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Alternative Uses of Rice-Straw in California

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OVERVIEW: RICE STRAW AND THE ENVIRONMENT

Interconnectedness and complexity are the hallmarks of almost every environmental problem and opportunity including the challenge of rice straw management in California. Although attempts are often made to solve environmental problems by working on single aspects, this rarely works, just as treating symptoms may do little to resolve diseases. The rice straw problem includes the physical systems of the atmosphere, air basins, soils, and local and regional watersheds, and reaches the global scale with concern over atmospheric contribution of methane and implications for global warming. It includes the biological systems of the rice crop, soil organisms, crop pests, and wildlife (both beneficial and harmful). And finally, it includes the economic and social systems of the rice growers, farm families, farm service industries, rural communities, the regional population, rice consumers around the world, fishermen and women, hunters, manufacturers of harvesting equipment, medical services, and potentially, builders and home buyers in the region. Complex linkages between the physical, biological and social systems are well illustrated in the rice straw problem, and like most problems these complex interactions make finding solutions challenging. They also can make it possible to find win-win solutions where multiple parties benefit from improvements in management strategies.

<u>An outline of the rice straw burning problem</u>

Rice production has become an important economic activity in California and in a typical year 400,000 acres of rice are planted (almost 500,000 in 1994). From two to three tons of straw are left per acre after the grain is harvested. The traditional grower practice has been to burn the residue. This is inexpensive, as little as $3 acre, and provides added benefits of reducing weed problems and more critically minimizing rice stem rot and other rice diseases. In recent years 75-135,000 tons tons of rice straw out of a total of 1-1.5 million tons produced on 300-400,000 acres have been burned in the fields in the fall. Over the entire year total amount burned can be two to three times as much. The rice straw burning in the fall is spread over a period of weeks or months and is regulated to discourage burning when meteorological conditions are likely to lead to smoke accumulation. Yet even under this careful control the smoke can cause health and safety problems, including asthma, allergies, bronchitis, and respiratory distress. Smoke can also contribute to highway accidents. No detailed epidemiological work-up has been done on the health costs associated with rice straw burning.

Health risks are minor due to burning management, but may be significant locally near burns. These risks include exposure to the various gasses (notably carbon monoxide and nitrous oxides) and particles created by recombination of gasses, ash, and dust raised from the soil surface. These include known carcinogens and mutagens, gasses that are hazardous or lethal at high concentrations, and a range of potentially harmful particles and byproducts of burning. These pollutants and other more dangerous materials are also generated by using firewood to heat homes, automobiles, and wild land and forest fires. Rice straw burning is a contributor, but other sources are more important on a regional basis. Concern has grown recently over the danger posed by small particles (less than 10 microns, PM<10, and more critically particles <2.5 microns). Health studies in other areas have showed a clear relationship between increased particulate levels and increased mortality. Silica content of rice straw is high and the silica rich ash particles may pose a slightly higher risk than other types of ash, but the organic condensates on these particles may be of more concern and would be similar for other types of straw burning. More detailed studies are needed to accurately assess health risks.

Rice straw burning and soil incorporation have global environmental risk implications. The carbon content of rice straw is about 40%, and the burning of 500,000 tons of rice straw may return 200,000 tons of carbon into the atmosphere. This carbon is fixed during the growing season by photosynthesis and there is little net gain. If the straw is incorporated in the soil it increases methane emissions, which are more damaging than the byproducts of burning. Methane is a special concern for global warming, because each methane molecule has 20-25 times the heat capturing potential of a carbon dioxide molecule. Even allowing for the lower level of emissions, the net impact on global warming would be 10-15 times worse than the effects of carbon dioxide from field burning. The use of rice straw for other purposes that would store or sequester carbon would decrease emissions and reduce global warming risks.

The obvious problems associated with rice smoke led to restrictions on burning beginning in 1971 under provisions of the Health and Safety Code, these were revised and made more flexible in the early 1980s. Sacramento Executive Airport records show smoky conditions 24% of the time in October-November in many years, although with restrictions in burning this dropped to less than 4% of the time in October-November, 1990. Current restrictions base allowable burn acres on atmospheric conditions. Predictions of weather conditions and measurements of particulate levels are used by the Air Resources Board to set allowable burn times and amounts. The specific allowable burns are made by the air pollution control districts or their agents. In 1991 an act was passed to phase down rice straw burning by 2000, with the exception of burning essential for disease control.

This has led to increased analysis of options for rice straw management; including field studies by the University of California, this review of uses of rice straw by the Renewable Energy Institute at Cal Poly San Luis Obispo, and many other reports and studies for the Air Resources Board. The University of California studies showed that the economic cost of incorporating straw was high, ranging from \$7 to \$80 per acre. A complete burn ban and change in management practices could increase growers costs millions of dollars each year. The added cost would be accompanied by increased risk of rice disease buildup and potential damage to crops from methane generated by straw decomposition in the wet soil. These problems have led to an effort to find uses for rice straw that would remove straw from the field and add value to the material.

Global annual methane emissions from rice fields are a major source estimated at as much as 150 million tons, more than the net annual increase in atmospheric methane (see also addendum on methane). Methane production from rice soils is limited if straw levels are low. When rice straw is added to the soil, methane emissions increase 3 to 12 times, with larger ʾissions when straw is added deeper in the soil. Annual emissions can be correlated with ˌdily mineralizable carbon in soils before flooding. The potential plowdown of straw and flooding of fields for waterfowl would probably generate the most methane.

For the 400,000 acres of rice grown in California current methane generation may exceed 50,000 tons per year. If emissions triple from increasing straw soil incorporation instead of burning this could increase 100,000 tons or more. Although this remains only a tenth of a percent of the global total, this is still significant. As organic matter builds up methane emissions would increase. Anecdotal stories from rice growers suggest increased methane "poisoning" of crops can occur after 3-4 years of plowdown. To offset nitrogen tie-up from straw more nitrogen fertilizer may be needed, but this has also been found to increase methane generation.

The use of non-renewable fuels would also increase as much as 2 gallons per acre for the plowdown, a total of 300-400,000 gallons for the plowdown. But it is likely the health risks in the region would be lower if burning was eliminated.

Solutions

The most environmentally acceptable solution is probably straw harvest and removal. This can reduce methane production, minimize health risks from burning, protect crops from disease carryover and limit risks to global ecosystems. If the straw crop is sequestered it may become a meaningful carbon sink.

The challenge is developing a series of markets and uses for the rice straw to offset harvesting costs. Promising options identified in the Renewable Energy Institute Cal Poly ıdy include: environmental use for erosion control and dust management, use of straw in mushroom production, straw use in biocomposite materials (i.e. straw panels and structural members made with rice straw and cement or plastics), and use in straw bale buildings. There may also be opportunities in paper production for some types of paper and fiberboard. Other options, not discussed in this report, include ethanol production and treatment to make the straw useful as animal fodder.

The use of straw bales in building is increasing rapidly across the country and in California, including a winery and architect's office in San Luis Obispo, walls of a retail center in Hopland, a mine storage building in San Bernadino County, and homes in Mendocino, San Luis Obispo, Contra Costa, and Inyo Counties. Many more projects including some commercial projects are underway and will be completed this year. Assembly Bill 1314 encouraging straw bale construction passed and was signed by Governor Wilson. This bill encourages local building departments to adopt straw bale building codes. Several counties adopted straw bale building codes in early 1996, including, Napa, Yolo, and Glenn counties. A straw bale sound control wall is slated for testing near Dunnigan.

The state of New Mexico, Pima County and the City of Tucson in Arizona have also developed codes and straw bale buildings are no longer considered unusual. Straw bale building has spread quickly across the United States and around the world and many hundreds of buildings are now in place. The primary markets have been for low cost owner built homes and expensive custom homes, including a 9,000 square foot home currently under construction in Santa Fe that used 4,400 bales.

Many of these alternative uses have potential but will take additional research and time to develop straw harvesting systems and improving markets. Rice straw disposal (incorporation v/s field burning v/s removal) illustrates the importance of reviewing systems implications of policy rather than simply focusing on single-issues. The limited data on many aspects of the rice straw system is also common to most complex environmental problems. If epidemiological studies had been done sooner and more completely the impetus for change would have been stronger and more emphatic. If the full range of impacts and opportunities had been reviewed, perhaps as part of a policy environmental assessment, a more complete picture of policy options and risks could have been developed. If government subsidies for timber harvest were removed the use of biocomposites would increase.

The challenge of rice straw management also illustrates equity problems common to many global resource issues. Although the growers have been forced to change practices to protect the health of the regional population by reducing smoke, the global considerations of methane and carbon emissions to the atmosphere have been ignored. Because these have been neglected alternative consumptive uses have been given limited attention. Reducing emissions from rice straw burning may be much more economical than limiting emissions from other sources, and provide more business opportunities.

Providing the money to improve rice straw utilization should come from a carbon emission fee for agricultural burning (rice straw is not the only source), perhaps beginning with a $3 per ton fee starting in 1996 rising to $6 ton in 2001. Similar charges have proved effective in Europe. One third of this should be allocated for a detailed assessment of respiratory illness epidemiology and costs in the valley. One third would be devoted to improving straw system harvesting and the remaining money would fund a competitive research and demonstration program for alternative uses of rice straw and rice hull ash. This section might provide the money needed to operate research, education, training and business incubation projects such as the Envirosave Research and Training Value Added Technology Center in Redding.

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POTENTIAL USE OF RICE STRAW IN COMPOSITE MATERIALS

Composite materials combine more than one material or substance, most commonly a matrix material and reinforcing fibers. The fiber and the matrix will act together if a good bond exists between the resin and the fiber. As loads increase some fibers will reach their breaking points first, and loads will be transferred to other unbroken fibers in a progressive failure, rather than a simultaneous break. Composites can be extremely strong and are also very flexible for manufacturing processes. The development of higher working stresses is largely a question of devising fabrication techniques to make fibers work together to obtain their maximum strength (Parratt, 1972).

Composites have long been used in airplanes and defense, but are gradually making inroads in the automobile industry. Race car builders have long recognized the weight and strength advantages and advanced composites are now extensively used in Formula 1 racing and exotic cars. The 2,380 pound, 854 hp Lotec C1000 (Anon, 1994b) and the 2,425 pound, 627 hp McLaren F1 sports car (Frere, 1994) demonstrate what can be done with composites. The McLaren survived a 30 mph barrier crash test with no structural damage.

In 1993 Amory Lovins suggested that super-efficient, light weight composite cars built with aerospace technology would soon exceed 200 mile per gallon. It happened sooner than he expected when a super car built by students at Western Washington University exceeded 0 mpg equivalent in tests in Los Angeles in 1994. He believes (1994) that hybrid drive ystems and components will be sold to local manufacturers, much like current computer clone makers, who could build a car to order in a matter of days out of composite materials.

Glass fibers have been the most common reinforcing materials for composites, but these pose health and environmental problems for disposal and require high energy inputs for manufacturing. More recently higher strength graphite, carbon, and boron fibers have been introduced in manufacturing of consumer items such as golf clubs, bicycle frames, and kit airplanes. Biological fibers and natural or synthetic matrix materials can be used to make composites that are environmentally friendly and strong. Glass fiber reinforced asphalt shingles for example are one of the predominant building wastes hauled to land fills. Every year enough asphalt shingles are thrown away to cover Lake Tahoe. Flax fibers have been replaced glass-fiber in roofing in parts of Europe. Rice straw fibers and stems, which are resistant to decomposition as a result of their high silica content, to 14%, (Walker, nd) and have a relatively high coefficient of friction (Usrey et al., 1992), may also prove suitable.

Plant cell walls and plant structures are natural composite materials with regular arrangement of reinforcing materials (Niklas, 1992). Evolution over millions of years has optimized structural design in many plant structures. Wood is a complex composite material, a fiber reinforced structural foam. It is extensively used and recognized as a structural material, but many other plant components are excellent raw materials for fabricating materials, structures, tools, and equipment. As the price of wood continues to climb, environmental problems with disposal of plastics and glass fiber reinforced materials increase, and the need for developing a market for agricultural fibers including rice straw (as field burning is curtailed), composites will begin to receive long overdue attention. Plant fibers can also be combined with recycled plastic to make a wide range of products.

Plant fibers can be surprisingly strong, Table 1, lightweight and inexpensive. They are more competitive with manufactured fibers than most engineers and manufacturers realize. They are attractive because they have chemically reactive surfaces which make more complete fiber-matrix bonding possible (Bolton, 1991). They can have a high work of fracture, a grass leaf was 4 times tougher than 2024-T6 aluminum (Vincent, 1982; Atkins and Mai, 1985).

Composites using natural fiber should prove safer to handle and work with and more environmentally friendly. Many biocomposite materials can be recycled (composted or digested) or burned, without the residues that are left with glass and carbon fiber composites. Plant fibers can be produced by sustainable agricultural systems (Mitchell and Bainbridge, 1991), with low embodied energy and atmospheric carbon rather than mined "carbon" from petroleum or coal.

Table 1. Specific tensile strength (strength on a weight basis)

Material	MPa
Biofibers	
flax ∂#	73.3-160
coir π	107-173
rice straw Δ	105-193
Annealed aluminum ø	21
Steel ∂	25
Fibers	
carbon #	171
graphite, intermediate †	142
e-glass †	136

† Rosato et al., 1991; ø Niklas, 1992; π Balaguru and Shah, 1992; ∂ Stamm, 1964; # Bolton, 1993, Δ Usrey et al., 1992. Measurements are not all similar tests. Density was estimated where it was not stated.

The mechanical properties of fiber reinforced composites can be predicted and controlled by selecting and specifying matrix material and reinforcing fiber composition and orientation. Virtually any shape can be produced, from simple building materials, to structural angles, channels, I and V beams, and complex moldings and shapes. A new V shaped joist is being manufactured with OSB panels (Wardell, 1995). A similar product could be made with rice straw board.

Reinforcement fiber and form (chopped, felted, woven, braided, etc.) will depend on the performance requirements. Reinforcement-to-matrix material ratios can also be varied to maintain desired weight and strength. Natural fibers may require pretreatment to ensure maximum performance, key issues include selecting matrix materials compatible with the fiber and pretreating or protecting fibers during handling and processing.

Woven fabrics, and expanded fibers may also be of interest. Unwoven reinforcing, including felts and paper, may be effective and economical. Combinations of different fibers (rice and flax for example) may prove desirable. Combinations of different fibers and fabrics can facilitate molding of complex shapes.

While much work on plant fibers has focused on the cellular level and small fragments, there are many advantages from using longer stems and leaves. Longer fibers may help optimize mechanical properties. Natural fibers can be quite long, with individual cells of up to 2.5 cm for flax, and flax line fibers to 900 mm (Gilbertson, 1993). Rice straw could be provided in 50 cm lengths. Stems can be slit or sliced to (rice and flax for example) may prove desirable. Combinations of different fibers and fabrics can facilitate molding of complex shapes.

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Composites with cementitious materials

More work has been done with composites made with natural fibers and cementitious matrixes than with manufactured or biological resins. Fiber reinforced concrete can be substituted for many wood and timber uses as well as sheet and roofing components. The most appropriate matrix materials are pozzolanas, including rice hull ash, which is up to 93% reactive silica by weight. This high silica content makes rice hull ash an excellent pozzolana (Stulz and Mukerji, 1988). Rice hulls needs to be burned at less than 700°C to remain amorphous and most desirable for pozzolana. Pozzolanas can be used to replace up to 30% of Portland cement without significantly reducing long term strength. Rice hull ash and 30-50% of hydrated lime can be used to make a hydraulic binder known as Ashmoh (RCTT, 1979). Rice hull ash also appears promising in manufacturing refractory or light weight brick silicate materials (Roberts, 1973).

Fiber reinforced cement is regarded as one of if not the most promising roofing materials, and can be produced at low cost, $2-4 per square meter (Stulz and Mukerji, 1988; Gram et al., 1986). Mechanically compacted fiber reinforced concrete contains one part cement, 3-6 parts sand and 1-2% fiber by weight. Pozzolanas are the best binder as they reduced alkalinity improves strength and durability.

Natural fiber reinforced cement roofing is produced as tiles, pantiles, troughs or corrugated sheets (Beck et al., 1987; Evans, 1986; Gram et al., 1984; Gram et al., 1986; Lola, 1985; Parry, 1985). Small beads of wax can be incorporated in the mix, which melts over time and seals the roofing (Gram et al., 1984). Companies including American Cem-Wood (shakes); Eternit (slates, panels); and Fibre-Cem (slates) use cellulose or wood fiber and cement to make roofing (Loken et al., 1994). A draft standard for natural fiber-cement roofing was developed in Sweden (Johansson, 1984).

Straw can be combined with cementitious materials to make building panels. Research in Sweden has refined a method of making cement-bonded straw panels (Hermansson, 1993). Panel density can be adjusted by changing the straw-cement ratio and compression to meet goals for insulation value and strength. Typical panels tested were 90cm x 60cm, 6 cm. Researchers found that soaking straw in a 5% solution of CaCl for 24 hours before fabrication improved performance. Estimated material cost was about $2.80 per square meter for a 10 cm thick panel with a density of 300 kg/m^3.

Straw and rice hulls can also be used to reinforce building block and clay products. INSUL HOLZ-BENSON has introduced the FASWALL system of insulated concrete to the ited States. These plant fiber based concrete products are lightweight, have R-values of 11+, can be cut with simple carpenters tools, and can provide construction labor savings of 20% (Midwest Faswall, 1993). Similar products are being developed or manufactured by others including, Hydromix, based in Boulder, Colorado.

Straw has also been combined with building materials to make Strawcrete which has been manufactured and used in Essex England for many years (Edwards, 1993). Straw cement can also be combined to make a easily worked or molded material that is fireproof (Babic, 1993).

Combining rice straw with foamed cement or similar binders may provide high strength, lightweight materials for a wide range of building purposes. Cement can be foamed with a range of organic and inorganic additives. It may be possible to make structural components with fiber reinforced foamed cement,

Straw has long been combined with clay to make insulating infill in the traditional German building method known as *leichtehmbau*.. Ten inch lengths of straw are dipped in a thin clay slurry and packed in wall forms. This fire-resistant, insulating, and environmentally responsible wall system has been used in homes in Texas (Fisk, 1990; Gibson, 1993) and Mexico.

Composites with manufactured resins and materials

Practically all thermoset TS and thermoplastics TP can be used in composites. Glass fiber-reinforced resins were first popularized in the 1950s (outgrowth of the war). Glass fiber and TS polyester combinations currently dominate the market. Other glues and binders can o be used. Building boards made with straw are feasible and are being explored in many areas. Pheno-formaldehyde resins have been used to make fiberboard with rice hulls and cereal straw (Eakin et al., 1982), but rice straw was not tested. Recycled post consumer and phenolic resin board was stronger than wood (Bixby, 1993), and a mixture including rice straw should be tested. Some rice straw is already incorporated in building board in California. Rice straw and wood chips were used to make a medium density fiber-board, but the rice straw was difficult to work with (Report to Rice Growers, 1984). Gridcore™, a pressed fiber panel system (Acello, 1993) would also be a good candidate for rice straw fiber.

Polyester resins can work well with natural fibers. Cotton, linen, and other fibers and polyester resin have been used to build and resurface boats. Work on plastic composites with other natural fibers, including bamboo, may provide useful information (Jain et al., 1993). Scientists at the Biocomposites Center in Wales have found that isocyanates and straw make an exceptionally water resistant fiber (Edwards, 1993).

Composites with recycled plastics

Composites made with rice straw fiber and recycled plastics are perhaps the most promising biocomposite and should be emphasized. Combinations of plant fibers and recycled plastic can make suitable composite materials for many uses. Despite glowing promises in the late 1980's the plastic industry has been unable or unwilling to develop recycling programs for many plastics (Kleiner and Dutton, 1994). While some progress has been made on PET (24% recycled), recycling of LD and LLD polyethylene (0.7%), HD polyethylene (5%), PVC (0.2%), PP (3%), and PS/HIPs (0.8%) is so low it be considered non-existent. More than 11 billion pounds of LD and LLD polyethylene are produced each year, and 8 billion pounds of HDPE and PVC.

Composites of biological fiber and recycled plastic may become important building materials. The Agronomic Systems process uses 70% biofiber and 30% recycled plastic to make a material they call Biocomp. A successful pilot run was made with rice straw from Sutter County. A package plant would utilize 14,000 tons per year.

Recycled plastic "lumber" is becoming more readily available, now manufactured by 30 companies nationwide, with at least 2 in California (California Recycling, Pico Rivera; Durapost, Eagle Recycled, Anaheim). While this plastic "lumber" has many desirable features, waterproof, durable, etc. its use is limited by the high density, which makes it awkward to carry and handle, the slick surfaces, lower strength and a higher coefficient of thermal expansion. TREX, for example, is twice as heavy as wood and can only span 80% of the distance of wood on a deck (Chapdelain, 1994). Combining recycled plastic with rice straw or processed rice straw fiber in the core and in lesser amounts in the matrix could bring density down closer to wood, increase strength, reduce thermal expansion, and provide texture against slipping. .

The composition of straw is similar to wood, Table 2, and the combination should be similar to the mixes developed for plastic and wood fiber (Raj and Kokta, 1991; Maldas and Kokta, 1989; Maldas and Kokta, 1990).

Table 2. Chemical composition in percent

	Cellulose	Hemicellulose	Lignin
Rice straw[1,2]	35	18.7	6-18.5
Wheat[3]	33-40	24-28	10-17
Softwood[3]	40-45	15-20	23-33

[1] Gerber and Van Sacon, 1991; [2] Chawla, 1993; [3] Robson, 1993.

Capturing even a small part of the market would create a very large demand for rice straw. Rice straw and recycled plastic could be used to make studs, headers, and paneling for shipment throughout the west. Because the plastic is being recycled into a building material rather than a food contact product the difficulties in cleaning the waste stream would be minimized.

Biocomposites

Biocomposites are a special class of composites combining natural fibers and natural resins. Natural biocomposites can be exceptionally strong, as anyone who has attempted to open a macadamia (*Macadamia ternifolia*) nut can attest. Macadamia nuts are as hard as annealed aluminum yet resist twice the force for fracture (Niklas, 1992). Many other biocomposites are very strong and resin selections can be made for ultimate strength, elastic modulus, fracture resistance or impact resistance.

Plant cell walls are composites of cellulose, hemicellulose (polysaccharides) and lignin (polyaromatic networks). The reactive hydroxyl groups on the polysaccharides provide a framework from which a wide range of polymers can be built (Bolton, 1993). Polysaccharides may be selected to meet both product and processing demands. Varying degrees of plasticity and biodegradability can be engineered in.

Straw can be compressed and heated to 280°C in a press to make a strong building panel without additives or adhesives. This process was invented in 1935 in Sweden by T. Dieden (Hermanusson, 1993). Stramit Industries in England makes a 5.8 cm thick, 120 cm wide panel in seven lengths, from 227-240 cm. These paper covered panels for interior partition walls have been used in 300,000 structures in England. The production of these panels uses 8,000 tons of straw a year, primarily wheat although rye is preferred and barley is acceptable (Stramit, 1993). An attempt to develop this system was started in Roseville in the 1980's and some material was manufactured, but the company was unable to develop a sufficient market. A company in southern California, Pyramod, intends to use a similar system to manufacture a pyramidal roof system.

Particle Compacting Development (PACO, Ltd.) has developed a method of turning straw into a natural plastic. High lignin content feedstock enables straw to be fabricated into car body components through molding, extrusion, and roll-form extrusion (Edwards, 1993).

Rice straw can be used to make cellulose acetate (McGee, 1980). Cellulose acetate is noted for its attractive appearance, toughness and strength (Rosato et al., 1991). Many other cellulosics and building blocks for industrial material can be extracted from rice straw by biological or chemical processes. Rice straw may also serve as an incubator or feed source for bacterial production of other biomaterials. Work on spider webs, which are super high strength (5x steel, 30 percent more flexible than nylon, 3 times impact strength of Kevlar) is progressing and it is likely these can be manufactured by bacteria in the near future (Graham, 1994). Mustard plants genetically altered to create plastic have been created at the Carnegie Institute for Plant Biology in Palo Alto.

The movement of the biotechnology industry into materials will be one of the hallmarks of the next decade. Biomedical development has been disappointing as a result of the complexity of development and testing medical products. Developing resins for composites will be much easier.

<u>Barriers to use of rice straw fibers in composite materials</u>

The obstacles to widespread use include:

1) ignorance of fiber properties and use, specialization and lack of systems training for engineers involved in manufacturing and research
2) lack of technical materials and <u>readily</u> available reference data
3) limited availability of cleaned, prepared fibers and woven or spun fabric and threads, without the lubricants used to facilitate spinning and weaving
4) limited data on straw harvest and processing
5) compatibility of fibers with matrix materials

6) potential plant cell wall swelling from water uptake by extensive hydroxyl groups.
7) potential reaction with alkalinity in cementitous matrix materials

Removing barriers

1,2. Education and development of technical materials

Technical materials should be collated, compiled and disseminated on paper and in electronic form. This should be done as part of a project to identify key research questions, information gaps, and opportunities. This will help stimulate interest in area colleges and industry.

The defense industry has trained many composite designers, fabricators, and manufacturers. These may well form the nucleus for a biofiber composite revolution. However, these individuals and companies need technical information and support on biofibers and bioresins. While much is already known, additional research is needed.

A biocomposite center should be set up at a local community college, UC Davis. In addition testing programs should be started at UC Berkeley and Cal Poly SLO. The Envirosave Value Added Technical Center proposed for Shasta College (Redding) is right on target for this work (Pennington and Justice, 1995). The community college composite center in the Los Angeles area is worth reviewing. A private rice straw center should also be created to speed implementation.

A competitive grants project for independent research and manufacturing should be established. A competition with substantial prizes for best development of rice fiber based products should be held. This could include student, farmer, and manufacturing divisions. Funding of at least a million dollars a year with priority on rice straw fiber utilization, this might be provided from air pollution credit or carbon tax payments.

3,4. Fiber production and fabric availability

Availability of clean rice straw fiber is primarily a matter of demand. The transition from combines to stripper headers, which leave a longer stem in the field, should make it much easier to obtain clean, long oriented fibers . It is also possible to obtain clean oriented fiber with binder reapers. The equipment for separating, cleaning and processing fibers is improving from year to year and should not prove a serious obstacle.

5. The wax of the cuticle can be removed in processing with solvents, or the resin or plastic may be compounded in a manner that will minimize problems. Woven and spun materials can usually be prepared by washing and rinsing. Weathering can also improve liquid flow into woven and spun materials. Fiber treatment for good coupling may also require additional research. The challenge appears to be developing an appropriate interphase to get good bonding (Garnier, 1993). Quillin (1993) found that stearic acid was once of the best surface modifiers.

6. Past attempts to prevent fiber swelling problems focused on reacting the fiber hydroxyl groups with monofunctional reagents (Bolton, 1993). This can make the modified fiber surfaces more difficult to 'wet' with matrix materials, and can result in the modified fiber and

resulting composite being weaker. Improved water resistance and bonding may result if difunctional reagents and methods of controlling reagent reaction can eliminate the fiber droxyl groups and form strong (primary valence) bonds with organic matrix materials.

7. The protection of straw fibers from alkalinity has been addressed in various research projects. One of the most effective methods appears to be presoaking and pretreatment. Calcium chloride has given good results with wheat straw (). Shah (1993) found that thin cement reinforced with recycled fiber had good flexural strength, stability and density and had the best initial lifecycle cost v/s commercial available materials.

Summary and conclusion

The potential economic benefits of using rice straw fibers in farming areas beset with economic and environmental problems cannot be underestimated. This is in many ways a new frontier and calls upon the talents and skills of engineers, chemists, botanists, biologists, agronomists, and ecologists. Integrated whole system development will be essential to recognize the full potential of these materials.

With appropriate attention to the opportunities in biological fibers and "natural" resins the transition to safer and environmentally friendly biocomposites can be made. Bioengineering should make it possible to grow plastic resins and reinforcing materials economically and safely. These materials can be used to make lighter, stronger and more durable products that save resources and energy. Long life and eventual recycling can be engineered into these products.

Integrating uses in a straw utilization complex, "Straw Town", would benefit producers and rice growers. Combined use can also create a critical mass to make rice straw harvest, collection, and storage practical. Rice straw harvesters like the two straw harvesting companies working in England, which both handle about 200,000 tons a year, could develop to feed these facilities. While independent companies might be marginal or non-economic, integrating uses could make them all profitable, and minimize waste streams.

For example, an energy facility can provide electricity and steam for construction material fabrication and production. The pozzolanic rice hull ash can be combined with straw fiber to make durable roofing tiles, sheets, and slates. Energy will also be needed to run a straw bioplastic production facility. And fiber can be mixed with recycled plastic to make lumber and panels. Recycled wood fiber could be combined with rice straw fiber 50/50 to make cardboard and paper. Closing the circle will be an essential part of business in the next Century.

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Potential uses of rice straw for environmental mitigation and on farm use

The market for rice straw for environmental uses is one of the easiest to enter and could absorb large quantities of straw with little change in policy. Uses include: rice straw for erosion control, rice straw for soil improvement and water retention, weed suppression, and site restoration. Many of these uses overlap with agricultural uses.

Rice straw for water erosion control

Rice straw has excellent potential for use in erosion control in the form of mulches. The use of straw mulch to prevent erosion has become a standard acceptable practice over the past several years. Straw mulch protects a site from erosion until plants are established. It also conserves moisture, moderates soil temperature, holds fertilizer (if used), absorbs the impact of rainfall, and provides useful soil organic matter upon decomposition (Versteeg and Earley, 1982; Highfill, 1980). The use of straw as a mulch over wood fiber or other wood products has generally been viewed as providing better results in both site protection and plant encouragement and is much more cost efficient (Jennings & Jarrett, 1984,1985; MacCaskill, 1978; Ross et al., 1990). Gilley et al. (1977) reported that straw mulch reduced erosion of topsoil by over 90%. Rice straw is preferred for many uses because it is less likely to incorporate dry land adapted weed species (OWPS, 1975).

Straw mulch is normally applied at a rate of 2-4 tons per acre. Application can be made by hand or with a mechanical blower. Straw must be anchored into the soil to prevent it from being blown away. This can be accomplished through crimping, disking, rolling or punching it into the soil; by covering it with netting (preferably a biodegradable netting such as coir or jute); or by spraying with a fiber binder (tackifier). Though the use of a glue or tackifier is common in the east, the California Department of Transportation normally uses a roller or puncher to anchor straw mulch on slopes along California's highways.

Tests comparing the costs and effectiveness of numerous erosion control methods were conducted by Burgess Kay at the University of California at Davis (Kay, 1984). A treatment of broadcast seed with a straw mulch applied by blower at 3,000 lb/acre and anchored with 300 lb/acre wood fiber and 60 lb/acre organic binder was the most cost effective at about $1000/acre ($2500/ha) in 1984 dollars (Goldman et al., 1986).

The use of straw wattles for erosion control on steep slopes has come into use over the past several years. These wattles are normally in the form of a nine inch diameter tube that is about twenty-five feet long and weighs approximately thirty pounds. Straw wattles are placed at selected intervals along the face of the slope and pinned in place. Wattles are excellent in slowing runoff, capturing sediment and promoting revegetation. The United States Forest Service presently uses straw wattles for erosion control in burned or other degraded areas.

Vertical mulching, or placing rice straw vertically in the soil may be especially effective for treating problem areas (Bainbridge, 1994). This method provides many benefits, including: slowing water movement; providing open channels for water penetration into the deep soil; safe sites for seeds to catch and sprout; wind breaks to trap seeds and dust; shade and cover for seedlings; and a source of below-ground organic matter to help return the soil ecosystem to health. Experiments have showed that vertical mulch can increase soil moisture storage substantially >20%, (Fairbourn, 1975; Bainbridge, 1995).

An additional benefit to the use of straw mulch as an erosion control method has been outlined by Mostaghimi et al. (1994). Their investigation centered on the effectiveness of different combinations of straw mulch, hydroseed and commercial synthetic polymers in controlling erosion. Results demonstrated that straw mulch not only was best for controlling sediment runoff, but that straw mulch was the most effective technique for reducing both phosphorus and nitrogen losses from the soil. The retention of nutrients is important for forest and agriculture, fisheries and water managers, and water pollution control agencies. The ability of rice straw to help retain nutrients is an excellent selling point.

Barriers and Incentives

Codes and regulations to reduce erosion already require straw mulch in many jurisdictions. California State Parks Department has favored rice straw for many projects and use could be further encouraged on state lands through policy and regulation. Modification to require or encourage the use of rice straw locally on Federal Highways, State Highways and construction projects would increase the market share. The California Department of Transportation manages 230,000 acres of right of way in the state. If 5% were treated each year, 50,000 tons of straw could be utilized annually. It is desirable for straw used for such purposes on or near critical habitats be weed free.

Sediment traps

Despite the best efforts to reduce erosion, some erosion is inevitable and the impacts of erosion are serious and costly throughout California. Rice straw can be used not only for preventive erosion measures, as described above, but also in the reduction of soil loss through erosion that may occur when no preventive measures are implemented or prove inadequate due to high intensity storms. Rice straw bales can be used in the construction of sediment retention structures.

Sediment retention structures do not stop erosion, but trap eroded soil before it can reach a body of water, block culverts and drains, or be dispersed from the original property. As such, sediment retention should be used as a back-up system to erosion prevention systems or until such permanent measures such as landscaping have been accomplished.

Sediment retention structures work by slowing the runoff velocity to allow suspended particles to settle by gravity. Sediment retention structures rarely trap 100% of the runoff sediment, but a 50-75% removal efficiency is acceptable. Straw bales have been shown to provide this level of performance as sediment retention barriers, traps and basins.

The use of straw bales as sediment retention barriers for small areas (i.e. several acres or less) has proven to be both successful and inexpensive (Highfill, 1980). A straw bale barrier can be used to prevent sheet flow or channel flow runoff along exposed slope faces; along the base of a slope; along small drainage ways; and near storm drain inlets. Straw bale barriers are usually best used for slopes with a maximum gradient of 2:1 and a maximum length of 100 ft. or across a small swale where the barrier receives no more than 1 ft^3/sec flow. When a straw bale barrier is constructed, bales should be inserted into the soil approximately 4-6 inches for stability and pinned with two pins per bale. Barriers made of more degradable straw bales have an average life span of about 3-6 months (Goldman et al., 1986), but rice straw bales may last several years in the dry areas of the state. At a restoration site at Red Rock canyon State Park straw bales have lasted for three years.

Straw bales can also be used as check dams (Bogovich, 1992; Miles et al., 1989). A check dam is used to prevent channel erosion by slowing the velocity of the flow. Check dams are used in situations of greater expected flow than sediment barriers and are constructed in a similar fashion to straw bales sediment barriers but with a sturdier construction (i.e. heavier pinning) and a downstream apron to prevent undercutting.

Straw bales are also used for sediment basins and traps (Secor, 1977). A straw bale sediment trap is constructed by placing a line of bales, two or three bales high, in much the same manner as a straw bale sediment barrier. The straw bales must be supported by a wire fence with outlet sections provided to relieve water pressure. Normally a straw bale trap can accommodate a 3-5 acre drainage area and has a life span similar to a straw bale sediment barrier.

A secondary result of straw bale basins and traps is the filtration that occurs as water passes through the straw bales. In situations where water supplies may be polluted through excessive sediment (i.e. fire, flood), straw bale barriers, traps and basins not only capture the sediment, but provide initial filtration of watershed runoff before water enters a reservoir or settling pond. This provides an inexpensive means to avoid costly dredging and drain clearing operations (Miles et al., 1989; Versteeg & Earley, 1982).

Barriers and Incentives

No simple technical guide is available, although various books and articles describe different approaches. Further development of reinforcement methods and apron/spillway designs are needed for straw bale dams for larger gullies and stream channels. Use of straw bale nutrient traps could benefit from field testing, funded by CalEPA, EPA, or the Dept. of Agriculture. Control of biocide runoff and decomposition byproducts should also be evaluated for crops with high pesticide loads. The nutrient traps provide additional opportunity for low-cost compost production.

Wind erosion control

Soil loss through wind related erosion is also a serious problem in many areas of California. This includes not only the loss of soil, but the resultant air pollution caused by airborne particulate matter and the health costs associated with this dust. Particulates are increasingly recognized as a health hazard (Dockery et al., 1993; Schenker, 1993). Particulate matter less than 10 microns in size is able to reach the smallest sections of the lung and is not cleared from these airways. These small particles may be among the most hazardous of all air pollution problems (Dockery et al. 1993).

Dust is also involved in the spread of disease. Valley Fever, which is endemic in parts of California, Arizona and New Mexico (Pappagianis 1988; Rippon 1988; CSDHS 1994), is an infection caused by the soil fungus *Coccidioides immitis.* (Pappagianis, 1988; Rippon, 1988). The arthroconidia, which are infectious, can become airborne in conjunction with dust and remain suspended in air for many hours or days. Dust control in agricultural regions could reduce costly infections and deaths caused by this disease.

Blowing dust has also caused many highway accidents in California. On Thanksgiving weekend, 1991, moderate winds (15-40 mph) caused severe dust and visibility problems on Interstate 5 in Fresno County resulting in a 164 vehicle pileup (Arax 1994). The first settlement with a woman severely burned in the accident cost the state of California $3.4 million dollars. A number of claims against the state still remain unresolved.

Abandoned agricultural land, active and fallowed agricultural land without windbreaks, urban and suburban development, road margins, pipelines, overgrazed range land, off-road vehicle operation, and water transfers all contribute to dust problems. Rice straw mulch and rice straw bale barriers can be used to prevent wind related erosion as well as water erosion.

Abandoned agriculture land is common in the drier parts of the state, including the South San Joaquin, Owens and Antelope Valleys. Particulates in the Antelope Valley exceeded the California 24 hour standard of 50 $\mu g/m^3$ of 10 micron particulates almost 10% of the time in 1992 (California Air Resources Board, 1993). Dust problems from abandoned farmland have also been exacerbated by sheep grazing (Pyle, 1991). Active farmland can also be a serious dust generator, with the state standard exceeded on 24 of 60 observations in Brawley (California Air Resources Board, 1993).

Diversion of water from the Owens Valley to Los Angeles has virtually dried up the once extensive Owens Lake, resulting what is considered to be the most severe dust problem in the nation (Roderick, 1989; Forstenzer, 1992). The winds through the valley now raise large clouds of dust that have caused particulate levels of up to 526 $\mu g/m^3$ in the town of Keeler (California Air Resources Board, 1993). Observations exceeded the State Standard almost 20% of the time. Particulate concentrations greater than 250 $\mu g/m^3$ have also occurred in Olancha and around Mono Lake, another lake affected by water diversion.

In areas with higher wind regimes, dust and sand can also become a physical problem, with drifts and dunes encroaching on highways, housing, farmland, crops, and developments. Removal of sand and dust is expensive and many parts of the state have experienced extensive crop damage from wind blown sand and gravel. Blowing dust and sand cause millions of dollars of damage to vehicles also.

Rice straw is ideal for dust control because it is fibrous, often longer length than wheat or other straws after baling, and highly durable. Dust control can use loose straw, straw flakes, or straw bales depending on goals and site conditions.

For long term dust management, soil loss could be lessened by constructing erosion barriers similar in form to the sediment traps mentioned above. Several barriers, 3-4 bales high and backed by a wire fence, could be constructed perpendicular to the prevailing winds across the dry lake, abandoned agricultural land, or roadside. Such barriers would decrease the wind velocity, reduce particulate matter uptake and also capture soil as the wind eddied around and over the barriers.

An important secondary effect of such a system would be the establishment of microsites for the re-establishment of vegetation. As the straw bales decomposed, the organic matter and nutrients from the bales would mix with the captured soil. These sites could either be seeded with a native seed mix or seeding could rely on the available seed bank from nearby vegetated areas.

The dust problems of Owens Lake are legendary and severe. The deposits on the dry lake basin are readily picked up by winds and carried in intense dust clouds to nearby towns. They are still in sufficient concentrations to be a health hazard more than 100 miles away. The area in and around Owens Lake and the Owens Valley is an example of an area that could profit tremendously from the construction of such barriers. The development of dust control strategies has been limited. Artificial dunes, irrigation and other schemes have been proposed--all would be very expensive. A series of rice bale fences 3-4 bales high, pinned with bamboo or backed by a wire fence, would provide dust control, retain rain and snow, and provide improved microsites for plant establishment. A pilot test on 160 acres is suggested. The bale fences would be 4-5 feet tall and spaced 75 feet apart. This project would require almost 3,200 tons of rice straw. If it proves successful the full treatment of the exposed lake bed might be progressively treated using 40,000 tons per year for more than 30 years.

Dust control along I-5 using rice straw bales would require about 600 tons of straw per mile for a three row fence system. This would be expected to last 10 years, and combined with a planting program would provide almost permanent control of dust in high risk areas. Vertical mulch treatment could be done with less straw at a much lower cost but would also be effective.

Barriers and Incentives

Field testing and cost evaluation are needed for bale fences and vertical mulch. Perhaps testing by CalTrans research lab along I-5 in the southern San Joaquin Valley would be a first step, or this work might be done with students and professors from UC Davis. A test at Owens Lake by the Los Angeles Department of Water and Power would be desirable. The straw might be delivered to site by rice growers in cooperation with the state. The straw bale test barriers could be constructed in cooperation with the Greater Basin Unified Air Pollution Control District that regulates Owens Lake.

Rice straw as an aid in revegetation and site restoration

Rice straw can also be used to aid in the establishment of vegetation. The use of native plants in landscaping and restoration efforts has increased throughout California not only due to an increase in popularity but through the enactment of environmental laws and regulations. Numerous studies have demonstrated the successful use of recalcitrant mulch, such as straw, to favor the growth of native perennials over exotic annuals (Zink and Bainbridge, 1994).

Studies have been conducted on the use of recalcitrant organic matter on both strip mine spoils (Elkins et al., 1984), degraded rangeland (Whitford, 1988), degraded desert and coastal sage scrub (Zink, 1994), and prairies (Morgan, 1994). The addition of straw and bark increased microorganism diversity, established a stable decomposition and mineralization cycle, and improved the physical characteristics of the soil. All these actions led to increased growth of native perennials and a decrease in exotic annuals. Numerous other studies have verified these findings (Ingham et al., 1985; Smith et al., 1986; Schuman & Belden, 1991). Rice straw, being more recalcitrant than wheat or oat straw, is an excellent mulch for aiding in the re-establishment of native perennials along road cuts, pipeline corridors and other construction sites.

Barriers and Incentives

Field tests in a range of native habitats would help sell this use. Ultimate use could be very large. California Department of Transportation is continuing to increase their use of native plants for right of way revegetation. Arranging with CALTRANS to establish and monitor several test sites along their rights of way could go a long way in convincing them on the usefulness of rice straw mulch for native plant establishment. The cooperation of the California Native Plant Society would be helpful in setting up tests plots across California.

§22 et seq Agricultural uses

Rice straw has many uses in agriculture and forestry. The primary uses are likely to be for soil improvement, soil protection and water retention (as with environmental uses), mushroom production, straw bale culture in greenhouses and weed management. Composted straw is most desirable for soil improvement for farm, forestry, and garden use. Mushroom production may have the most potential as a market for large quantities of rice straw.

Soil improvement

Numerous studies have demonstrated that rice straw can be a valuable asset to the agricultural community. The use of rice straw as a mulch on maize crops in Nigeria has been shown to significantly reduce the occurrence of brown spot disease (Osunlaja, 1989). In Japan rice straw mulch has been used to enhance root growth of grapevines (Takahashi, 1988) and to increase tomato plant yields by over 16% in Indonesia (Gunadi & Suwandi, 1988).

A study by Bhagat and Verma (1991) demonstrated that a combination of farmyard manure and incorporation of rice straw into fields of winter wheat in India led to higher grain yields than several other mulch procedures and control. Rice straw was incorporated into the soil at a rate of 5 t/ha^{-1} for a period of five years. The use of incorporated rice straw led to improved soil physical characteristics such as high soil porosity, low bulk density and high water content. similar improvements in grain yields through the use of rice straw have also been reported by Kawata and Seijima (1976) and Bhagat and Acharya (1987, 1988).

Mineralization, the process by which organically bound nutrients are released into the soil as available inorganic minerals, is of primary concern to any agricultural community. Rice straw mulch has been shown to increase mineralization rates in several ways. Shepard et al. (1989) demonstrated that rice straw bundles left in fallow fields increased the diversity and overall number of arthropods, thereby increasing soil microbial activity and, in turn, mineralization. Such an increase in mineralization allows a greater amount of nutrients to become available to plants, resulting in increased crop yields.

Straw mulch benefits saline or other degraded agricultural soil by improving both physical characteristics such as bulk density, aggregation and water infiltration rates, and through its slow release addition of soil organic matter through decomposition.

Table 22.1. Land use in acres

	California
Cropland	10,209,000
Range	17,719,000
Forest	15,073,000

Statistical Abstract US, 1993.

Fifty percent of the California range is in fair to poor condition. Much of the forest land is also in poor condition. More than 8 million acres of range and 4 million acres of forest or land that was previously forest would benefit from application of rice straw mulch and erosion control structures. Despite the great need for environmental protection and improvement work of these lands, little work is done to restore productivity each year. Only about 80,000 acres of forest land improvement are made each year, about half a percent of the area that would benefit from treatment. If rice straw land treatment rates of 2-3 tons per acre are used, the full production of rice straw could be absorbed on either forest or rangeland -- if someone would pay for the transport of the straw. Changes in tax policy that currently discourage active land stewardship could conceivably increase use dramatically and provide many other economic and environmental benefits to the state.

Barriers and Incentives

Low cost straw is important for these low value, long-term payback projects. If large scale straw harvest can reduce cost and increase availability, use of rice straw would increase. Cost disincentives for land stewardship and reforestation should be removed. Changing tax laws to allow current cost charges for improvement activities rather than discounting them till tree harvest would increase use. Increasing user costs for offsite erosion damages and nutrient impacts would also stimulate straw application.

Forestry soil rehabilitation of burned areas

Every year the state of California experiences the destruction caused by forest fires, figure 1. While there is no accurate accounting of the amount of straw used, the California Department of Forestry and the United States Forest Service use straw for erosion control and soil rehabilitation on approximately 5 to 10 percent of the burned area, depending on soil condition, accessibility and steepness. Using the data in figure 1 as a typical 10 year period, and based on an application rate of 1.5 tons per acre, approximately 36,000 ton of straw might be used in an average year.

Barriers and incentives

The amount of rice straw used for rehabilitation of burned land cannot be viewed as a stable demand because yearly damage and conditions caused by forest fires are likely to fluctuate from year to year. However a steady order could be placed to keep rice straw in regional depots to facilitate rapid application after fires.

Straw bale culture

An area in the field of food production that has almost unlimited potential for using rice straw is straw bale greenhouse gardening (Walls, 19__). Straw bales are used as substrates to grow many vegetables under greenhouse conditions. Water and fertilizer is first added to the bales along a slot on top of the bale to initiate decomposition. Once this process has begun, planting of seedlings can begin. Commercial planting techniques allow between 13,000 and 14,000 tomato plants per acre. Tomatoes and cucumbers have been extensively grown in this manner. Rice straw, with its slower decomposition rate than wheat or oat straw, would serve as an excellent substrate on which to grow greenhouse vegetables.

Barriers and Incentives

Lack of current technical information on rice straw response to straw bale culture techniques inhibits use. This would be worth investing in research at local colleges. Straw bale culture provides both the benefit of a marketable crop and compost material.

Mushroom production

Another fairly new field in the area of food production with excellent opportunities for rice straw use is mushroom production. Mushrooms normally grown as a food source, such as *Agaricus bisporus* (Button mushroom), *Pleurotus ostreatus* (Oyster mushroom) and *Lentinellus edodes* (Shiii Take), are decomposers and receive their nutrients from the substrate upon which they grow. The use of straw as a substrate has been much studied over the years (Straatsma et al., 1994; Atkey & Wood, 1983; Chang & Hudson, 1967; Fermor et al., 1985; Gerrits, 1988; Senya, 1988) with reported excellent results. Atthasampunna and Chang (1994) report that the amount of cultivated mushrooms has risen from 2000 tons in 1986 to over 4000 tons in 1990, and is expected to continue increasing at a rapid rate. Pudwell (1993) reported that 400,000 tons of straw was used in 1992 by the commercial mushroom industry in the United Kingdom and the amount continues to increase every year. The compost left after the mushrooms are harvested is used for livestock feed and soil conditioner, increasing the economic value of the straw.

The demand for a cool, dark and stable environment for production could be met by building long straw bale "caves" for production. These could be temporary with a plastic liner or plastered for permanent use. The production of the mushrooms and mushroom "caves" could be very profitable.

Barriers and Incentives

Lack of information on straw bale caves and mushroom culture is probably limiting consideration of this option. The large companies now involved in the mushroom market may respond to mailing of information on the straw resource, local nutrient sources, and straw bale buildings. A test cave would be even more effective. The closeness of the Valley to Sacramento and transport to the Orient (an extremely large mushroom market) is a big plus. In 1993, Honda of North America established commercial mushroom cultivation on its Ohio property with the express purpose of growing Shiii Take mushrooms for export to Japan (Chappell, 1993).

§ 21 Compost

Composts are complex communities of decomposers and grazers and can provide positive benefits for gardens, field crops, orchards, vineyards, forest and rangeland. Making compost with rice straw may require research to reduce costs. Compost production should be a good outlet for dirty or moldy hay that fails to meet standards for building material or industrial feedstock. Because the C:N ratio in compost is moved closer to the ideal ratio for plant growth by adding nutrients compost can be added to soil in very large quantities, with some market gardeners using more than 20 tons per acre year.

Keeping compost costs low is challenging unless the process also provides waste disposal benefits. The large scale rice hull and poultry waste composting operation at Foster Farms in Livingston converts rice hulls and poultry waste into a popular Organic Soil Amendment. In the Sacramento Valley similar opportunities may exist for composting with dairy waste, feed lot manure, clean small town sewage sludge, and processing wastes. Composting is a natural outcome of mushroom production with straw and mushroom compost is valued by farmers and gardeners. Combining waste manure and rice straw to create high value mushrooms and compost should prove very profitable.

Barriers and Incentives

It would be desirable to do a waste stream search to identify the best sites for composting operations. Benefits of various composting systems could be evaluated and improved. Perhaps best left to the private market, with a yearly purchase of 1000 thousand tons for CalTrans and other state agency use.

§A28 Disease and weed suppression

Rice straw mulch can be used in orchards and vineyards to suppress weeds. Laying in a thick layer of straw is a proven method of weed control. Several inches of straw are added to the surface of the soil. Especially compatible with drip irrigation. Current use is limited by availability and cost of straw. Mulch may need to be held back from tree and crop rows to protect them from mice.

As methyl bromide and other biocides are phased out and become more costly the search for biological solutions for pest problems becomes more essential. Many soil diseases can be suppressed or controlled by stimulating the 'friendly' soil organisms. Springtails (Collembolas) for example, will feed preferentially on pathogenic fungi (Klironomos and Bainbridge, 1995). Increasing the organic matter content of soil and improving aeration usually provide benefits for the plants and the plant symbionts such as mycorrhizal fungi (Allen, 1991).

Increasing the populations of beneficial soil organisms can also suppress or control many invasive weeds. While many crop plants benefit from association with mycorrhizal fungi, weeds can generally grow without them and the fungi may in fact act as pathogens on their roots. For example Allen et al. (1989) found that tumbleweed (Salsola) was attacked by these friendly fungi. Use of rice straw and straw compost on problem weeds is little studied but worth pursuing. Yellow star thistle and other noxious weeds are usually found on degraded soils, and improving the soil may provide better long term control than repeated spraying, tillage, or mowing.

Barriers and Incentives

These applications are little studied despite their potential long term value. This would make a good competitive grants offering for the UC Sustainable Agriculture Education and Research Program. A funding level of $400,000 year could provide rapid answers and many benefits to the State of California. Funded by rice grower assessment and CalEPA, EPA.

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Rice straw harvest

Most uses for rice straw require clean straw. Harvesting should also be done in a way that removes stem rot organisms from the field and does not compact soils. The basic steps are to remove the grain, cut and dry the straw, bale it and remove it. Typically this would involve grain harvest, increasingly with stripper headers which are fast and leave the stem standing; swathing with the machine set to cut at 4-6", run against the direction the straw was harvested.

Straw should be dried for 1-2 days if the weather is clear, then windrowed and baled. The type of baler will depend on end use. This must be done in a timely manner before fields get wet, and drainage must be timed well to get fields as dry as possible for equipment operation.

A tracked machine is preferred to minimize ground loading and compaction.

The ASV POSI-TRACK™ combines Kevlar reinforced rubber tracks with a hydraulic drive system to provide loading of only 1.5 pounds per square inch (much less than a human footprint) and can be run in water [ASV (800) 346-5954]. It should have enough power for swathing and baling. Modified balers and bale handlers with flotation wheels or tracks will be helpful.

If the straw is run through a conventional combine it will usually need a longer drying time (4-5 days) and the stems are more likely to be crushed and short. Alternative harvesters could include a combine/binder or binder (tying bundles of straw for environmental uses or long oriented fiber).

The straw or straw bales should be graded and stored off the ground under shelter. This may be as simple as pallets and a quality tarp, but a pole barn or shed is preferred. Bales with weed seeds, rot, or dirt should be marked and separated. Large bales are more likely to be economical. These can be rebelled at the storage site for building and other uses.

As straw burning was phased out in England two companies developed to remove straw from farmers fields. They don't pay for straw or charge for their services. Both handle about 200,000 tons of straw a year, which is stored on old WWII landing fields. Straw is baled in large Hesston balers (4'x4'x6') and then broken down to smaller bales if needed later. A sophisticated and effective home developed system of bales handlers has been created to minimize handling costs.

Processing the straw may include cleaning, sorting, slicing, flaking, orienting fiber, air classification, fractionation, milling, chopping, steam treatment, biological treatment or chemical treatment (Edwards, 1993). Slicing requires less power (Knight, 1993) and may prove more suitable for producing biocomposite materials. Various air/blower, combing, and sorting mechanisms can be used to orient fibers for use in manufacturing.

Biological processing of fibers may prove especially useful. This might require other types of storage and handling. It is possible that an inoculum might be added to the straw as it is harvested for some uses.

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Paper and packaging materials

Despite some drawbacks, agricultural waste products such as rice straw have great potential for paper and fiberboard production. World paper and pulp production from non-wood fibers was estimated at 15.6 million tons in 1990 (FAO, 1991) out of a total of 1,000 million tons of available cereal straw (O'Brien, 1993). Wheat and rice straw provide 63% of total fiber for China's paper and pulp production (Cheng, 1993), and rice straw paper is also used in other areas (Chawla, 1993; O'Brien, 1993). Rice and other cereal straw were once used in Europe but these uses have declined.

Rice straw is also an acceptable material for many types of paper products, although "rice paper" is not made with rice paper but from the bark of a shrub. In Brazil more than 12 million tons of paper from rice straw are produced every year, a 200 Ton per day plant was being brought on line to make liner board paper and fluting (Gerber and Sacon, 1993). Tests for this mill showed that soda pulp was slightly better than lime pulp treatment. Pure rice straw paper was too brittle, but paper with rice hull fiber included was better. From 25-50% rice straw can be combined with more flexible fibers such as hemp or cotton to improve performance.

New methods of pretreatment for the straw are improving the acceptance of straw fiber for paper and fiberboard. Research is needed on alternative paper production processes from straw, 200 years of work on wood fiber have refined that process but straw has received ˈatively little attention. Developing equal capability for rice and wheat straw will take time .d money. Steam exploded and biologically treated straw might provide better fiber quality at lower prices than traditional methods. Industrial uses require a consistent supply, quality and delivery.

Barriers and Incentives

Rice paper and cardstock would be suitable for many uses. The current shortage of newsprint might encourage exploration of alternative fibers. If fast-food providers used rice-straw paper for place mats a significant demand for paper would result. MacDonalds, for example, serves 18 million meals per day, 1/2 are used in house. This is about 14 tons per day, or 5,000 tons per year. State law might require rice straw paper content for fast food suppliers, file cards and file folders, and boxes for government use.

Rice paper could also be incorporated in many paper blends. The state might require recycled paper for all official use. Manufacturers would need a stable, long-term market to invest in the highly capital intensive paper plants, which may cost more than $2,000 per ton of production capacity. Cardboard was once made in California with rice straw and this worked well, but production ceased in 1989 (Moss et al., 1993).

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Energy production with straw

Straw and straw bales are increasingly being used to provide heat and energy in the United Kingdom and Europe. Much use in the U.K. is for individual boilers for greenhouse heating and space heating (Teisen, 1987). The Danish systems are the most sophisticated. There are 59 straw fired district heating systems with a total boiler output of 220 megawatts, consuming 270,000 tons of straw a year (Centre of Biomass Activity, 1993). There are also 12,000 small straw and wood fired plants in Denmark, using 450,000 tons of straw per year. These district systems are very efficient because they provide not only electric power, but also hot water for heating buildings and water. The program is subsidized to make it possible to prevent field burning of straw. Emissions are limited by sophisticated burn management.

The larger facilities are computer controlled and utilize the large bales, 4 x 4 x 6 feet. These are stored in a warehouse where they are picked up by an automatic transport system and fed into the boiler. Costs are minimized by this automation, some operate without people on site, with emergency pagers and computer controls linked to home offices.

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