Project No. RM-5

Comprehensive Research in Rice
Annual Report

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Project Title: Soil Incorporation and Cropping Systems as an Alternative to Agricultural Burning - A Literature Review

Status of Project: Closed 1980 ($3,000)

Project Leader and Principal U.C. Investigators

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Objectives of Proposed Research

Agronomic alternatives to open field burning for rice crop residues disposal are needed to enable the California rice industry to remain economically viable and to reduce this agricultural source of air pollution. Soil incorporation, currently the most practical option, is difficult to practice for several reasons: (1) the large physical mass involved (average 7000 pounds straw and 3000 pounds of roots); (2) the problem of incorporating straw into heavy clay soils that are often wet after harvest when disposal is most desirable; (3) the lack of suitable agricultural implements and unfavorable economics of soil incorporation; (4) the lack of time and favorable climatic conditions after rice harvest for soil incorporation; (5) the high C-N ratio and lignin content of straw contributing to slow decomposition (0.66 to 3.4 years); (6) the production of toxic products of anaerobic fermentation when rice straw decomposes just prior to planting rice; (7) aggrevated stem rot infection and weed problems when burning cannot be practiced; and (8) the lack of other economic alternative uses of rice straw.

The proposed literature review would examine the individual problems associated with the soil incorporation of rice straw, stubble and roots and the practical management alternatives to burning.

Summary of literature review - Part 1

Crop residues which have commercial value are usually harvested, but materials like rice straw must be economically disposed of in such a way that agricultural land will remain productive and farmers can economically survive. Agricultural burning has been the most widely practiced means of straw reduction in the past but with smoke pollution, contributing to a deterioration of air quality, it can no longer be considered the only disposal alternative.

Soil incorporaton of crop residues is widely practiced with some crops, but with rice the physical and chemical characteristics of straw, the time of incorporation and disposal in seasonally wet, heavy and impermeable clay soils makes disposal difficult. Also associated with rice straw disposal are the difficulties of using agricultural implements for chopping, spreading and incorporating straw, the large expense involved, the possible consequences of increased foliar diseases and possibly development of adverse soil conditions. These make soil incorporation a potential disposal system, but one not suitable to all years and rice management situations.

The acreage of rice harvested in California between 1975-79 was 450,000 acres and in 1981 the largest crop was harvested on 580,000 acres producing an average of 7,100 pounds of rough rice per acre. Every ton of grain produced yields about 0.90 tons of straw from typical short statured rice varieties. Statewide average straw yields are about 3 tons per acre, but may be twice this amount in some situations. Machine combined grain and residual straw each represent about 40 percent of the dry biomass or about 80% of the total biomass produced per acre. The stubble and roots, representing another 20 percent of the total crop dry matter, remain in the field and is returned to the soil even when the straw is harvested or burned. By conservative estimate this amounts to about 2 additional tons of organic matter returned per acre of rice.

Rice straw is high in celluloses and lignin and contains 15 to 17 percent ash, composed primarily of silica. It typically contains from 0.42-.70% N, 0.15-0.20% P_2O_5, and 1.3-2.1% K_2O. Because of its high carbon to nitrogen ratio straw does not decompose readily in the soil. In an average California rice field the cut straw contains some plant nutrients, averaging about 30 pounds of nitrogen (N), 11 pounds phosphorus (P_2O_5) and 110 pounds potassium (K_2O) per acre, all useful for the maintenance of soil fertility (Mikkelsen and Patrick, 1968). During burning, almost all of the nitrogen and plant sulfur are lost by volatilization but other plant nutrients remaining in the ash are returned to the soil.

Factors Affecting Rice Straw Decomposition

A number of factors and interactions affect the decomposition of rice straw under field conditions. The rate with which straw is decomposed will depend upon its chemical composition particle size and physical contact with the soil. The physical and chemical aspects of the air and soil environment are also important. Major factors are moisture, temperature, oxygen supply and soil conditions, including available nutrient supplies. The quantity and quality of the straw applied, its nitrogen composition, straw particle size, the time and method of incorporation, crop and soil management practices and crop rotations also affect the success of straw reduction.

Moisture is one of the most important environmental factors determining straw decomposition rate. Although there is a wide range within which microorganism reproduce and metabolize straw substrate, there are seasonal moisture conditions in California rice soils which retard straw decomposition rates. Pal, Broadbent and Mikkelsen (1975a and 1975b) observed that mineralization was most rapid in soils at 60% of water holding capacity (WHC) but was delayed at 30% and 150%. This is because 30% WHC moisture is near the minimum threshold level for microbial activity; and at 150% WHC, movement of air was restricted so that low oxygen levels reduced decomposition rates. At 150% WHC about 62% of the straw carbon was oxidized over a period of 4 months.

In California where most of the annual rainfall occurs during the winter months, the rate of straw decomposition is strongly influenced by seasonal soil moisture conditions. Sain and Broadbent (1975) noted that dry straw absorbed moisture readily and reached equilibrium values in from 1 to 4 days depending on relative humidity. Straw decomposition, however, was very slow below 90% relative humidity and the threshold moisture content for the initiation of fungal growth was 7.5%. Because of relatively dry atmospheric conditions, straw does not decompose in the field in California as rapidly as it does in the Southern U.S. rice belt.

Temperature likewise governs the extent and rate of straw decomposition at each biochemical step. Microbial decomposition and carbon mineralization is slower at low temperature than at temperature optima. Pal, Broadbent and Mikkelsen (1975c) observed that at 7.2 C the lag period for evolution of carbon dioxide or release of straw carbon was much longer than at either 22 or 37 C. At near ideal soil moisture conditions of 60% WHC, Pal et al. (1975) found that about 33% of the straw carbon was lost during a 4 month period on a typical Sacramento clay at 7.2 C. At 22 C the loss was about 47% and at 37 C, about 53%. Soil microbial species have different biochemical capacities so that the effects of temperature may vary slightly as soil conditions change, but generally in the range of 5 C to 30 C, rising temperature accelerates straw decomposition.

Air supply or, more specifically, oxygen supply is another factor governing the rate and extent of straw decomposition, since it plays a direct role in microbial metabolism. In aerated soils, straw is mineralized with the release of carbon dioxide, water and the production of microbial cells, but in the absence of oxygen, organic carbon is not completely oxidized and intermediate substances other than carbon dioxide accumulate. Likewise the energy yield during anaerobic fermentation is low so that fewer microbial cells are produced per unit of carbon degraded. Rice straw decomposition is most rapid under well aerated conditions, slower in saturated soils and most retarded under complete anaerobiasis (Patrick and Mikkelsen, 1971, Broadbent, 1978).

Various other conditions involving physical, chemical and biological properties affect the soil environment in which microorganisms operate and decompose rice straw. Physical conditions such as soil texture and soil structure, percentage clay and clay type; physicochemical properties of soil, including pH, redox potential, conductivity, gaseous exchange, soil fertility, and biological characteristics such as soil microflora and factors affecting their metabolic processes--all profoundly influence the rate of rice straw decomposition. As a result, substantial variations in straw decomposition rates are found among the soil series on which rice is grown in California.

Effects on following crops

Several investigators have studied the effect of soil incorporation of straw on subsequent rice growth under flooded conditions. Williams et al. (1968) found that straw incorporation did not depress rice growth and yield if the straw contained more than 0.54 percent nitrogen. With less nitrogen in the straw, yields were depressed by nitrogen deficiency induced by nitrogen immobilization. Broadbent and Nakashima (1970) found the amounts of nitrogen immobilized by straw in flooded soils intermediate between those obtained under aerobic and strictly anaerobic soil conditions. In their study the nitrogen immobilized per unit weight of straw varied with the quantities added, the nitrogen content of the straw, and the nature of the soluble nitrogen applied. Brandon et al (1969) conducted a field experiment on Sacramento clay with 0, 3 and 6 tons of rice straw incorporated with 0, 40, 80 and 120 pounds nitrogen per acre. Both fall and spring application were tested. The straw initially contained 0.6% N. At 3 tons per acre, soil incorporation significantly reduced rice yields, but statistically no more than 6 tons. The depressed yields were due to both nitrogen immobilization and the formation of toxic anaerobic decomposition products. Spring applications of fertilizer nitrogen partially overcame the effects of nitrogen immobilization, but fall applied nitrogen did not. Broadbent (1972) showed that nitrogen applications with straw hasten decomposition but have only short term effect (3-4 weeks). The rate and accumulative decomposition of straw over 90-120 days was not affected by added nitrogen.

Where rice straw is properly managed, however, incorporation has effected an increase in rice yields and over a period of years has improved the nitrogen status of rice soils.

The mechanical process

Rice straw from a grain combine is difficult to handle and incorporate into the soil. This is a special problem on California's rice soils which are high in clay content, have a higher water holding capacity and are almost impossible to work with tractors and tillage implements when waterlogged. Under proper soil conditions and good weather, rice straw can be incorporated with conventional tillage equipment, but under adverse conditions, which frequently prevail during the fall and winter in California, soil incorporation is difficult.

Burkhardt et al. (1975) studied different types of machinery for chopping, spreading and incorporation of rice straw. These operations appear necessary for effective straw disposal but adequate equipment is not commercially available. These researchers found that shear-bar forage choppers were effective for chopping, but require modification for use in rice. Generally, pull-type flail choppers, impact-type rotary cutters and shredders have not been satisfactory over a range of straw management conditions. Rotary tillage or discing effectively establishes straw-soil contact during fall preparation on ideal soils and under ideal conditions but had several short-comings. Researchers have found fall season incorporation usually superior to spring since it provides better soil and weather conditions, and gives the most satisfactory results for continuous rice production. Costs for soil incorporation obviously are much greater than for burning ($4.00/acre vs. $15 to $40/acre). Also, problems may develop in subsequent rice crops because of increased stem rot disease and possible crop injury from anaerobic fermentation products in flooded soils.

Sain and Broadbent (1977) observed differences in rates of straw decomposition on different soils, but incorporated straw decomposed significantly faster than straw left on the soil surface. The need for particle size reduction was not clear since the length of straw did not affect the rate of decomposition on Myers clay, while on Sacramento clay coarse straw decomposed most rapidly.

Toxicity and stem rot

In flooded soils where rice straw has not been completely decomposed, or where it is incorporated shortly before flooding are susceptible to the formation of organic acids and various gases that may be toxic to rice. Rice straw produces acetic and butyric acids which peak in concentration and toxicity about 15 to 20 days after flooding (Rao and Mikkelsen, 1977). The magnitude of crop injury is a function of the kind, concentration and dissociation of the organic acid. Anaerobic fermentation also often is associated with the release of gases such as carbon dioxide, methane, and hydrogen sulfide in flooded soils. Rice roots growing in soils where these gases have accumulated are adversely affected, limiting plant growth and nutrient uptake (Rao and Mikkelsen, 1977). Under conditions favorable for rapid straw decomposition, the toxicities caused by organic acids and gases are usually dissipated after about 30 days. Hydrogen sulfide toxicity persist through the growing season and may result in serious crop losses (Kuo and Mikkelsen, 1981).

Incorporated straw previously infected with stem rot contains sclerotia which may overwinter either free in the soil or in association with rice straw (Webster and Bockus, 1978). Studies show that a high positive correlation exists between inoculum levels in the soil and the severity of stem rot and yield reduction in the subsequent crop. This finding indicates that soil incorporation of infected straw can have serious ramifications if the sclerotia of stem rot occurs at high levels (0.2-0.3 viable sclerotia/gram of soil). Webster and Bockus (1978) showed that soil incorporation of 8 to 12-inch-high rice stubble resulted in a 2 to 5 fold increase in inoculum level which was accompanied by increases in stem rot and yield reduction in subsequent crops. This negative aspect of straw incorporation must be given careful consideration in formulating plans for straw management. It is possible that with the use of an effective fungicide (re. Du-Ter) or development of resistant varieties, that this problem might be circumvented.

General Conclusions

From the research conducted on the soil incorporation of rice straw, it appears clear that soil incorporation should be practiced only on selected soils where straw has been spread by the grain combines or suitable straw chopping devices, to facilitate incorporation. In addition, soils high in clay or with a high exchangeable sodium content, which tend to retain moisture, often do not lend themselves to straw incorporation during most years. Furthermore, where stem rot disease is a problem or where soil toxicities develop from straw incorporation, alternate disposal methods such as burning or complete straw removal should be practiced. Table 1 summarizes the positive and negative effects of straw incorporation in respect to the various management options currently available.

Table 1. Comparison of straw removal methods on production factors.

	Plant Nutrients		Potentially Harmful Products			
Straw handling*	N+S	P-K-Ca-Mg	organic acids	toxic gases	stem rot disease	Economic cost
Burning	●	0	S	S	S	S
Incorporation	0	0	L	L	L	L
Removal	●	●	S	S	S	L

0 Returned to soil
● Removal from soil

S = small effect
L = large effect

* Roots and stubble returned in all cases.

The choice of alternative methods of straw disposal must remain as management options in California rice production. Conditions vary too much from soil to soil and depend on other factors (weather and seasonal climatic conditions, crop rotations, disease, weed and insect problems, and crop management practices) to define which systems may be needed from season to season. Soil incorporation is sometimes a valuable option, but the agricultural and the consumer sector would both suffer economic loss if incorporation were mandatory.

<u>Researchable areas to enhance soil incorporation of rice straw</u>

The practice of soil incorporation of rice straw could be made more practical by the following procedures:

1. Producing of early maturing rice varieties (120-130 days) so that rice straw could be incorporated after harvest when soils are dry and before winter rains begin.

2. Considering alternative crop rotations in which rice would not be planted after rice, thus allowing greater flexibility in time of straw incorporation before subsequent crops.

3. Requiring the incorporation of straw when soil and weather conditions are favorable and where stem rot is not a problem, but allow alternatives such as burning in emergency situations.

4. Considering planting legume green manure crops in the standing stubble after rice harvest, and managing the legume and straw residues for optimum soil incorporation and soil resource conservation.

5. Examining the possibilities of wet soil incorporation of rice straw or winter irrigation practices to enhance straw decomposition during dry years.

6. Examining the possibilities of rice-livestock agricultural systems, with planted winter forage to complement feeding of rice straw.

7. Developing of agricultural implements that would more adequately and economically allow for soil incorporation of rice straw, or chopping implements which would promote decomposition with a minimal amount of soil incorporation.

Bibliography

Brandon, D. M., D. S. Mikkelsen, R. A. Kepner, M. D. Miller and J. Quick. 1970. The effect of rice straw incorporation in relation to rate and timing of nitrogen applications. Coop. Extension Colusa Co. Mimeo 1-5.

Broadbent, F. E. 1978. "Nitrogen transformations in flooded soils" in Soils and Rice, p. 543-559. The International Rice Research Institute, Philippines.

Broadbent, F. E. 1972. Crop residue disposal by soil incorporation. Calif. Plant and Soil Conf. Proc., p. 52.

Broadbent, F. E. and T. Nakashima. 1970. Nitrogen immobilization of flooded soils. Soil Sci. Soc. Amer. Proc. 34:218-221.

Burkhardt, T. H., R. A. Kepner and J. E. Miller, Jr. 1975. Management of rice straw by soil incorporation. Trans. ASAE 18(3):434-438, 443.

Kuo, S. and D. S. Mikkelsen. 1981. The effects of straw and sulfate amendments and temperature on sulfide production in two flooded soils. Soil Science (in press).

Mikkelsen, D. S. and W. H. Patrick, Jr. 1968. Fertilizer Use on Rice in Changing Patterns in Fertilizer Use. pg. 403-432. Soil Science Society of America, Madison, Wisconsin.

Pal, D. and F. E. Broadbent. 1975a. Influence of moisture on rice straw decomposition in soils. Proc. Soil Sci. Soc. Amer. 39(1)59-63.

Pal, D. and F. E. Broadbent. 1975b. Kinetics of rice straw decomposition in soils. J. Environ. Qual. 4(2):256-260.

Pal, D., F. E. Broadbent and D. S. Mikkelsen. 1975c. Influence of temperature on the kinetics of rice straw decomposition in soils. Soil Sci. 120(6):442-449.

Patrick, W. H. Jr., and D. S. Mikkelsen. 1971. Plant Nutrient Behavior in Flooded Soils in Fertilizer Technology and Use. p. 187-215. Soil Science Soc. America, Madison, Wisconsin.

Rao, D. N. and D. S. Mikkelsen. 1977a. Effect of rice straw additions on production of organic acids in flooded soils. Plant and Soil 47(2)303-311.

Rao, D. N. and D. S. Mikkelsen. 1977b. Effects of CO_2, CH_4 and N_2 on the growth and nutrition of rice seedlings. Plant and Soil 47(2):313-322.

Sain, P. and F. E. Broadbent. 1975. Moisture absorption, mold growth and decomposition of rice straw at different relative humidities. Agron. J. 67(6):759-762.

Sain, P. and F. E. Broadbent. 1977. Decomposition of rice straw in soils affected by some management factors. J. Envir. Qual. 6(1): 96-100.

Webster, R. K. and W. W. Bockus. 1978. Effects of various methods of rice straw disposal on the epidemiology of rice stem rot. Calif. Air Resource Board Contract A6-138-30. p. 1-32.

Williams, W. A., D. S. Mikkelsen, K. E. Mueller and J. E. Ruckman. 1968. Nitrogen immobilization by rice straw incorporation in lowland rice production. Plant and Soil 28(1):49-60.

Publications and Reports

A review of the world literature concerned with soil incorporation of rice straw as an alternative to burning was completed and is being prepared for distribution to the Rice Research Board.

As a follow-up on the literature review, a second study is being prepared on the potential for rice straw incorporation under California soil and climatic conditions, the possible impact of straw incorporation on rice production and the possible use of crop rotations or alternate cropping to alleviate the rice straw disposal problem. This follow-up report, not funded by the Rice Research Board, will be submitted for publication and distribution to the public.