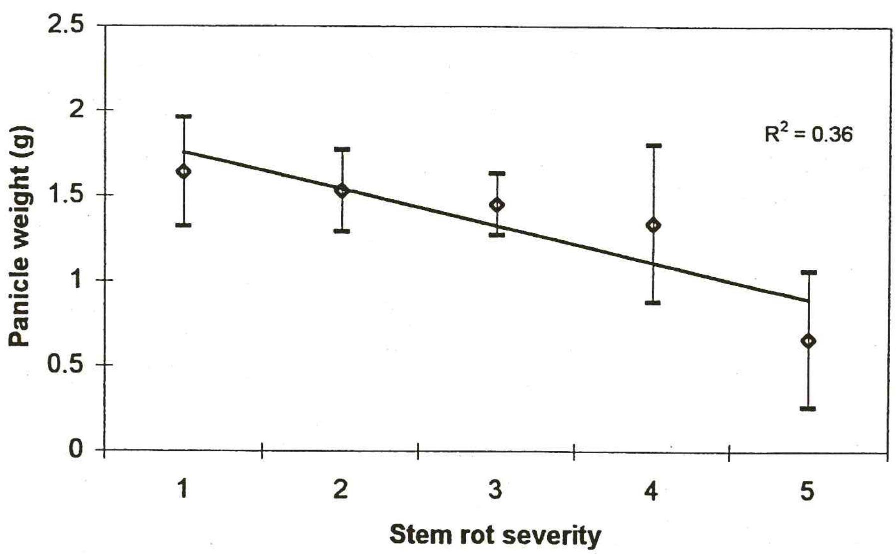

Fig. 1. Increased Stem Rot severity results in decreased panicle weight. Panicles were collected within each stem rot severity class (1=healthy to 5=severe). Over 10,000 panicles were included in this sample from the 1997 season at the Colusa site. Bars at each point represent the standard deviation.

Table 2. Effects of winter flooding and various residue management treatments on stem rot disease severity and yield of rice at the Colusa site

	1994	1995	1996	1997	1998	1999	Mean
			Stem rot severity[z]				
Main Plots							
Flood	2.61	3.18	3.66	2.58	3.06	3.02	3.01
Non flood	3.02	3.72	4.14	2.67	3.31	3.37	3.37
LSD	0.19	0.28	0.17	0.15	0.19	0.21	
Sub plots							
Burn	2.77	3.26	3.77	2.60	2.90	2.87	3.02
Incorporate	2.67	3.39	3.73	2.62	3.06	3.21	3.11
Bale	3.04	3.65	4.08	2.69	3.39	3.38	3.37
Roll	2.79	3.49	4.00	2.60	3.37	3.21	3.24
LSD	0.27	0.39	0.25	0.21	0.17	na	
			Yield pounds\acre @14%				
Main Plots							
Flood	8300	9084	9250	10366	7825	9214	9006
Non flood	7846	8076	8927	10331	7287	8823	8548
LSD	421	413	236	272	243	283	
Sub plots							
Burn	8882	8561	9240	10496	7665	9285	9021
Incorporate	7820	8774	8766	10072	7721	8512	8610
Bale	8167	8255	9137	10365	7365	9149	8739
Roll	7424	8730	9192	10462	7472	9114	8732
LSD	596	584	334	385	224	429	

[z] Stem rot severity is based on a scale of 1-5, 1=healthy and 5=severely infected.

Impact of Straw Management Practices on Rice Weeds

Rice Straw Management Update, Yuba City, March 6, 2001
Michael Hair, UC Davis, UC Cooperative Extension

1. Watergrass control, herbicide program, costs, and rice yields.

History of watergrass control at the Maxwell site. Most of what is known about how straw management affects rice weeds is based upon observations during the past seven years at the straw management project in Colusa County near Maxwell. A similar 5 year study of straw management practices was conducted in Butte County. This second site, however, was relatively clean to begin with and remained free of all rice weeds by an effective herbicide program of Ordram and Londax combined with rather deep water management.

At the Maxwell site, where straw was left in the field, whether incorporated or rolled, a conventional herbicide program of Ordram and/or Bolero into a continuous flood, has failed to control watergrass. Where straw has been burned or baled and removed, excellent watergrass control has been obtained with the same herbicide program.

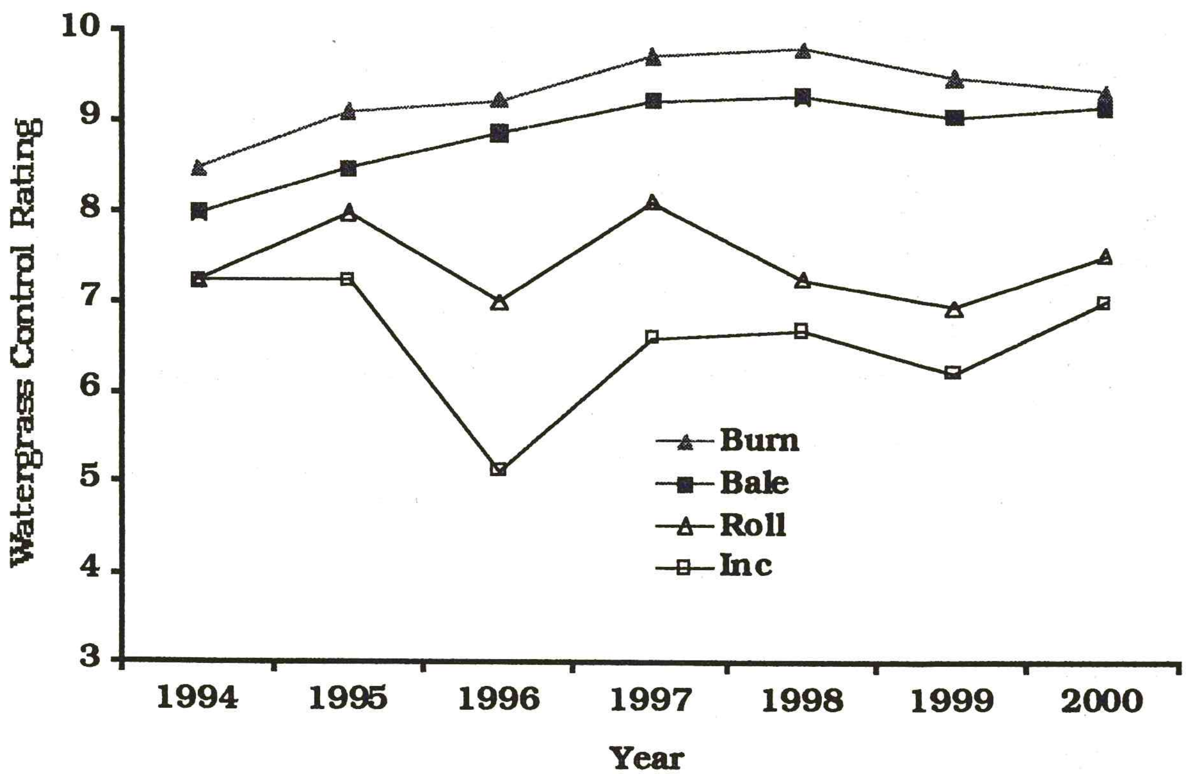

Figure 1. Watergrass control ratings during the seven years of the Maxwell project (1= 100% weed cover; 10= no weeds). Regression analyses on years indicate a statistically significant positive slope for burn and bale lines.

Watergrass control ratings over the years indicate steadily improving control in burned and baled plots, and constant lack of control in rolled and incorporated plots (Figure 1). This field had a significant watergrass infestation at the beginning of the study. Differences in control by straw treatment developed rapidly; they were already significant after the first year and increased in subsequent years. The failure of the conventional granular thiocarbamate herbicides despite increased rates, necessitated the application of a rescue application of Whip in 1994 and propanil in other years except in 1999 when only Ordram and Londax were used.

Watergrass densities recorded in the straw incorporated plots were, on average, about 1,000 times the density of watergrass in the burned plots (Table 1). Baled plots were almost as clean as burned, and rolled plots were slightly cleaner than incorporated. Overall, there was a highly significant difference between the straw removal treatments (burn and bale), which were very clean, and the straw incorporated and rolled treatments which were very weedy. Winter flooded plots were somewhat cleaner than drained for the same straw treatment, although this was not a statistically significant difference.

Table 1. Rice grain yield and watergrass densities from the large plots at the Maxwell site. Means over 7 years and 4 replications.

Management Practice		Rice Yield	Watergrass Density
Winter	Fall	(lb/ac)	(#/m^2)
Drain	Burn	8868	0.012
Drain	Bale	8260	0.20
Drain	Roll	8431	1.63
Drain	Inc	8116	5.19
Flood	Burn	9031	0.008
Flood	Bale	8825	0.009
Flood	Roll	8783	0.94
Flood	Inc	9102	2.07

Watergrass impact on rice yield. Measurable reductions in rice yield are usually observed at watergrass densities in the range of about 1 to 5 plants/m^2 or more. In Figure 1, a weed control rating of 7 is equivalent to a density of about 1 watergrass plant/m^2; and 6 is equivalent to about 5 plants/m^2. These data therefore suggest that in some years and in some plots watergrass has limited yields at the Maxwell site, especially where straw was incorporated. This was confirmed by more statistically rigorous analyses.

An examination of the seven year mean yields recorded from the large plots appear to indicate a general yield benefit to winter flooding, and, if not winter flooded, to burning (Table 1). Rice grain yield is the final result of the whole production system composed of many factors. The factors of watergrass competition, soil electrical conductivity (EC), and Ph for example, all had some effect upon yield. Significant effects of straw and water management practices remain, however, even with these factors taken into account. Perhaps other factors such as disease severity, nitrogen availability, and incidence of insect pests may explain the remaining differences.

Increased herbicide costs. The effect of weeds on yield was minimized by using higher rates of the "standard" granular herbicides, Ordram and Bolero, and by the addition of the rescue treatment of propanil. The total cost of this aggressive herbicide program is in the range of $150 to $200 per acre – roughly double the average cost estimated by a UCCE study in 1998. Especially in a time of depressed prices, herbicide costs in this range are probably not economically sustainable. It is clear that this extra cost of 80 to 100 $/ac was incurred because of poor watergrass control associated with the straw incorporated and rolled treatments only. If the extra herbicide had not been used it is likely that a significant yield reduction of even greater cost would have occurred. If this cost is added to the cost of the field operations, the straw treatments of incorporation and rolling would become prohibitively expensive. Another concern is that increased use of granular thiocarbamate herbicides may compromise water quality.

2. Possible explanations; resistance and seed survival.

Herbicide resistance. In recent years a screening program began to detect watergrass populations throughout the valley that are resistant to thiocarbamate herbicides. Greenhouse tests in 1998 on seed from the straw incorporated plots at the Maxwell site indicated resistance to Bolero. Ordram resistance was confirmed in 2000. Herbicide resistance thus explains the failure of the herbicide program to control watergrass but it cannot explain why this failure occurred only where straw was not burned or removed. Also unexplained is the observation that Gregg's arrowhead was significantly more prevalent in plots where straw was incorporated or rolled.

Watergrass population dynamics. An average density of one watergrass plant/m^2 present in the rice crop in August represents a level of infestation above which rice yield may be affected. This density will typically produce about 1000 new seed/m^2 on the soil surface under the rice straw after harvest (see Figure 2 below). If all of these seed survive the winter and early spring period, preplant seed density in the following year will also be 1000 seed/m^2. About 10% of the viable seed present before planting will emerge to produce a density of about 100 watergrass weed seedlings/m^2 along with the rice seedlings. If herbicidal control is 99% effective, then a density of 1 plant/m^2 will again be present in August. This population remains constant.

For populations just beginning to develop herbicide resistance, control may begin to slip to about 90% for example (As measured in greenhouse tests and confirmed in the field, 90% control is a typical value for a population with some resistance to Ordram.) In this case the density of escapes present in August would be 10 instead of $1/m^2$ – a rapid increase in population in just one year.

Suppose, however, that winter seed survival could be reduced to only 5% of the new seed. This would leave 50 $seed/m^2$ preplant, 5 $seedlings/m^2$, and with only 90% control, 0.5 $plants/m^2$ in August. This population is halved in density each year and decreases steadily even though resistance to the herbicide may enable 10 times the number of escapes as a susceptible population would. This is roughly the same rate of decrease in population that was observed from 1994 to 1997 at the Maxwell site (Figure 1. Watergrass control values of 7, 8, and 9 are equivalent to 1, 0.1, and 0.01 $plants/m^2$ respectively).

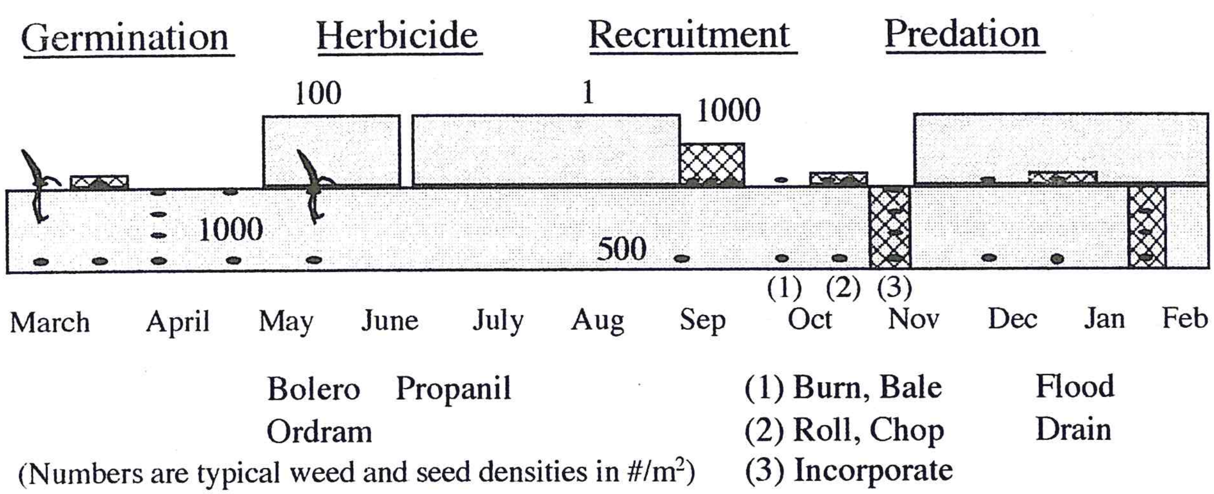

Figure 2. Straw management practices affect winter survival of watergrass seed mainly by the mechanisms of seed predation and spring germination.

Winter seed survival. Figure 2 illustrates the position of seeds and straw for various straw treatments. If straw is not incorporated after harvest, seeds remain on the soil surface. If straw is burned or removed then seeds are exposed to bird predators; savannah sparrows in the winter drained case and ducks if winter flooded. If seed are buried by fall tillage, mashed into the mud by wet rolling, or hidden under a layer of straw, then predation losses are minimized or prevented.

Germination in early spring is another important mechanism for reducing winter seed survival. Exposed seed on the soil surface in early spring are subject to fluctuating day/night temperatures that trigger germination. Buried seed or seed beneath a straw layer do not germinate. Rain before planting can enhance seed loss by germination, especially in the upper soil layers. Flushing the field prior to planting is a technique being tested by organic farmers. (Caution! It is important that any germinated seed be killed by thorough tillage of a dry seedbed before flooding for planting.)

Winter seed survival of watergrass in small plots of a rice field have been measured at 6% when straw was burned compared to 100% when incorporated. Comparison of seed densities measured October 1998 and May 1999 at the Maxwell site resulted in winter seed survival values by straw treatment as follows:

Roll/Flood 29%, Roll/Drain 37%, Inc/Flood 43%, Inc/Drain 45%.

These data suggest that winter seed survival may explain the differences in weed densities among these treatments discussed above. Seed density in the baled and burned plots, however, was too low to measure and so we could not obtain seed survival data for these treatments. At the watergrass resistance management site at Maben Farms, however, 6% winter survival was measured under a burn and flood treatment applied to the whole site. Replicated straw management studies were initiated at that site in the fall of 2000.

Is herbicide efficacy reduced in straw amended soil? There is some evidence from a greenhouse experiment in 2000 that Bolero efficacy on both resistant and susceptible seed was reduced by the addition of straw. It appeared that perhaps a nitrogen benefit from the straw may have increased early growth of the watergrass seedling allowing it to better tolerate the herbicide. If this effect were confirmed it could provide an alternative explanation for the Maxwell results, independent of the resistance and seed survival factors. Even if it proves not to be a dominant factor here, the implications for interactions of straw amendments, nitrogen fertilization and weed control warrant further study which is continuing.

3. Modified straw treatments.

Chop and flood. Some growers have developed a method of chopping straw with a flail mower and flooding for decomposition. At the Maxwell site chopping replaced the roll/flood treatment in the fall of 2000. This operation could possibly enhance winter seed loss relative to the roll. It was compared with incorporation in the fall of 1999 by leaving 20 ft x 50 ft subplots within the large incorporated plots untilled. Soil sampling for seed densities provided a means of evaluation and indicated that seed survival is about half that when seed was incorporated (Table 2). This chop and flood treatment is being compared to burn and incorporate treatments at the Maben resistance management site.

Table 2. Seed density and survival under straw chopped and incorporated treatments at the Maxwell site.

Management	Practice	Seed Density (#/m2)			Survival
Winter	Fall	5/99	11/99	5/00	(%)
Flood	Inc	300	6,400	2,100	33
Flood	Chop		1,200		19
Drain	Inc	2,200	11,900	9,000	76
Drain	Chop		3,700		31

Spring bale and spring burn. Rainy weather prevented the baling and removal operation in the fall of 2000; these plots will be raked and baled in the spring of 2001. This may possibly enhance watergrass seed survival relative to the very clean fall baled treatment. Spring burn replaces the dry roll treatment; this may increase spring germination and decrease seed survival.

4. Conclusions

In fields where significant watergrass infestations are present straw incorporation or rolling should be avoided if possible.

The practice of baling and removing straw appears to be an acceptable alternative from a weed control perspective.

Winter flooding may have some benefit independent of straw treatment, but to a lesser degree.

Two factors appeared to contribute to the present situation:

1. Increasing resistance, first to Bolero and now to Ordram, allowed some escapes each year. If thiocarbamate resistance is suspected, propanil should be used as the primary grass herbicide if possible.

2. Winter seed survival was increased by straw incorporation and rolling (into the range of 40 to 100%), and reduced by burning and baling treatments (to about 5%).

Rice Straw Management and Rice Invertebrate Pests

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Introduction

Invertebrate pests potentially inflict serious damage to rice crops in California on an annual basis. These pests include insects such as the rice water weevil, rice seed midge, rice leafminer, and armyworms and crustaceans such as tadpole shrimp and crayfish. Populations of these pests respond to local field conditions and to wide-scale environmental conditions. The two crustaceans and rice seed midge are pests of germinating seeds and emerging seedlings. Rice water weevil adults feed on the leaves of seedlings in the 3-5 leaf stages. This timing generally corresponds with that of the rice leafminer. Rice water weevil larvae damage rice roots in June and July, whereas armyworm infestations can develop in July and August. Of these pests, the rice water weevil generally has the most severe economic consequences; however, the tadpole shrimp, crayfish, and seed midges can be devastating to seedling establishment in some situations. For a more complete description of the biology of these rice pests, see the Univ. of California Integrated Pest Management web site (http://www.ipm.ucdavis.edu/).

The straw management site near Maxwell provided an excellent opportunity to study the effects of straw management techniques on populations of invertebrate pests of rice. As these methods for straw degradation/removal are developed and adopted, the hope is that they will be, at least, neutral in terms of their effects on invertebrate pests. Knowledge of the effects on invertebrate pests will allow sound IPM programs to be put in place. The crustacean pests are relatively immobile, therefore altering the local conditions by removing straw, winter-flooding, etc. may have a noticeable effect on these pests. The first study was designed to investigate the effects of straw management method and winter flooding on arthropod pests of seeding rice. Secondly, given the importance of rice water weevil to rice production, the effects of straw management methods on this pest comprised the second approach (to investigate the effects of straw management method and winter flooding on rice water weevil spring populations).

Materials and Methods

Maxwell Location - Overall Site Design:

At the Maxwell study site, winter-flooded and without a winter flood treatments comprise the main plots and straw removal treatments (burning, baling, rolled, and incorporated) are the subplots within these main plots. There are four replications of each of the eight treatments.

Maxwell Location - Invertebrate Seedling Pests:

Populations of invertebrate pests of seeding rice were monitored in all eight straw management treatments. Seed midges, tadpole and clam shrimp, and crayfish are pests of rice at or near the time of seedling emergence. The shrimp and crayfish biologies are closely aligned with the conditions in the particular fields; seed midges are mobile and can fly in from adjacent fields.

Two sampling methods were used to monitor populations of these pests. Small glass petri dishes (~4 inches diameter) were filled with a thin layer of soil from a rice field and with 12-15 presoaked rice seeds. Dishes were placed in each basin about 1 week after seeding the field. After 7-10 days in the field, the dished were collected and returned to the laboratory. The seeds were separated from the soil and counted. In addition, the seeds were examined and any damage noted. Damage was classified as cracked, tip chewed, hollowed seed, and shoot chewed, and seed midge tubes were counted. This damage is indicative of injury by crayfish, tadpole shrimp and/or seed midge. These samples were collected in 1994 to 1996.

The second sampling method used was a visual search for tadpole shrimp, clam shrimp, and crayfish. The search was made along two 25 foot sections of each basin about 5 feet from the levee. These data were also collected about 1 week after plot seeding in 1994, 1995, and 1996.

Maxwell Location - Rice Water Weevil:

The rice water weevil is the most important (damaging) insect of rice in California. This insect overwinters as an adult in a diapause state in protected areas, i.e., ditchbanks, levees, roadsides, etc. In the spring, the adults break diapause and fly to flooded, newly-emerging rice fields. These adults deposit eggs in the rice leaf sheaths. The resulting larvae can severely damage rice roots, which results in a reduction in yield.

The influence of the treatments on rice water weevil populations was examined in 1994 to 2000. Both damage by the adults (insignificant in terms of yield reduction) and larval populations were measured. For the adults, the percentage of plants with weevil feeding scars on either of the two newest leaves was determined. This was done by carefully examining 100 plants per basin when the plants were in the 4-5 leaf stage. In addition, larval population densities were quantified from 1995 to 2000. Soils samples, ~4 inches diameter, containing at least one plant were collected from each basin. Samples were collected in June and July. Five core samples were taken per basin per date. Samples were processed with a soil washing/flotation technique to recover rice water weevil larvae and pupae.

Grower Field Sites:

During the 1997-98 and 1998-99 winters, and subsequent production season, the effects of winter-flooding on Rice Water Weevil populations were studied in selected grower fields in the Sacramento Valley. The goal was to locate neighboring fields (side-by-side, if possible), one that was flooded during the winter and the other field without a winter flood. Samples for adult feeding and larval populations, as described above, were taken during the production season. Five such comparisons were done the first year and seven the second year.

Results

Maxwell Location - Invertebrate Seedling Pests:

There were no significant differences in damaged seed incidence among the eight treatments or within the main effects of winter condition (winter-flooded vs. non-flooded) or straw technique in 1994 to 1996 (Fig. 1; 1995 data). Seed midge damage ranged from 0 to 52%

in 1994 and from 53 to 69% in 1995. Damage indicative of crayfish feeding ranged from 0 to 33% in 1994 and from 25 to 40% in 1995. There were no trends of damage associated with straw treatments.

In 1994, only clam shrimp were observed in any substantial numbers from the visual observations. Among the 8 treatments, densities ranged from 16.5 to 66.7 per 25-foot observation zone. Clam shrimp are not considered significant pests of seedling rice. Higher densities of clam shrimp, tadpole shrimp, and crayfish were observed in 1995 then in 1994; however, again there were no treatment effects on densities of these arthropods. Data from 1996 were similar to 1995.

Overall, it appears the straw management treatments had little to no effects on populations of tadpole shrimp, crayfish, and seed midge. Given the immobile nature of the shrimp and crayfish and that they are thus very dependent on their immediate environmental conditions, we thought the treatments may have some effects on populations. Crop rotation is one of the recommended management techniques for these pests which again takes advantage of their immobile nature. Although intensive sampling for these pests was discontinued after 1996, visual observations have indicated similar results thereafter.

Maxwell Location - Rice Water Weevil:

Examination of RWW populations in the eight straw management treatments revealed that populations differed significantly between the winter-flooded and nonflooded, but that the straw "tillage" treatment had no effect. The incidence of scarred plants over the 3 years (1994-96) averaged 9.9% in the winter flooded plots compared with 20.1% in the nonflooded plots (Fig. 2). The differences in damaged plants between the winter conditions occurred for each of the 3 years. The straw tillage treatment had no significant effects on the incidence of rice water weevil damaged plants. Rice water weevil larval populations were also reduced in the winter flooded plots in 1995 and 1996 (larval populations were not evaluated in 1994). Larval densities averaged 0.7 and 1.2 in the winter flooded and nonflooded plots, respectively (Fig. 3). As with scar incidence, the straw tillage treatments did not significantly effect larval population density. Populations averaged 1.15, 0.8, 1.05, and 0.73 RWW per sample in the burn, incorporated, rolled, and baled treatments, respectively (Fig. 3).

From 1997 to 2000, RWW populations were monitored only in the winter flood vs. no winter flood main plots. The trends of higher populations in the areas without a winter flood compared with winter-flooded areas continued except for 1998. In 1998, all plots were winter-flooded at some times and to some extent because of unusually high winter precipitation during the 1997-98 winter. Adult damage, indicative of population levels, was about two-fold higher in the non-flooded vs. winter flooded plots (Fig. 4). Similarly, larval populations were 1.7 to 2.6 times higher in the non-flooded compared with winter-flooded plots (Fig. 5).

The significant effects of the straw management treatments on rice water weevil populations were unexpected. The differences could be important because they were of the magnitude such that economically important populations could be reduced to non-economical levels. The reason for these differences is uncertain at this time. Although the plots were relatively large, we thought the mobility of the rice water weevil adults in the spring would mask any possible effects of the treatments. The adults are capable of flying several miles, although the importance of such flight in establishing infestations in the spring is unclear. In addition, the plots intended for non-flooded conditions during the winter were partially flooded (because of winter rains) during some years. This also makes it surprising that this treatment influenced rice water weevil populations. If differences had occurred only in larval density, some effects on the soil properties would have been proposed. However, differences in scar incidence were also seen.

Grower Field Sites:

Research in 1997-98 was hindered by unusually high winter rainfall and all fields were largely flooded during parts of the winter. Therefore, it was impossible to accurately conduct this research. For the seven grower field sites in 1998-99, overall the percentages of scarred plants were reduced by the winter-flooding (Table 1). On average, there were no differences among the sites with regard to rice water weevil per core sample (2.2 vs. 2.8 RWW per core sample). However, in four of seven sites, a significantly lower number of larvae was found in the winter-flooded plots compared with the nonflooded. plots (Table 2). The larval population reduction due to winter-flooding was as high as 80% and was present in two sites that had very high larval populations. In two of the seven locations, there were no differences in rice water weevil levels between winter-flooded and no winter-flooded plots and in one location the inverse trend was seen. The reasons for these differences are unknown. We attempted to have a comparable planting date, rice variety, water depth, proximity to overwintering sites, etc. between the two paired fields at a research site, but this was not always possible. Rice water weevil populations are historically nonuniform across a field and this also makes the research more difficult.

Acknowledgments

The author thanks Terry Cuneo, Rich Lewis, and Drew Palrang (Dept. of Entomology, Univ. of California-Davis) for assisting with the coordination of this project as well as numerous student summer field assistants who assisted with the field duties. We thank the Rice Research Board and the Dept. of Pesticide Regulation for funding this research.

Table 1. Scar incidence and larval density data from winter-flooding study – grower fields, averaged over Sutter, Butte and Colusa counties.

Treatment	% Scarred Plants	Rice Water Weevil per Core Sample
Winter-flooded	29.0	2.2
No winter-flood	48.6	2.8

Table 2. Larval density data from winter-flooding study in grower fields - comparison of sites where winter flooding was effective vs. ineffective.

	Rice Water Weevil per Core Sample	
Treatment	Winter-flooded	No winter-flood
Effective Sites		
Sutter Co. site 1	0.2	1.0
Sutter Co. site 2	0.4	1.8
Colusa Co. site 1	3.3	8.8
Colusa Co. site 2	1.2	5.2
Ineffective Sites		
Sutter Co. site 3	2.2	2.6
Sutter Co. site 4	6.9	5.3
Colusa Co. site 3	4.7	1.9

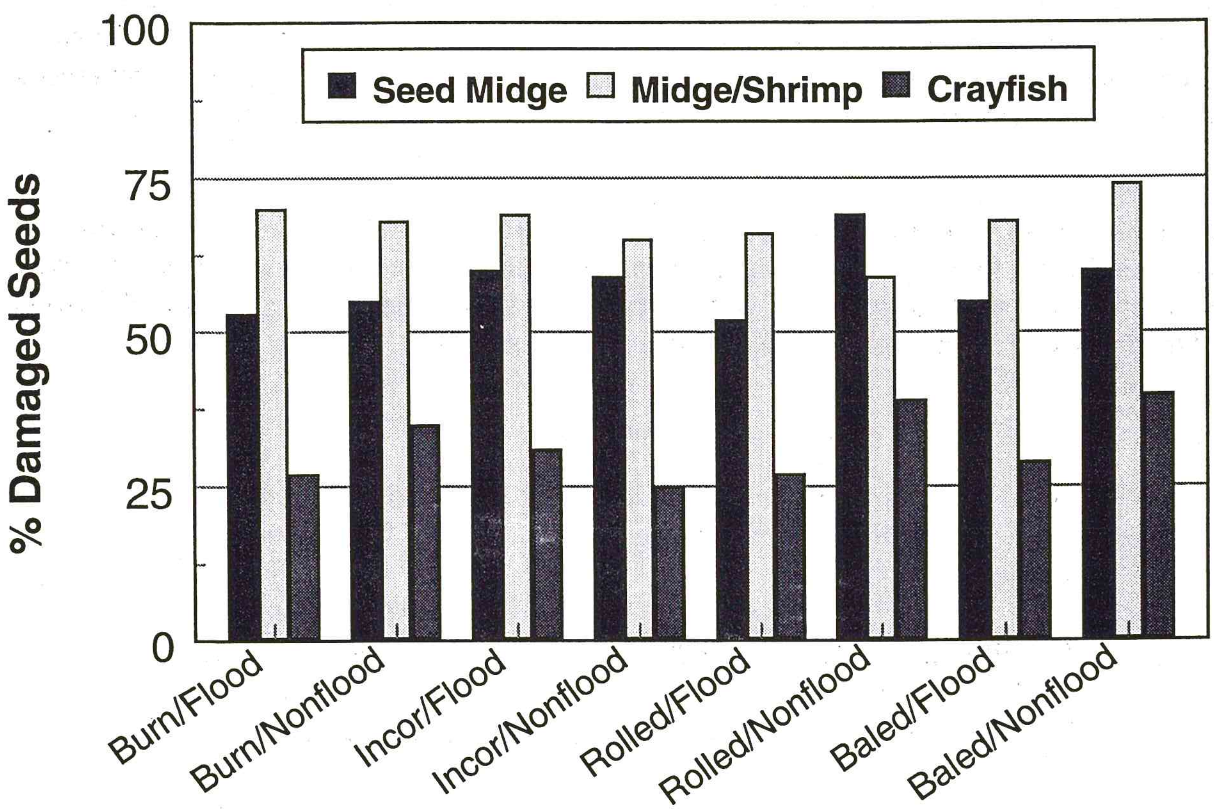

Figure 1. Influence of straw management treatments on rice seed/seedling damage in dish samples from invertebrate pests - 1995, Maxwell location.

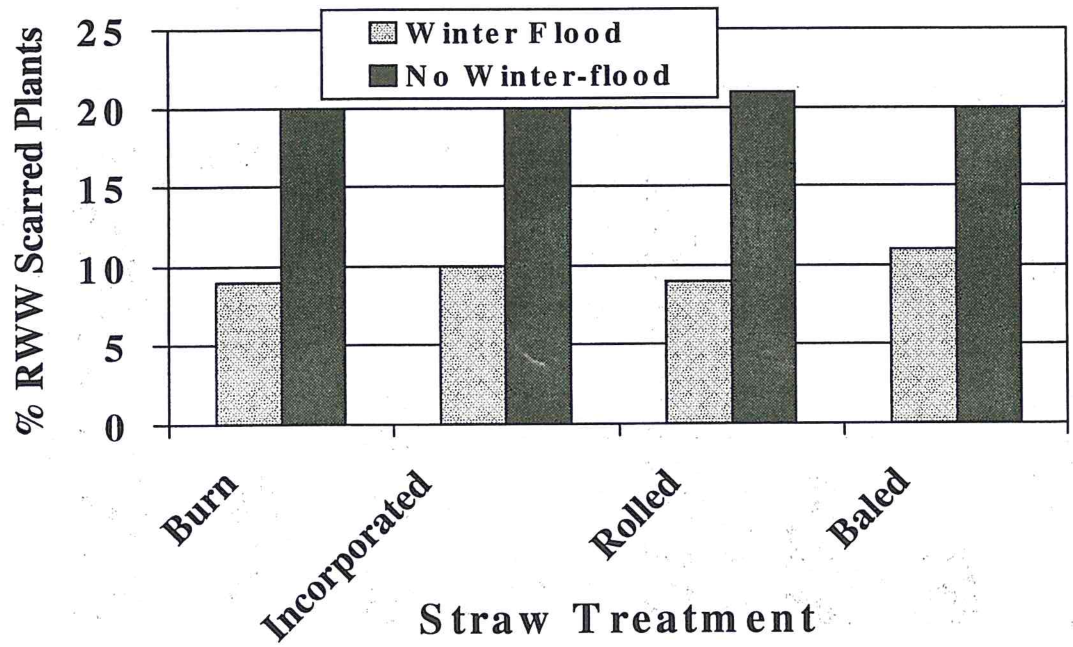

Figure 2. Influence of straw management treatment on rice water weevil adult population, as indicated by rice plant scar incidence - 1994-96, Maxwell location.

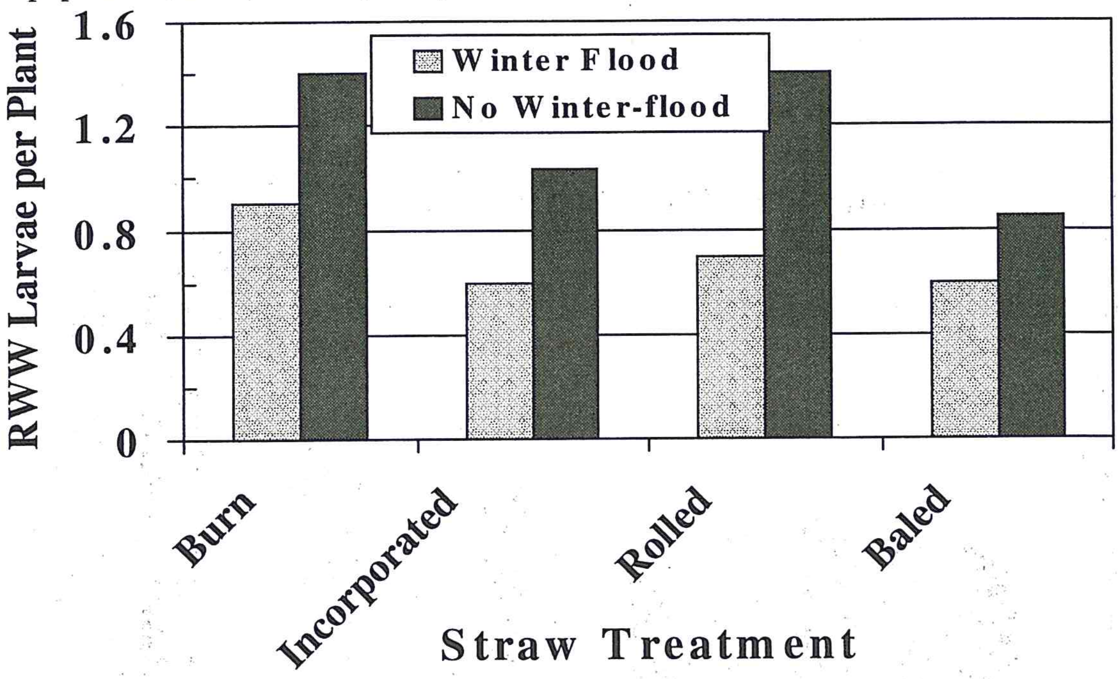

Figure 3. Influence of straw management treatment on rice water weevil larval populations - 1995-96, Maxwell location.

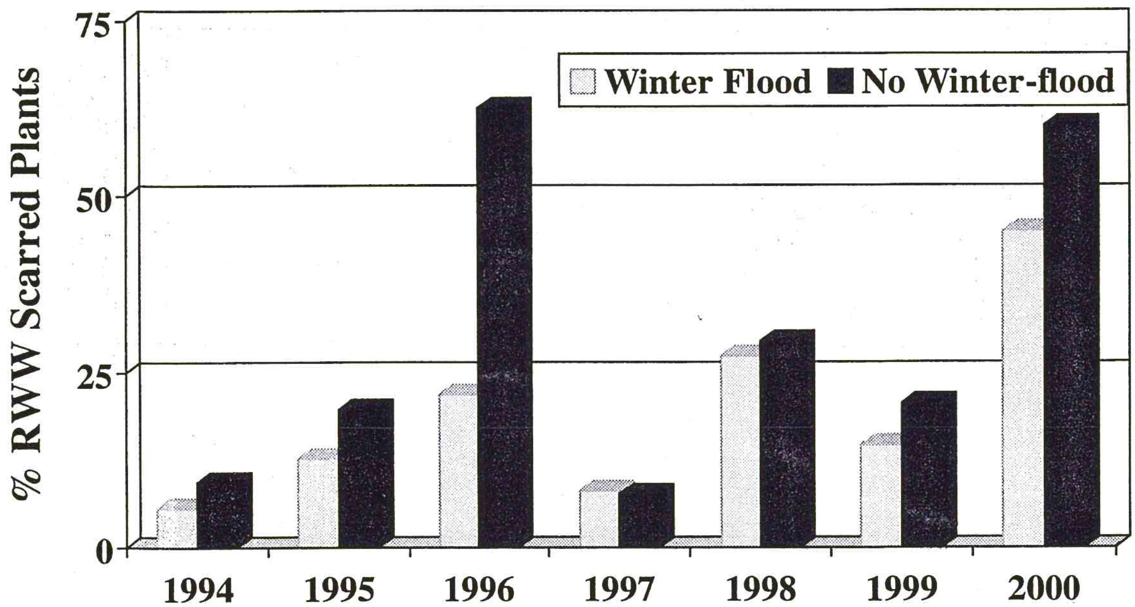

Figure 4. Effect of winter flooding on rice water weevil adult populations, as indicated by adult feeding incidence - 1994-2000, Maxwell location.

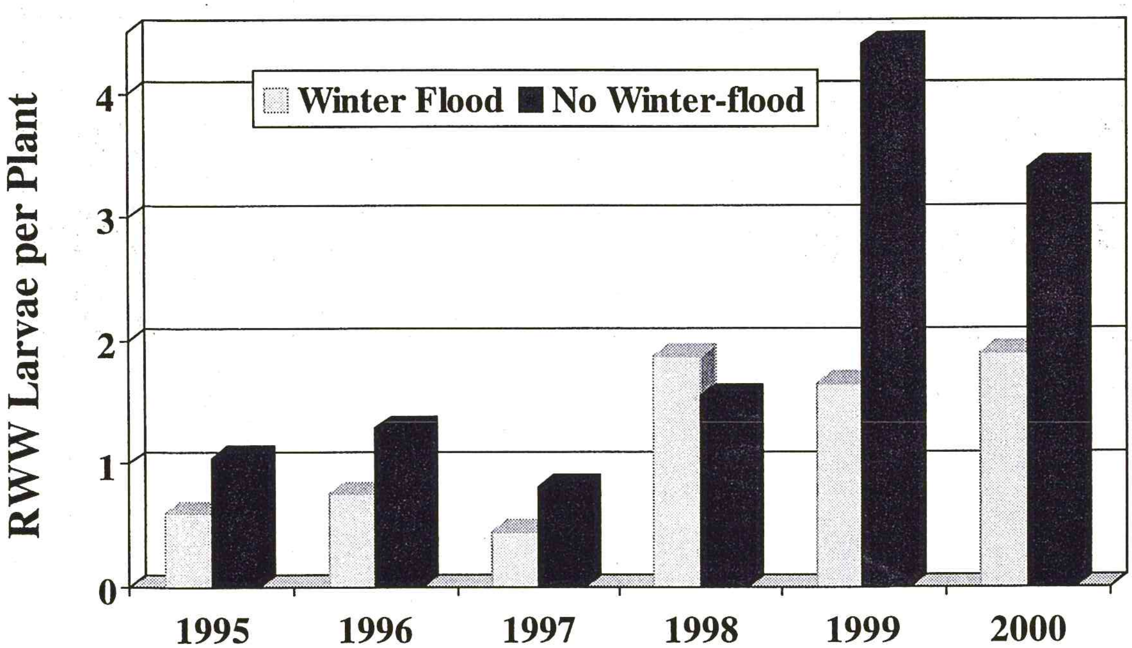

Figure 5. Effect of winter flooding on rice water weevil larval populations - 1995-2000, Maxwell location.

Performance and Economic Issues in the Utilization of Rice Straw

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Rice Straw in California

A number of important attributes of rice production in California influence the feasibility of straw utilization, including:

- Annual area planted to rice varies between about 250,000 to 600,000 acres in rice, more typically between 400,000 and 500,000 acres.
- With straw biomass yields averaging about 3 dry tons per acre, the crop produces 1 – 2 million dry tons of straw each year.
- Of this total straw production, estimates of annual harvestable production range between 0.5 – 1 million tons. Some straw will be field burned for disposal as allowed under current legislation, other straw will be incorporated into the soil.
- The historical practice of open burning for disposal was curtailed by state legislation (AB 1378) in 1991.
- As of fall 2001, 25% of acreage is allowed for burning, up to a maximum of 125,000 acres.
- Soil incorporation is the current principal alternative to field burning, but many fields are showing stress from increasing weed and disease problems.
- Baling of straw for off-field uses has been effective in reducing weed and disease pressures.
- Fall harvesting of straw leads to the removal of important nutrients, including N, P, K, S, and Zn. Nitrogen is also mostly lost by field burning, as is a large fraction of sulfur. Export of potassium from fields in straw can lead to K deficiencies, requiring additional cost in K replacement, a cost not borne by the system when field burning or soil incorporation is practiced.
- Delayed harvesting of straw in the spring results in reduced fertilizer replacement costs. More than 80% of K is leached from the straw by rain and remains in the field. Chloride is also leached from straw, and this improves the value of the straw for some industrial uses, especially power generation. Delayed harvesting suffers from increased risk due to timeliness constraints (prolonged rainy seasons delay drying and access to fields for straw harvesting, thereby delaying spring planting operations), and potentially from reduced quality of straw (e.g. organic matter loss, loss of mechanical strength, increased soil contamination).

Cost Considerations in Utilization

Utilization of straw involves grower-harvester-user interactions with associated costs and benefits for each sector. Some of these include:

- Grower impacts
  - Avoided costs of straw incorporation or disposal
    - Straw harvesting reduces the cost associated with incorporating straw into the soil. Fewer tillage operations are required when straw has been removed from the field.
  - Agronomic impacts including nutrient replacement
    - As indicated previously, straw harvesting removes nutrients that generally require replacement in a sustainable system. Different in-field management techniques, such as delayed (spring) harvesting, can reduce nutrient export by leaching nutrients from the straw prior to harvest.
    - Removal of straw can be effective in reducing the incidence of disease and weeds, reducing the cost and environmental impact of chemicals otherwise used for control.
  - Timeliness of farm operations (e.g., delays in spring planting)
    - Harvesting involves one or more additional operations that can lead to delays in other cultural activities. This is a risk in delayed harvesting when extended rainy seasons delay the drying and harvesting of straw, potentially delaying access to the field for spring planting.
- Straw acquisition and processing
  - Direct costs of harvesting and handling
    - Harvesters (either growers or contractors) incur costs associated with equipment operations to remove, transport, store, and process straw.
  - Grower payments to harvesters/users
    - Harvesters benefit from fees paid by growers for straw removal. Growers may be willing to pay all or a portion of the straw harvesting cost in order to reduce their overall cost of straw management.
- User operations
  - Straw acquisition costs
    - Cost to purchase straw from suppliers.
  - Straw handling and storage
    - Costs are incurred for additional straw handling and storage at the user site.
  - Plant performance/quality effects
    - Some users may realize changes to their plant operation due to quality differences between straw and other materials available to them.
  - Byproduct/waste handling
    - Rice straw utilization may involve byproduct or waste generation with different costs and benefits compared with other available materials.
  - Tax credits/payments/other incentives
    - Various incentives may be available to users. California currently has several incentive programs supporting rice straw utilization.

Straw Harvesting Costs

Straw harvesting, transport, and storage costs depend on the number of equipment operations, the type of packaging used (e.g. small bales vs. large bales), number of times the straw is handled, transportation distance, and duration and quality of storage. Estimates of straw harvesting costs for California using new large bale equipment with 20 mile transport and storage in metal barns are shown in Figure 1 below as a function of straw yield. Three different systems are included. The lowest cost system does not include a swathing operation. The highest cost system includes a raking operation after swathing.

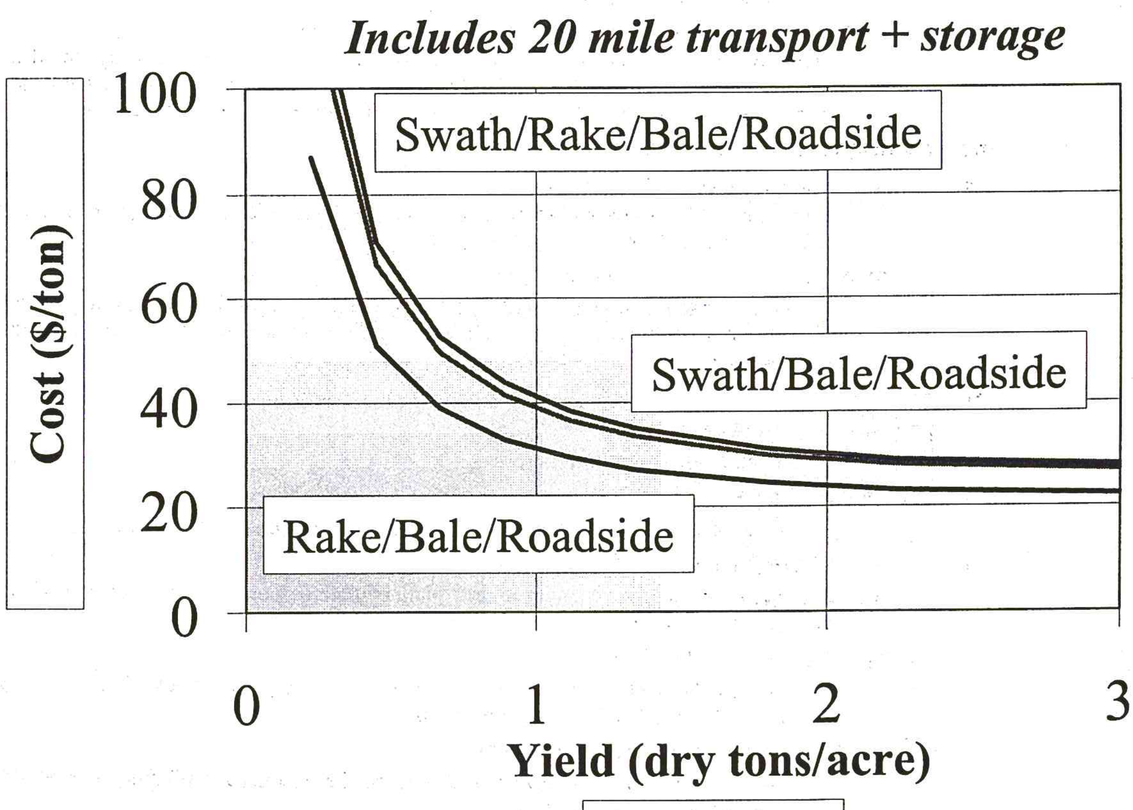
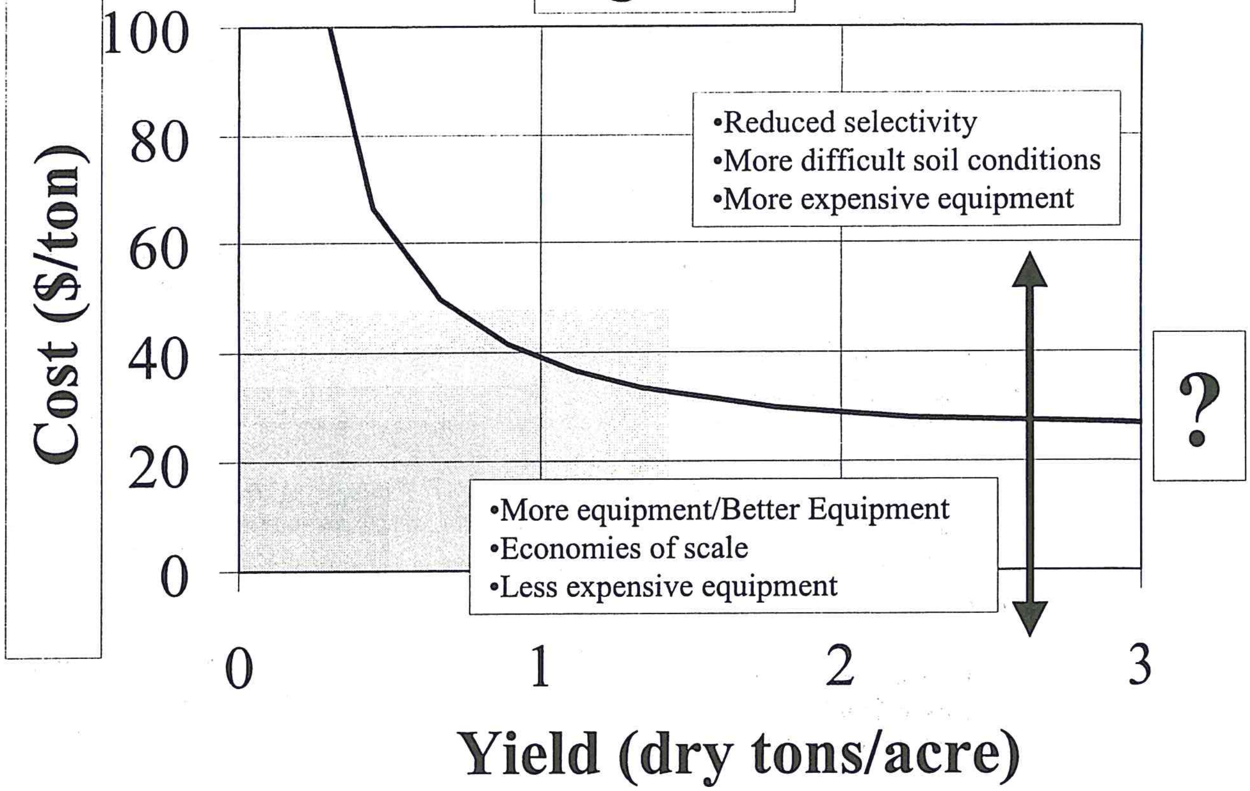


Figure 1

Sensitivity to Increasing Scale of Harvest

The cost of straw harvesting in the future is sensitive to a number of factors. As the amount of straw harvested increases, harvesters will have less flexibility in selecting fields that have good soil conditions, hence higher cost, higher flotation equipment may be needed. Extended harvesting times may also be needed, again involving more expensive equipment or additional operations. Larger scale harvesting of straw can lead to economies of scale in equipment acquisition and deployment, however, potentially reducing harvesting cost. The net effect is not yet known for harvesting large amounts of rice straw.

Figure 2



Incentives

Incentives for straw harvesting include any payments made by growers to harvesters, plus state and other government incentives.

- Grower payments for field sanitation
  - Growers may be willing to offset costs of harvesting to reduce total straw management costs. Current cost of straw incorporation averages $36 per acre. Growers may be willing to pay contract harvesters up to this amount. The grower may be willing to incur a higher cost if a sufficiently high value market for straw can be identified.
  - $0 – $36/acre, $0 – $33/ton
- Tax Credit to purchasers of rice straw
  - California Revenue and Taxation Code/Section 17052.10 provides a tax credit to purchasers of rice straw. To take advantage of the tax credit, the purchaser must, of course, generate taxable income.
  - $15/ton up to a total $400,000/year (through 2008). This credit can support up to 26,667 tons of straw per year.
- Grants to rice straw end-users
  - AB 2514 provides direct grants to end-users of rice straw. Recipients of a grant from this program are not eligible for the tax credit under Section 17052.10 of the Revenue and Taxation Code.
  - Not less than $20/ton, $2 million appropriation, equivalent to 100,000 tons of straw per year.
- Agricultural Biomass to Energy Incentive Grants
  - AB 2872/2825 provides grants to energy facilities using qualified biomass including rice straw. Recipients of grants under this program are not eligible for emission reduction credits, tax credits, grants, or other incentives provided for rice straw. Qualifying facilities must realize net NOx reductions through use of the straw.
  - Grants for qualified biomass are $10/ton, but reduced by the administrative costs of the applying air district (5% or $0.50/ton is allowed).
- Emission offset credits
  - Emission reduction or offset credits may be available in certain circumstances. Although the economic benefits associated with emission offset credits can be quite high (for all emissions, ranging from $0 to 200/ton of straw), in general these are likely to remain low or unavailable for users of rice straw in the Sacramento Valley.

Applications in Power Generation

Power generation is one potential industrial use of rice straw. As way of illustration, the cost of power derived from rice straw is examined for various assumptions regarding the availability of incentives.

- The Sacramento Valley region has a number of existing biomass fueled power plants.
- None of these power plants is currently burning rice straw due to the high fouling, slagging, agglomeration, and corrosion rates associated with the K, SiO_2, and Cl in straw. Rapid buildup of fouling deposits on superheaters and other boiler heat exchangers leads to reduced efficiency, capacity, and availability, and increases operating costs for the plants.
- At current efficiencies, 1 million tons of straw could yield 100 – 150 MWe generating capacity. This capacity could produce 800 – 1200 GWh/year of electrical energy, worth $60 – 100 million/year at $0.08/kWh. The power industry would have no difficulties in absorbing the capacity and energy from straw-fired power generation.
- Although existing California power plants cannot use rice straw as it would typically be available after a fall harvest, there are a number of potential options available for its use:
    - Leached straw, or straw that has been washed with water either by rain or in an industrial facility, has been demonstrated successfully in existing power boilers in California. Leaching removes K and Cl, and radically improves the combustion properties. The primary difficulty in burning straw in existing power boilers stems from the reaction between K_2O and SiO_2 in ash leading to molten glassy formations at elevated temperature. Chlorides contribute to corrosion, and removal of Cl from straw is beneficial in extending the life of the plant and reducing costs
    - Whole-bale and other power generation technologies have been developed in Europe for wheat straw. These technologies do not entirely solve the problem of ash fouling, but the designs are more tolerant than current California facilities.
    - Close-coupled gasification systems, and other thermal gasification systems can operate at lower temperatures, reducing slagging problems. Product gas fired to a companion boiler reduces fouling on heat exchangers, and can be used to reduce NOx emissions. More advanced technologies may operate at higher efficiency.
    - Biochemical conversion methods, such as anaerobic digestion, operating at lower temperatures in aqueous environments avoid high temperature ash fouling.

Leached Rice Straw

Leaching is one method for making rice straw suitable for use in existing power generation units.

- Leaching with water is effective in removing more than 80% of K and 90% of Cl from straw.
- Full scale as well as lab and pilot-scale tests have demonstrated the technical feasibility of burning leached rice straw in existing power boilers when blended up to 20% of heating value with wood or rice hull. Field leached straw has been tested in stoker-fired traveling grates, circulating fluidized beds, and suspension-fired units.
- Leaching can be accomplished naturally by leaving the straw in the field over the winter, or at least through several periods of rain (delayed harvesting with rain washing), or by harvesting in the fall and then washing at the plant site. Rain washing requires 4 to 8 inches of precipitation, and is most effective when the straw is spread rather than windrowed. Standing stripper harvested straw is also effectively leached.
- Leaching at the facility is more expensive than field leaching, generates wet straw that requires dewatering and possibly drying, and produces a leachate stream that may require disposal if not suitable for land application to recover nutrients. Membrane concentration of leachate has been tested for water and materials recovery.
- Field leaching (rain washing) also recycles K and other nutrients directly back to the field, thereby reducing nutrient replacement costs.
- Leaching occurs in both anaerobic digestion systems and in ethanol fermentation system. Residues of these biochemical conversion schemes are of generally lower fouling potential, if care is used in the design and operation of the system to avoid contamination from acid and alkali materials used for pretreatment and other conversion operations.

Cost Considerations in Power Generation

Cost considerations for growers, harvesters, and fuel purchasers are similar to those discussed previously. Additional costs are incurred for existing power plants that would burn leached straw.

- Fuel acquisition costs
  - The delivered cost of straw fuel was shown earlier as a function of yield and harvesting system. Transportation costs increase for some power plants located at greater distances.
- Fuel yard and fuel handling modifications
  - The existing power plants in California are not designed to handle straw fuels. Additional capital cost may be required if the straw is not first densified (e.g. as pellets, cubes, or briquettes). Densified fuel could be handled in the same manner as wood chips and similar materials already handled at these facilities, but the cost of such fuel would be higher due to the cost of densification.
  - Some cost reductions would occur where densified fuel were transported due to increases in truck payloads.
- Changes to plant efficiency, parasitic load, capacity, availability, emissions
  - Straw may result in increased parasitic load on the power plant for grinding, densification, or other fuel handling operations.
  - Nitrogen in straw leads to generally higher NOx formation in furnaces compared with wood. This extra NOx incurs higher cost of control, such as by ammonia injection.
  - High combustion temperatures can lead to the formation of crystalline silica (a breathing hazard), but for most units temperatures are sufficiently low to avoid this issue.
- Ash handling/byproduct recovery
  - The high ash content in rice straw compared with wood leads to higher costs in ash handling and disposal. A 20% blend of rice straw in wood roughly doubles the ash content of the fuel.
  - Byproduct recovery of ash may offset higher handling costs where the ash has economic value.
  - Separate firing of straw, or blending with rice hull rather than wood offers the means to recover high silica ash with economic value. Blending straw with wood contaminates the high silica straw ash and the blended ash would generally have lower value.
  - Emission of any crystalline silica needs to be controlled, although this should not be a problem with well operated facilities.
- Tax credits/other incentives
  - Some special incentives for using rice straw are available to power generators, in addition to the incentives generally available to straw users. Grants and credits from the separate programs are mostly exclusive of each other.

Rice Straw Fuel Costs

The incremental costs of power for a plant burning a 20% straw-wood fuel blend under three different scenarios appear in Table 1 below.

Table 1

	Incentives+Tax Credit		Without Incentives		State Credits/Grants	
	$/ton	$/MWh	$/ton	$/MWh	$/ton	$/MWh
Rice Straw Fuel Costs						
Harvesting/Handling	24.38	35.31	24.38	35.31	24.38	35.31
Transportation	7.10	10.29	7.10	10.29	7.10	10.29
Storage	3.45	4.99	3.45	4.99	3.45	4.99
Nutrient Replacement	3.93	5.69	3.93	5.69	3.93	5.69
Plant Handling/Processing	9.07	13.14	9.07	13.14	9.07	13.14
Total Harvesting/Handling	47.92	69.42	47.92	69.42	47.92	69.42
Incentives						
Grower Payments	-32.65	-47.30	0.00	0.00	0.00	0.00
State Tax Credit	-15.00	-21.73	0.00	0.00	0.00	0.00
State Grants	0.00	0.00	0.00	0.00	-20.00	-28.97
Total Payments/Credits	-47.65	-69.03	0.00	0.00	-20.00	-28.97
Net Costs						
Net Straw Cost	0.27	0.39	47.92	69.42	27.92	40.45
Wood Fuel Cost	25.00	25.84	25.00	25.84	25.00	25.84
Blend Cost	18.58	20.75	30.94	34.55	25.76	28.76
Incremental Costs						
Fuel	-24.73	-5.09	22.92	8.71	2.92	2.92
Ash	1.47	0.46	1.47	0.46	1.47	0.46
Ammonia	0.24	0.08	0.24	0.08	0.24	0.08
Total	-23.02	-4.54	24.63	9.26	4.63	3.47

Incremental Power Costs due to Rice Straw

The incremental costs shown in Table 1 include three different scenarios. The costs are shown per ton of fuel and per unit electrical energy generation, $/MWh including the added ash handling and ammonia injection for NOx control (1 MWh = 1,000 kWh).

- The first includes grower payments in the amount of $36/acre with a low straw yield on spring harvested straw, along with the current state tax credit of $15/ton. With these incentives, the straw is essentially available at no net cost to the generator, and the cost of power decreases relative to wood alone, even including the higher costs associated with NOx control and ash disposal.
- The second scenario includes no incentives. In this case, the use of straw as fuel increases the cost of power by roughly $10/MWh ($0.01/kWh). For most biomass plants, this would increase the cost of generating power from about $60/MWh to 70/MWh ($0.06/kWh to $0.07/kWh).
- The third scenario uses only the incentive available as a grant under AB 2514. The incremental cost of power increases by a third of that for the case with no incentives, or by only $0.003/kWh.
- Substantial uncertainties exist in the cost of straw processing at the power plant, and in the total quantity of leached straw that may realistically be available in any year. The incremental costs associated with increased ash handling and ammonia injection for NOx control are relatively minor in comparison to the fuels acquisition and processing costs.
- Current state incentives, exclusive of grower payments, offset about half the total cost of straw harvesting, transportation, and storage for facilities located within the rice growing region.

Developing Engineering Data on Rice Straw for Improvement of Harvesting, Handling and Utilization

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Introduction

Biomass utilization systems require accurate data on yields and properties for design purposes. Most information to date on rice straw yields has been provided by monitoring baling operations to measure the tonnage of straw obtained from fields. In previous studies, there has been a large variation in yields, from 1.3 to 4.2 tons ac^{-1}. Yield variations are difficult to account for, and have been anecdotally attributed to effects of variety, season, location, stubble height, equipment losses, etc. There is a need for baseline straw yield information for variety, location, season, and cutting height in order to understand rice straw harvesting and handling losses. Baseline information is also needed on rice straw properties for machine and process design. Currently, this information is limited and insufficient for engineering uses. The goal of this study is to generate accurate yield and property data for rice straw of common varieties grown in typical California conditions. The effects of long-term storage were also investigated.

Materials and Methods

Six common early varieties of rice (M202, M204, L204, L205, S102, and CM101) and two late varieties (M401 and M402) were tested. The early trials took place at two California sites, one in Colusa county, the other in Yuba county; late trials were held in Sutter county and Glenn county. All trials were located adjacent to the Statewide variety trials in a grower's field of an equal maturing variety and were subjected to the grower's management practices. The varieties were planted in a randomized complete block design with four replications. Plots measured 10' x 20'. Plots were harvested with a rice plot harvester fitted with a catch-bag at the back of the combine. The container was weighed after collecting straw and chaff discharged by the combine. Grain was also weighed and both straw and grain were sampled for moisture content. Whole plant samples were collected at harvest for chemcial composition and biomass distribution analyses. Randomly selected plant samples from each plot were measured for length, weighed, and divided into panicle, node, internode and leaf components. Component length and weight were recorded and used to determine linear weight of each internode. The resulting biomass distribution was used to calculate yields expected at different cutting heights. Ground samples were ashed and analyzed for silica (acid-insoluble ash) and structural properties.

Table 1. Straw yields and straw:grain ratio results from rice straw variety trials.

	Straw Yield (ton/ac)		*Straw:Grain Ratio*	
Early Varieties	*Colusa*	*Yuba*	*Colusa*	*Yuba*
M204	4.70	5.18	1.19	1.57
L204	4.50	4.89	0.95	1.65
L205	4.27	4.69	1.08	1.69
M202	4.11	4.50	0.74	1.17
S102	3.79	4.20	0.72	0.97
CM101	3.51	4.25	0.70	1.08
Late Varieties	*Glenn*	*Sutter*	*Glenn*	*Sutter*
M401	3.56	4.92	0.86	1.47
M402	3.34	4.88	0.86	1.43

In separate experiments straw properties were monitored during storage. Storage methods include indoor, pole-barn, tarped and uncovered as shown in Figure 1. Samples were taken from large (4'x4'x8') bales before and after a one-year storage period. Bale temperature relative to ambient was also monitored during the storage period as an indicator of decomposition activity in the bale.

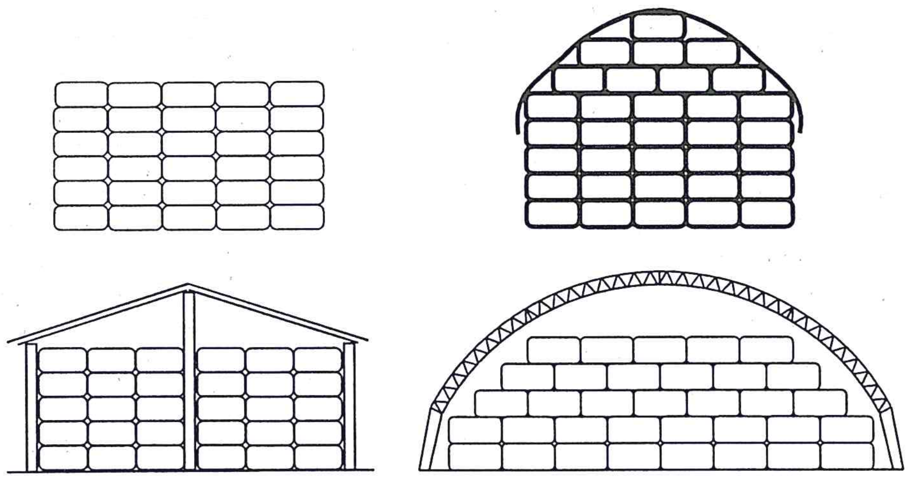
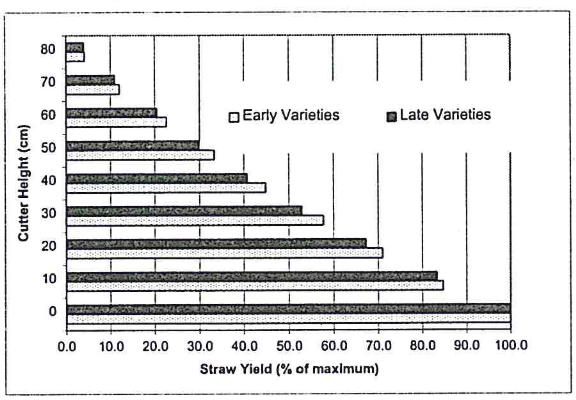


Figure 1. Typical large bale storage systems. Clockwise from top right: uncovered, tarped, indoor (fully enclosed), pole-barn (sides exposed).

Results

Straw Yields: Field results for straw yield and straw to grain ratios are shown in Table 1. Biomass (straw) yields ranged from 3.3 ton ac^{-1} (Glenn, M402) to 5.2 ton ac^{-1} (Yuba, M204) showing a statistical relationship to variety. On average, straw yields from Yuba and Sutter counties were higher than those from the Colusa and Glenn sites. Straw to grain ratios were also highest in Yuba and Sutter for the 1999 growing season. In addition, individual plant weights were greatest in these counties, contributing to higher yields. Although these results come from only one season of data, they do indicate that site and variety have an impact on straw yields and straw to grain ratios. Farmers in different counties may expect straw yields to differ as well. This study is ongoing for the early varieties in Colusa and Yuba counties.

Straw yields also vary greatly due to cutting height. Figure 2 shows the percentage straw yield at different cutting heights. As expected, cutting closer to the ground yields greater harvestable straw yield. For example, the common practice of cutting at or above the water line at 8 to 12 (20 to 30 cm) can result in a reduction of 30 to 50% of potential yield. This is due in part to a nonlinear biomass distribution, with more weight concentrated near the base of the rice plant.



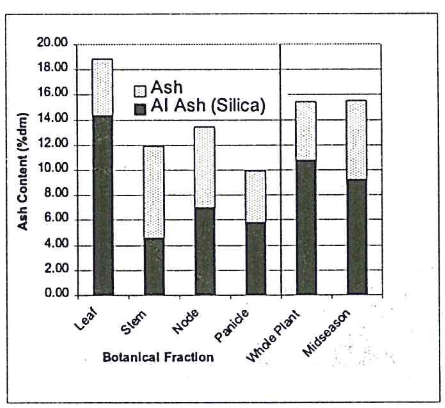


Figure 2: Straw yield as effected by cutter height. Figure 3: Ash and silica content of M202 fractions

Straw Properties: Typical elemental and structural compositions for rice straw are shown in Table 2. Ash, silica, extractive, and cellulose concentrations were not significantly different among the varieties tested. However, only samples from one season have been tested, and further work is continuing.

Table 2. Typical rice straw properties for California varieties

Elemental Analysis (% by weight, dry basis)							Structural (% by weight, dry basis)					
C	H	O	N	S	Cl	K	Cellulose	Hemicell.	Lignin	Ash	Silica	Extract
41	5	38	0.7	0.08	0.4	1.7	33	28	10	16	12	10

Straw properties, particularly ash and silica content, did vary significantly by botanical fraction. Rice straw varieties tested were 62% (by weight) leaf (including sheath), 28% stem, 5% node, and 5% panicle. Figure 2 shows ash and acid insoluble ash results for M202, the most common variety grown in California. Acid-insoluble ash gives a relatively good estimate of silica content in rice straw. While silica is less than 5% of the stem fraction, it makes up nearly 15% of leaf dry weight, so that the total stem contributes 2.0% of dry matter as silica, whereas the leaf contributes 9.3% out of the total 11.3% silica in the M202 plant. These results were typical for all varieties. Silica increased with height above the ground, presumably because more leaf tissue makes up a higher percentage of biomass near the top of the plant. Silica concentrations also increase as the plant matures. At harvest plants had higher silica contents than in plants collected midseason (figure 3). Silica and ash are typically undesirable properties in rice straw and there may be ways to take advantage of variations by variety, location, fraction and maturity.

Straw Storage:
Decoposition and self-heating of straw during storage was also investigated in single bale experiments. Moisture is the main trigger for bale self-heating and moisture sources include "wet" bales placed in stacks (>14% wb moisture content), moisture directly entering stacks (through rainfall, leaks, flooding, etc.), and ambient humidity conditions. Self-heating mechanisms include heat released through moisture adsorption and increased microbial activity and heat-releasing respiration. Bale temperature and oxygen availability are also factors for level of microbial activity/decomposition. During single bale experiments self-heating followed periods of rainfall in exposed bales. Bale temperature peaks about 7 days after moisture exposure and then diminishes over time. Large (4'x4'x8') bales reached maximum temperatures of 62°C and peaks generally diminished over time. The moisture-heating relationship is seen in figure 4.

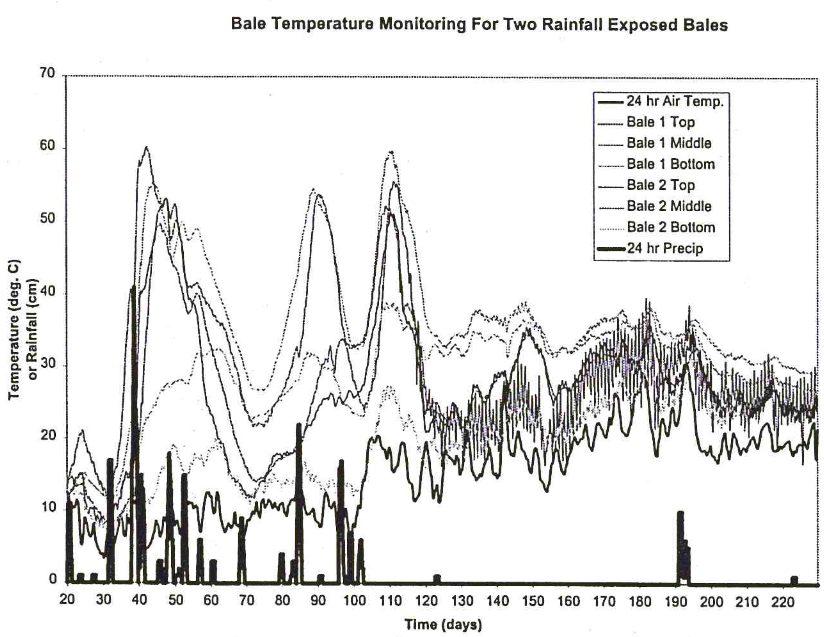


Figure 4. Data for bale temperatures for two uncovered bales (A,B) in relation to daily rainfall.

Level of decomposition was monitored for bales in these experiments by monitoring increase in silica ash to determine loss of organic matter. Table 3 shows the results. Indoor and pole-barn stored bales had insignificant changes in organic matter during one year of storage. Tarping showed 18% change in organic matter however some rainfall penetrated a leaky tarp resulting in an estimated 9 in of rainfall exposure. Rainfall exposed bales lost over 50% of organic matter in the full year experiment and 20 to 25% in shorter 220 day experiment where bale orientation was varied.

Table 3. Property changes in large bales of rice straw in various storage scenarios.

Storage Method	*Exposure Time (days)*	*Rainfall Exposure (in)*	*Acid-Insol. Ash (% change)*	*Dry Matter (% change)*	*Organic Matter (% change)*
Indoor	391	0.0	1.8	-1.8	-2.0
Pole Barn	391	0.0	5.0	-4.2	-4.5
Tarped	391	9.0	30.4	-14.3	-17.9
Uncovered	391	27.0	71.4	-40.9	-53.1
Uncovered A	220	8.7	35.4	-20.7	-26.5
Uncovered B	220	8.7	22.2	-12.2	-20.4

Integrated Harvester Operations for Enhanced Straw Recovery

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Harvesting and Handling of Rice Straw for Off-field Utilization Project

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Abstract

Off-field utilization of rice straw has initiated improvements in straw handling techniques. One possible improvement involves using the combine to increase straw yield, either through ground level harvest or through the attachment of a stubble cutting device operating behind the main header. Alternative designs for stubble cutters were examined and a sickle cutter prototype was fabricated and tested. The stubble cutter did increase straw yield compared to standard harvest practice, although the theoretical yield was not achieved. Field capacity of the harvester was slightly decreased while operating the stubble cutter. Ground level harvesting also resulted in lower harvester capacity but better overall cutting compared with the secondary stubble cutter. Several potential improvements in the stubble cutting design are under investigation.

Introduction

The reduction in rice straw burning has required alternative practices dealing with rice straw. Current alternatives include incorporating the straw back into the soil and off-field utilization. Both incorporation and straw harvesting are costly in comparison to field burning, but each has agronomic and environmental benefits. To reduce the cost of straw for off-field utilization, improvements to the straw harvesting system are needed. One possible innovation is to cut the stubble left behind the primary header of the grain combine. This has the advantage of increasing overall straw yield and providing a means to move stubble from out of the way of the wheels or tracks. The latter improvement increases both yield and quality of straw compared to conventional harvest. The alternative and expedient technique of ground level harvest accomplishes a similar result, but may lead to decreased capacity and higher cost of grain harvest.

Objectives

The objectives of developing a stubble cutting attachment for a combine harvester include:

1) to increase biomass yield compared to the standard harvesting practice (when lower stem is acceptable for utilization)
2) elimination of a secondary cutting operation (swathing) or prevention of slower harvesting at ground-level, to recover the same material
3) improved straw quality by avoiding trampling of the stubble by the combine harvester tracks and/or tires
4) better management of disease and pests by improving the removal of infected material

Design and Construction

Several cutting and material handling alternatives were considered for the stubble cutter. After cutting the stubble, the attachment was to clear the straw from the path of the harvester's tracks. Two options were considered to clear the pathway: 1) windrowing all of the stubble, and 2) simply clearing the pathway of the tracks and tires.

Windrowing the straw requires more drying time before baling and most likely, the windrow would require turning for complete drying. Leaving the straw spread except for the path of the harvester allows quicker drying, although the potential for the straw to be trampled by the harvester and bankout wagons is greater. The spread straw would have to be raked into a windrow before baling.

Traditional cutting methods using sickle bars and rotary cutters were considered applicable for the stubble cutter. Material handling options that were considered were draper belts and augers.

Mechanisms that would cut and move the straw were also examined, such as an auger cutter and a continuous belt cutter. These mechanisms showed some potential, but implementing them in field conditions would require extensive development.

Design considerations for the stubble cutter included physical space constraints and power requirements. The proposed placement on the harvester was between the header and the tracks, where little space is available. Space constraints were the main considerations as the operation of the harvester's header was not to be affected. Figure 1 shows the selected location for the stubble cutter and the available space.

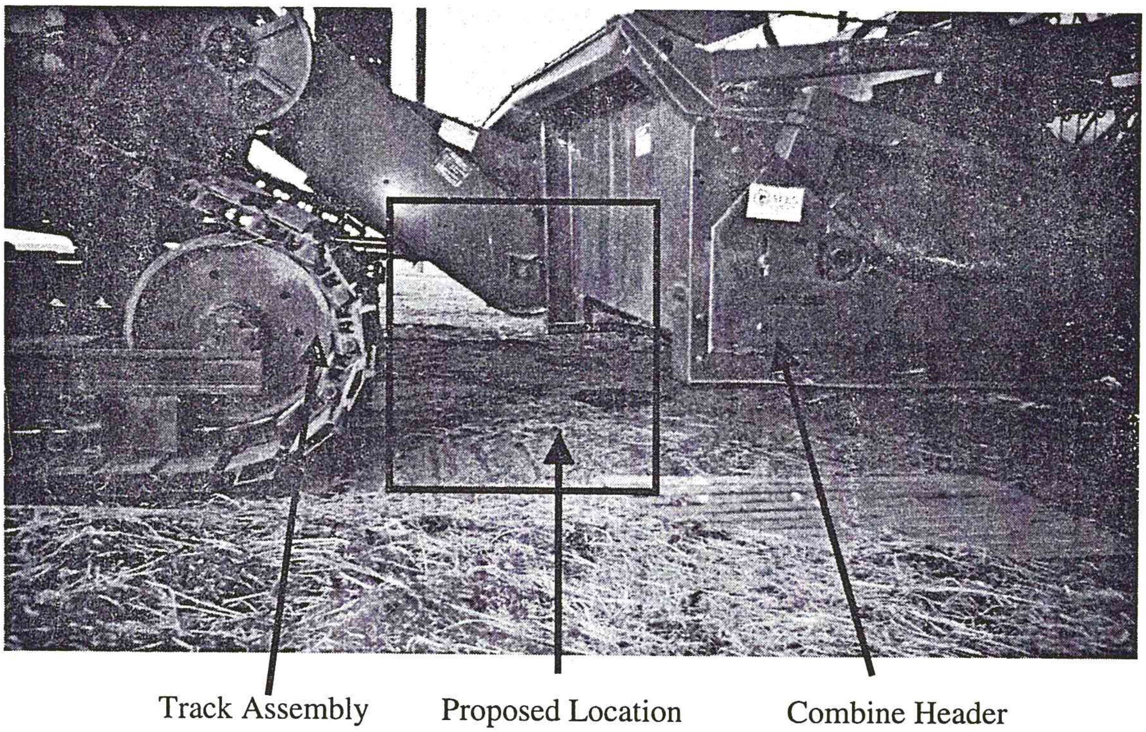

Figure 1. Proposed location for the stubble cutter.

A stubble cutter utilizing a sickle bar cutter and windrowing drapers fit the profile of the available space and had the lowest power requirement of the concepts considered. For these reasons, the sickle bar with drapers was chosen for prototype development.

A frame system was designed to support the stubble cutter and provide vertical movement of the attachment. This frame was mounted to the combine's frame. Hydraulic cylinders were used to adjust the cutting height by pivoting the stubble cutter frame about the same axis as the combine header.

A hitch system was designed to allow the lower portion of the stubble cutter to be removed from the frame assembly. This provided flexibility for the grower to make it possible to harvest without the stubble cutter.

A sickle bar from a combine header was used on the stubble cutter. A standard wobble box was used to drive the sickle bar. A swing arm and connecting rod were designed to allow the wobble box to be mounted on the back of the stubble cutter to prevent interference with the combine header. The wobble box was driven with a hydraulic motor via v-belt.

Draper belts were designed to have a low profile and be as close to the sickle bar as possible. The limited space available prevented a reel or similar mechanism to be used to move straw from the sickle bar to the drapers, requiring the straw to fall onto the belts after being cut. Draper belts were designed with cleats to help grip the straw, and a tracking rib to keep the belts on the rollers. The drive rollers were driven directly by hydraulic motors.

Figure 2 is a drawing of the stubble cutter mounted on the combine harvester indicating the location of components.

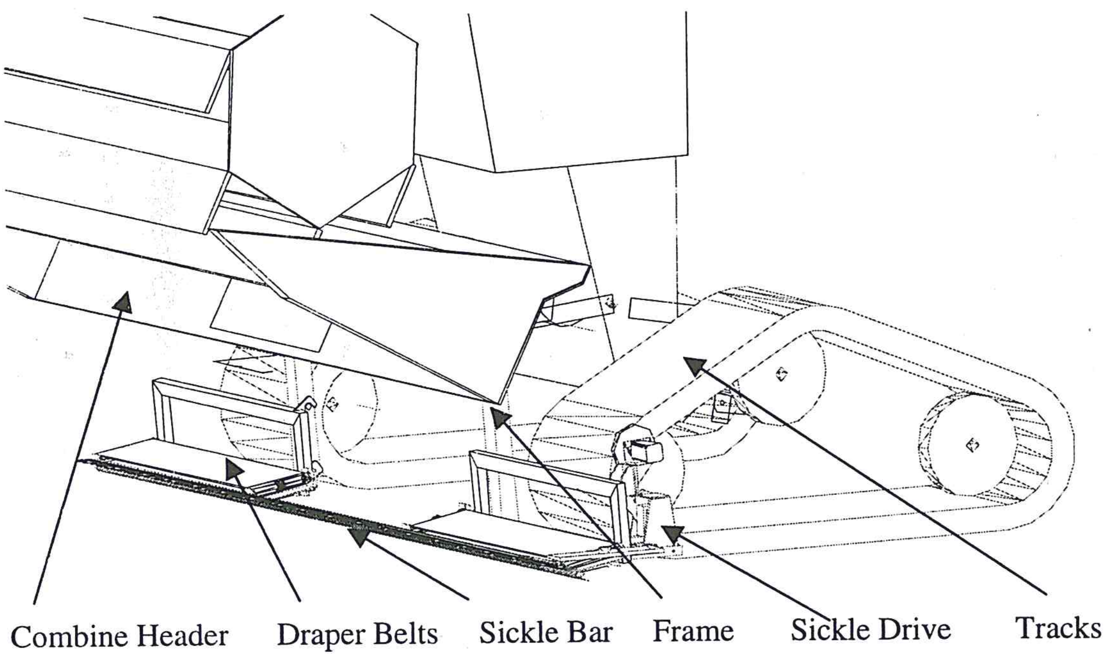

Figure 2. Stubble cutting attachment.

Figure 3 shows the stubble cutter prototype mounted on the combine for testing.

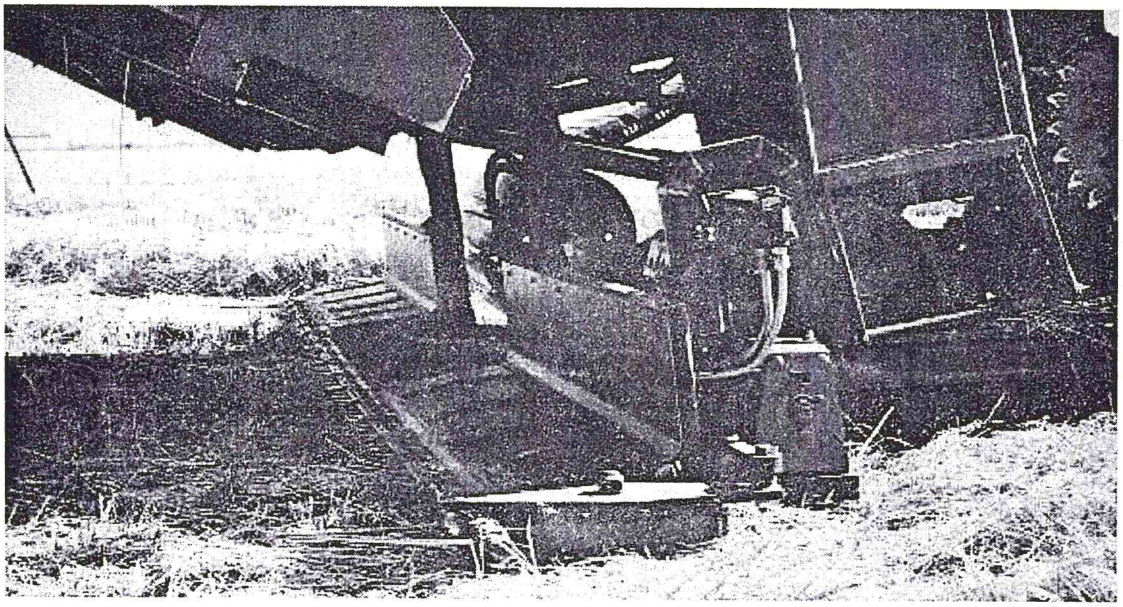

Figure 3. Prototype stubble cutter.

Power for the prototype was supplied by a self-contained engine driven hydraulic power supply carried on the back of the combine harvester. This power supply consisted of a 2 cylinder gasoline engine with battery and fuel tank, a variable displacement axial piston pump to power the sickle bar and draper drive motors, an auxiliary pump and directional control valve to control the lifting cylinders, pressure relief valves, filters, and a hydraulic fluid reservoir. The variable displacement of the main pump was controlled from the operator's cab and was utilized to control the speed of the sickle bar and draper belts. Hoses were routed alongside the combine to connect the stubble cutter to the power supply. The auxiliary power supply meant that minimal modifications had to be made to the combine during the prototype testing stages.

Testing and Results

Initial testing was done with the stubble cutter mounted on a tractor cutting wheat stubble. These tests justified further development and showed that the cut stubble could fall onto the draper belts without being forced by a reel mechanism.

After the stubble cutter was mounted on the combine, testing was done during rice harvest. An experiment was designed to evaluate the performance of the stubble cutter by measurements of straw yield and field capacity. Operation of the combine with the stubble cutter was then compared to the combine cutting at different heights without the stubble cutter. Without the stubble cutter, the combine was operated at a normal harvesting height (15-20 inches), cutting just above the water line (8-9 inches), and cutting as close to ground level as the combine header allowed (3-5 inches). Figure 4 shows the stubble cutter cutting rice stubble. The windrow formed is shown in Figure 5.

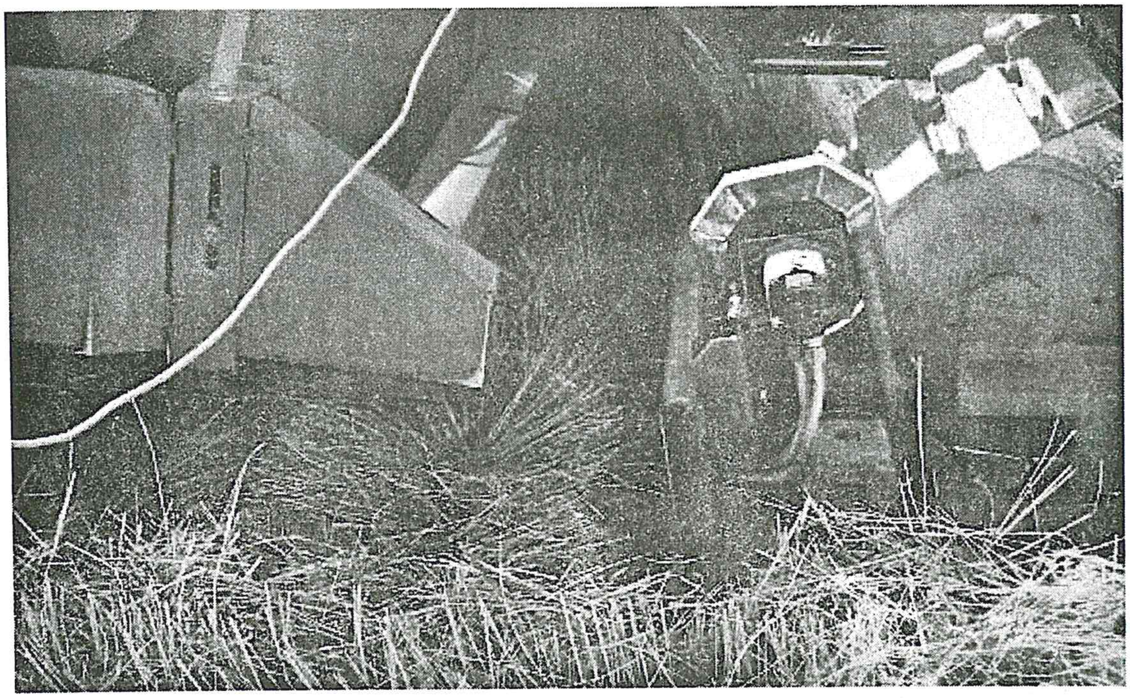

Figure 4. Stubble cutter in operation.

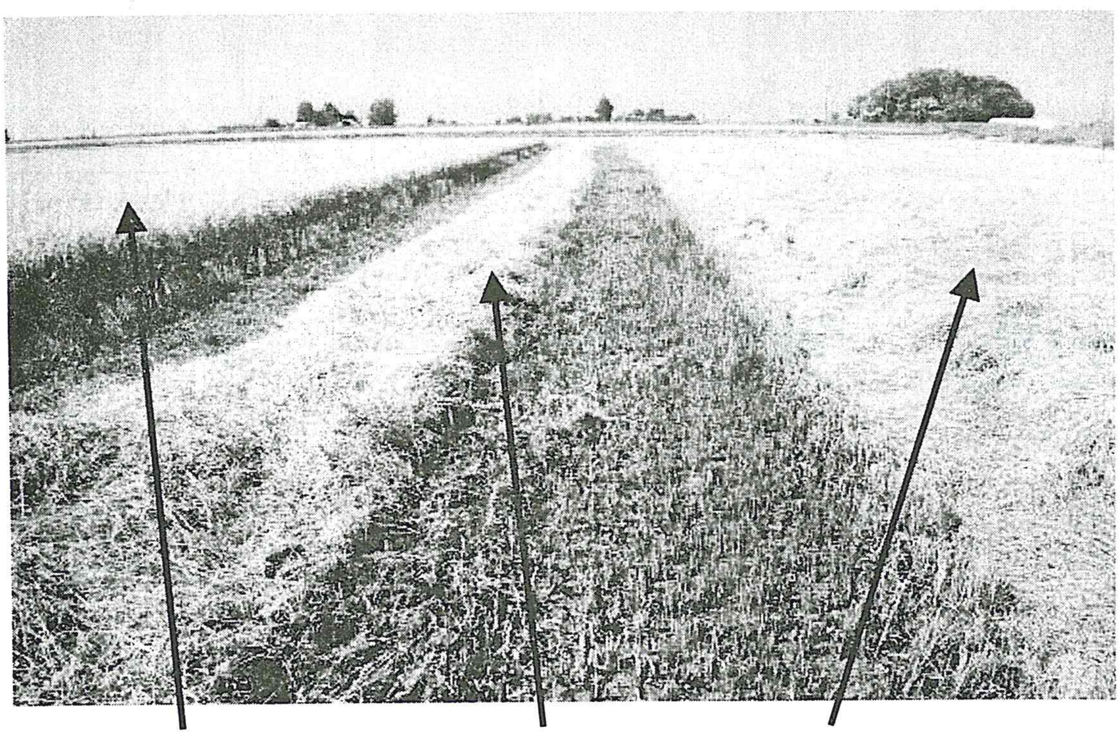

Figure 5. Harvested swaths.

Straw yields were obtained by weighing sections of the windrow. A 5 ft section of the windrow was separated and weighed in-field. Grab samples were collected from the windrow samples, bagged, and oven-dried to give moisture content. Dry weights of the windrow samples were then calculated for the analysis.

Field capacity was obtained by monitoring combine speed. The cutting width and harvesting speed were then used to calculate the combine field capacity. Turning time and other unproductive times were not included in the analysis. Straw yield is shown in Figure 6 against the combine header cutting height.

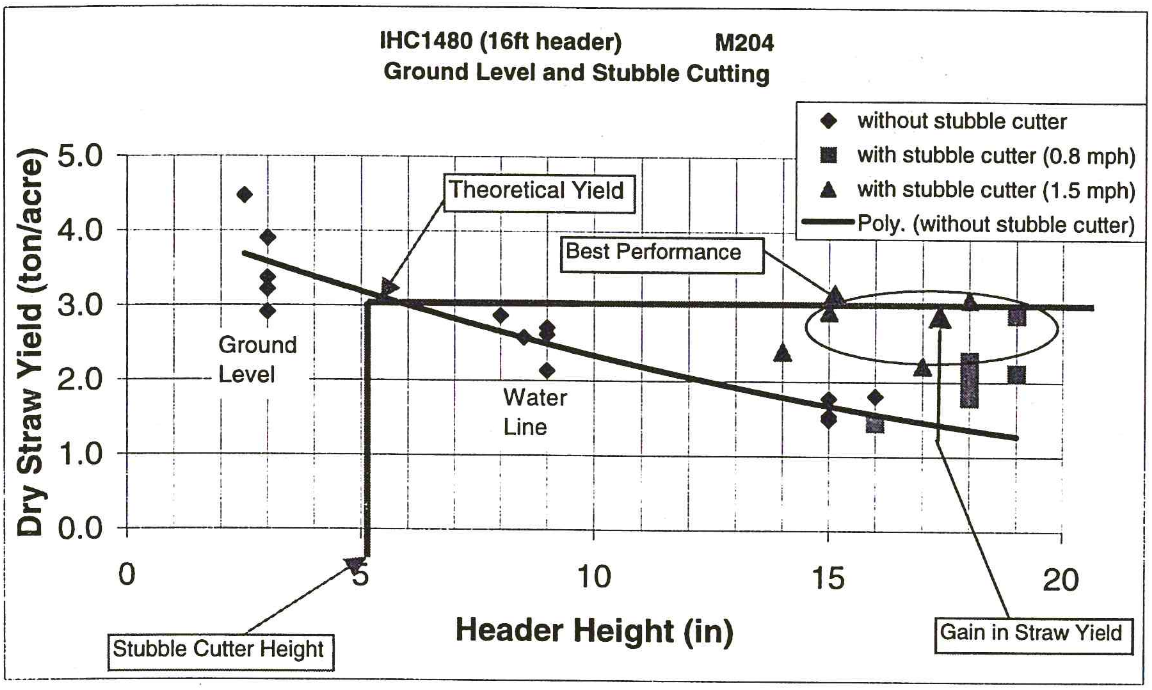

Figure 6. Straw yield results.

Straw yield was regressed against header height to provide an operating curve for the combine cutting at different heights without the stubble cutter. With the stubble cutter cutting at 5 in, the theoretical straw yield can be estimated from this curve and is shown in the figure (3 tons/acre). The actual operating points for the stubble cutter are shown on the right side of the plot. The points near the theoretical yield are from the stubble cutter operating at its best performance. The points below this line are from periods when the stubble cutter was partially plugged. Plugging was a serious problem with the prototype, due largely to the inability to move the relatively short stubble away from the sickle. A gain in straw yield by the stubble cutter is shown, however, by the data points lying above the combine operating curve.

The losses in straw yield indicated in Figure 6 occurred when the cut stubble lodged on the draper belts. Cut stubble would be plowed forward by the sickle bar, causing the cutter to ride over the top of the uncut stubble. Figure 7 shows areas of the swath where straw yield losses were high due to this plugging problem.

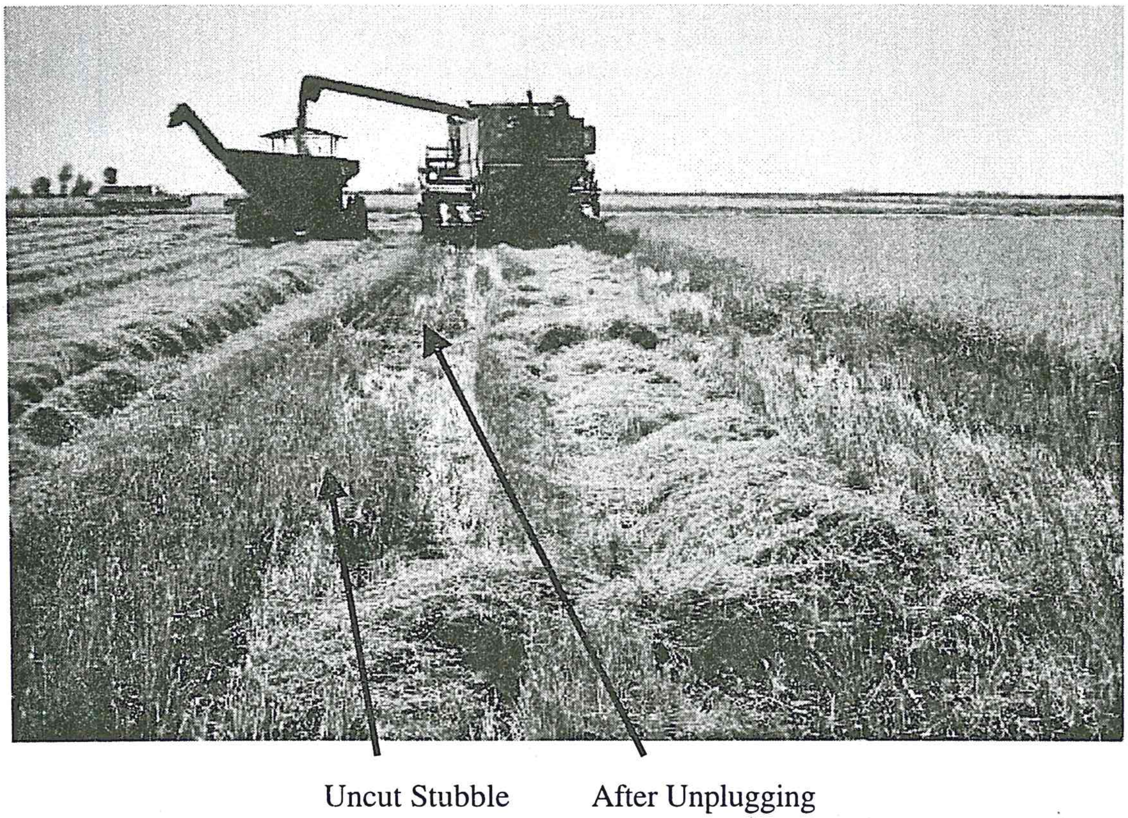

Figure 7. Uncut stubble due to plugging.

The operator controlled the combine speed by monitoring grain loss to keep it within an acceptable range. Cutting lower with the combine header required slowing the harvester speed, decreasing field capacity. The decline in field capacity is shown in Figure 8.

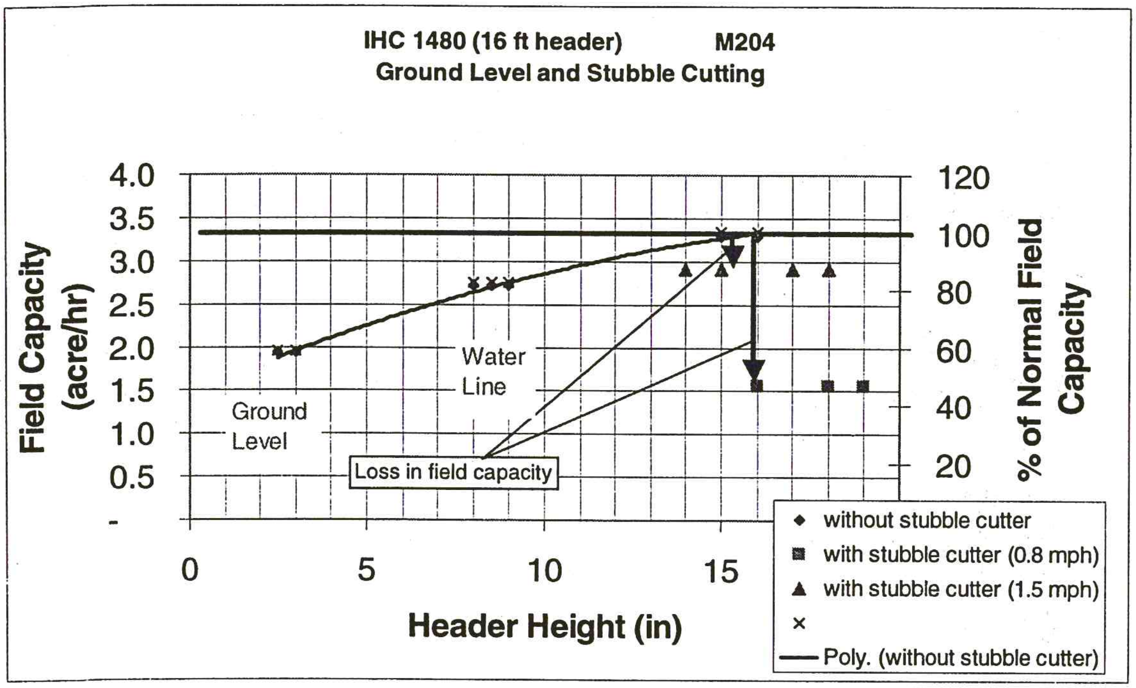

Figure 8. Field capacity results.

A regression was also performed to give a combine operating curve for field capacity at different cutting heights. The curve is shown in terms of actual field capacity and percent of normal field capacity. A 60% reduction in harvesting speed occurred with the International Harvester 1480 harvester used while cutting at ground level. This is due to the mass of straw passing through the thresher, and the need to control threshing losses.

The figure shows the two speeds at which the stubble cutter was operated. The faster speed shows a slight drop in field capacity while the slower speed is similar to that of the ground level harvest. The slower speed was examined to determine if the cutting speed would affect plugging. Straw yield data from Figure 6 does not indicate a significant effect on straw yield between the two speeds.

Discussion and Conclusions

The main issue with the prototype stubble cutter was its vulnerability to plugging with cut stubble. Interference by the combine header and elevator was responsible for most of the plugging. A more aggressive draper system could potentially solve the problems associated with plugging, although modifying the harvester to make more room for a stubble cutting attachment would allow a more dependable solution by making changes to the stubble cutter possible. Potential changes would be mechanisms to promote straw flow from the sickle bar to the draper belts.

For stripper headers, a stubble cutter that could handle higher ground speeds would be valuable. A 3 disk rotary cutter was temporarily mounted on the stubble cutter frame and used to cut stubble left from a stripper header. The cutter was effective at combine speeds typically achieved with a stripper header. Rotation of the disks may help to convey the cut stubble, but this could not be adequately demonstrated with the cutter available.

The option of leaving the cut stubble spread to dry as apposed to windrowing would make a sickle bar type and a rotary type stubble cutter more reliable. Cutting the stubble was not difficult compared to handling the cut straw. Some concepts have been developed to clear spread straw from the path of the tracks, but these remain to be tested.

Another concern with the stubble cutter's location on the combine was poor visibility from the operator's seat. System monitors and mirrors could help the operator monitor the stubble cutter, but without major modifications to the combine, most of the stubble cutter would remain out of view by the operator. A number of safety issues also remain to be resolved with the use of stubble cutting attachments.

The prototype stubble cutter provided a good assessment of the technical difficulties in adapting a simple mechanism within the limited space behind conventional combine headers. Improvements are needed to eliminate plugging, but the concept appears to offer promise for improving straw yields, straw quality, and field sanitation in the absence of burning.

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