AGRICULTURAL FIBERS IN COMPOSITION PANELS


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ABSTRACT

This paper addresses options for using agricultural materials alone or in combination with wood to produce composition panel products. Past research and technology available on a regional basis throughout the world is reviewed first. Agricultural fiber options for North America are discussed and a brief review of performance properties that can be obtained using these fibers is provided.

Commercial standards for particleboard and hardboard are used as a baseline by which to comparatively judge the panels. Alternative agricultural fibers that seem most appropriate and available in North America are bagasse, cereal straw, corn stalks, cotton stalks, kenaf, rice husks, rice, straw, and sunflower hulls and stalks. Technically speaking, these agricultural fibers can be used to manufacture composition panels. However, it becomes more difficult to use certain
kinds of fibers when restrictions in quality and economy are imposed.

In general, it can be concluded that composition panels made from agricultural fibers are of somewhat poorer quality than those made from wood; however, blending in small amounts of agricultural fibers (e.g., 10% to 20% by weight) may have no significant impact on quality. Bagasse, cereal straw, and kenaf appear to have the most promise for continued panel development.

INTRODUCTION

Never before has there been so much demand placed on the world’s fiber resource. Worldwide economic growth and development have generated unprecedented needs for converted forest products. Congruently, the energy needs of developing countries are creating increasing demands for fuelwood, which now represents 50% of all wood fiber consumption. At the same time, global fiber production systems, in total, are demonstrating the capability to meet these demands. In other words, regardless of tremendous pressures for fiber resource, there is not a global fiber shortage or crisis. However, there are some serious local and regional fiber shortages and resource management conflicts that will play a critical role in the immediate and long-term future.

In the latter part of the 20th Century, people are concerned about the future of their forests—their health, wildlife diversity, productivity for wood, environmental roles, and aesthetics. As a result of these concerns, forestry practices are changing, resulting in localized wood fiber supply shortages. The challenges are how the wood fiber demand is balanced and how, simultaneously, the earth’s population and ecological needs are met (McNutt 1992).

Additionally, many developing countries do not possess adequate forest reserves to cover their needs for fuelwood, industrial wood, sawn wood, and wood-based composition panels. However, many of these countries do have relatively large quantities of other lignocellulosic materials available in the form of agricultural residues from annual crops. Several of these lignocellulosics have been used to successfully produce particleboards, fiberboards, and, to some extent, inorganic-bonded boards.

This paper addresses options for using agricultural materials alone or in combination with wood to produce composition panel products. Past research and the technology available on a regional basis throughout the world is reviewed first. Agricultural fiber options for North America are discussed and a brief review of performance properties that can be obtained using those fibers is provided. The paper closes with a discussion of economic considerations affecting the use of agricultural fibers in panels.

GLOBAL PERSPECTIVE

Globally, many fiber options are available. A literature search was conducted at the USDA Forest Service, Forest Products Laboratory (FPL), to survey the worldwide use of agricultural fibers. A total of 1,039 citations were selected from the vast number available. From these citations, it was learned that the world is busy producing and conducting research on composition panels from agricultural fibers.

Composition panels made from agricultural materials are in the same product category as wood-based composition panels. These categories are low density insulation boards, medium density fiberboards, hardboards, and particleboards. Composition panel binders may be synthetic thermosetting resins or modified naturally occurring resins like tannin or lignin, starches, thermoplastics, or inorganics. There seems to be little restriction on what has been tried and what may work.

The following materials are selected highlights, by region, from the literature search. These highlights are categorized by geographical area, which may be a region or a country, and are presented alphabetically.
Africa (Botswana, Nigeria, Sudan)

Port Harcourt, Nigeria (Odozi et al. 1986), was the site of a study to determine if particleboard could be made from agricultural wastes. In this study, naturally occurring tannins from mangrove and red onion skins were used to modify and reduce the costs of synthetic resins. Reportedly, particleboards with high strength were made with combinations of bagasse, mangrove bark, wood shavings, and corncobs. In Sudan (Gahir et al. 1990), a study to make composition boards from guar and sorghum stalks was undertaken. In Botswana, the Ministry of Agriculture searched for alternative uses for sorghum (Kgotlele 1987).

The Americas (Cuba, Mexico, Peru, United States, Venezuela)

The literature search showed that bagasse, the residue fiber from sugar cane processing, is the agricultural fiber of choice in much of the Americas. The first bagasse composition panel plant was built by Celotex in Louisiana (United States) in 1920. Since then, more than 20 bagasse particleboard plants have been built throughout the world (Atchison and Lengel 1985). In Venezuela, Tablopan de Venezuela started producing a line of bagasse fiberboards in 1958 (Smith 1976). Production boards included those of low, medium, and high density. As a result of increased prosperity in Venezuela and a decrease in wood fiber availability, the company purchased a second line in 1975. Sidney (1986) described an insulation board and hardboard plant in Navolato, Mexico. In 1987 (Valdes et al. 1989), bagasse particleboards from the three main factories in Cuba were tested. The board quality was reported to be quite high, with 21 of 24 samples passing Cuban Standard NC43 18:86, which generally agrees with international standards.

Bagasse is not the only agricultural fiber being utilized in the Americas. In Peru, prefabricated panelized construction was developed that utilized bamboo and wood (Kuroiwa 1984). In this type of construction, prefabricated panels of bamboo and wood are produced using low technology methods. The finished structures are plastered with cement mortar and are earthquake resistant. Wheat and ryegrass straw were used for the production of panels in the Northwest region of the United States (Loken et al. 1991). Gertjejansen and others (1972, 1977) experimented with sunflower stalks and hulls in Minnesota (United States).

Asia (China, Japan, Taiwan, Thailand)

Although bamboo is given limited use in the Western Hemisphere, its use in Asia is widespread. A special building center was established in Kyoto, Japan, after World War II for the development of building materials from bamboo (Iwai 1983). The building center was formed through the cooperation of bamboo wholesalers, producers, and manufacturers.

Bamboo has been made into a variety of composition panels. A study conducted in Taiwan (Chen and Wang 1981) determined the feasibility of producing oriented and random three-layer boards from bamboo and wood waste. A similar study (Tsai et al. 1978) showed that Moso bamboo residue and red cypress shavings exceeded the National Chinese standard. A stressed-skin panel-type product was produced using plywood as faces and polystyrene foam for a core (Wang and Joe 1983).

Other agricultural materials are also used in Asia. Currently, bagasse particleboard is made in China (Jingxing 1988). Soybean stalks were investigated (Shi et al. 1988), and hardboards were produced from Thai hardwoods and coconut fiber that met or exceeded Japanese standards (Krisnabamrung and Takamura 1972).

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1 The use of trade or firm names in this paper is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.
Europe (Bulgaria, former Republic of Czechoslovakia, Sweden, former West Germany)

Wood fiber shortages and lumber price increases make bagasse particleboard an attractive supplement to wood fiber in Sweden. In Sweden, as well as other countries, there is a growing interest in compact, versatile, particleboard plants that can handle wood, wood waste, and agricultural materials (Dalen et al. 1990). Sweden is not the only country in Europe that has looked into composition panel production utilizing bagasse. In the former Republic of Czechoslovakia, researchers addressed many production parameters involved with bagasse particleboard production (Lois Correa 1979). This study addressed depithing and year-round storage.

Europeans also felt that there were opportunities for building materials that contain a certain amount of straw. Researchers in the former West Germany produced a variety of wood and straw and straw composition panels (Hesch 1978). In this work, boards made from straw at the same resin content and density as those made from wood generally had better properties. In another West German study (Troger and Pinke 1988), a series of three-layer boards using straw and softwood particles had slightly different results. In this study, straw boards did not perform as well as wood, but all straw boards nearly met or meet European standards for particleboards.

Interest by the Europeans in agricultural fibers was not limited to bagasse and straw. A Bulgarian study (Tsолов 1985) examined a multitude of agricultural waste fibers. In this study, fiberboards were produced by mixing varying amounts of beech fibers with hemp, vine, tobacco, cotton, raspberry, maize, or sunflower stalks. All these wastes were suitable for board production, but the best results were obtained with hemp and tobacco. Bamboo was also examined in West Germany (Heinrichs 1989). Special winter-hardy varieties were studied to use in building materials.

India

Binderless particleboards from bagasse were produced in India (Shuala and Chandra 1986). The boards were produced by cooking the bagasse in a 1% to 2% alkali bath and then tempering the pressed boards with oil. When compared to other agricultural residue panel products in India, bagasse also proved to make a good insulation board (Srivastava and Gupta 1990).

Inorganic boards appear to be growing in popularity in India. Researchers and industry teamed up to develop a variety of building materials using industrial and agricultural wastes that incorporated cement and cementitious materials as binders (Mohan 1978). The resulting combinations were used to produce composition boards, roof sheathing, flooring tiles, and weatherproof coatings.

The Middle East (Egypt, Iraq, Saudi Arabia)

Rice straw is the main lignocellulosic material in Egypt. This country uses rice straw to produce fiberboard, most of which is inferior quality compared to that made of wood fiber. This is due to the high percentages of nonfibrous materials included in the straw. When care is taken to fiberize the rice straw, board properties can increase significantly (Fadl and Rakha 1990). Other lignocellulosic materials available in the Middle East include cotton stalks, bagasse, and kenaf. One study (Fahmy and Fadl 1974) showed that hardboards prepared from these materials were generally better than those made of commercial rice straw.

In Iraq, particleboards were made with varying mixtures of reed or cattail mixed with wood. Properties were significantly impacted by the addition of the reed, with strength properties increasing, but water resistance properties decreasing. At 50% reed levels, most properties of the panel met or exceeded specifications (Al-Sudani et al. 1988). In Saudi Arabia, bagasse is considered an attractive source of fiber for composites for building materials (Usmani 1985).
Philippines

The Forest Products Research and Development Institute in Laguna, Philippines, has an active research program that examines the utilization of agricultural fibers in the production of composition panels. Much of the research at the Institute has focused on coconut coir (or husk) and banana stalk. In one study, coconut coir and pineapple fiber were blended with wood wastes for the production of particleboard (Pablo and Lovian 1989). In another study of underutilized agricultural species (Pablo et al. 1975), banana stalk was blended with wood chips to make particleboard. Finding uses for banana stalk is warranted because each banana tree plant produces only one banana bunch, and the stalks are generally burned.

Former USSR

In the former USSR, building materials with high compressive and bending strength were made using wastes from flax or cotton fabrics and phenol-formaldehyde resin (Inyutin et al. 1983). Rice straw boards with excellent properties were also produced (Kluge 1978). The rice straw was treated with steam and ammonia to increase the natural thermosetting properties of straw. When pressed to high density, the boards had excellent bending strength and minimum water absorption.

ALTERNATIVE FIBER OPTIONS FOR NORTH AMERICA

The first major awareness of the importance of resources and the environment came from our forebears working in forestry and conservation. The early leaders in this area can be described as militants with a tremendous consciousness of their mission. The FPL and major forestry schools came into existence because of the direct personal involvement of these pioneers of resource management. If such inheritance counts for anything, this audience should be deeply concerned with what seems to be a conservation renaissance in this country.

As managers of the wood resource, we wish to make sound decisions. But in the face of the present flood of diverse and divergent opinions, good decisions are more and more difficult to make. What will be the need for timber when the present crop or the next crop matures? Our professional responsibilities and native instincts force us to be extremely aware of the environment. Forests provide great aesthetic pleasure and other values, and it is obvious that the future of forest life will depend overwhelmingly on our ability to balance conservation and utilization.

Today in the United States, wood fiber is the main source of material for composition panels. However, as has been shown, other sources of fiber are available. These alternative fiber options have the potential to alleviate regional wood fiber shortages. Shortages that have been partially created because of renewed concerns about how forests should be used.

For the purpose of this paper, the discussion of agricultural fibers is limited to those that seem most appropriate and available in North America. These materials are bagasse, cereal straw, corn stalks and cobs, cotton stalks, kenaf, rice husks, rice straw, and sunflower hulls and stalks. Technically speaking, these agricultural fibers can be used to manufacture composition panels. However, it becomes more difficult to use certain kinds of fibers when restrictions in quality and economy are imposed. The remainder of this section addresses the issues of quality, which involves harvesting, handling, manufacturing, and properties of the finished panel. Commercial standards are used only as a baseline by which to comparatively judge the panels.

Bagasse

Bagasse is the residue fiber remaining when sugar cane is pressed to extract the sugar. Some bagasse is burned to supply heat to the sugar refining operation, some is returned to the fields, and some finds its way into various board products. Bagasse is composed of fiber and pith. The fiber is thick walled and relatively long (0.03 to
0.12 in., 1 to 4 mm). It is obtained from the rind and fibrovascular bundles dispersed throughout the interior of the stalk (Hamid et al. 1983). For the best quality bagasse fiberboard and particleboard, only the fibrous portion is utilized. As may have been ascertained by the continual reference to bagasse in this paper, it is the agricultural residue that might offer the greatest opportunity for composition panel production in North America. In what could be considered a definitive work, Atchison and Lengel (1985) told of the history and growth of bagasse fiberboard and particleboard at the 19th Washington State Particleboard/Composite Materials Symposium. In their paper, the authors described the various success and failure stories of bagasse utilization.

Bagasse is available wherever sugar cane is grown. In North America, that constitutes just about everywhere between Canada and Mexico. As such, almost no harvesting problems exist. Large volumes of bagasse are available at sugar mills. In the United States, the cane harvest usually lasts about 2-1/2 months. During this time, bagasse is readily available. For the remainder of the year, the material must be stored. Special care must be taken during storage to prevent fermentation, because bagasse does have a high sugar content. To reduce the sugar content and increase storage life, bagasse is usually depithed before storage. The pith is an excellent fuel source for the sugar refining operation. Generally, if the bagasse is depithed, dried, and densely baled, it can be stored outside. If handled in a careful manner, bagasse can also be stored wet. In the wet method, large bales of bagasse are specially fabricated and stacked to insure adequate air flow. Heat from fermenting sugars effectively sterilize the bales. Bagasse can be stored for several years using this method (Chapman 1956). Other storage options are available, including some that keep the bagasse wet beyond the fiber saturation point.

As previously mentioned, only bagasse fiber is utilized for the production of high-quality composition panels. As such, various schemes are available to separate the bagasse fiber from the pith. The fibers after depithing are more accurately described as fiber bundles. These fiber bundles can be used, as is, to make particleboard, or they can be refined to produce fibers for fiberboard. In either product, dry or wet layup is possible. Some properties of bagasse composition panels are shown in Figure 1. Specifications for these panels are 92% bagasse, 8% urea-formaldehyde, 0.74 specific gravity, and 0.3 in. (10 mm) thickness (Salyer and Usmani 1982).

**Cereal Straw**

Cereal straw is probably the second most used agricultural fiber for reconstituted panel production. For the purposes of this paper, cereal straw is meant to include straw from wheat, rye, barley, oats, and rice. Straw, like bagasse, is an agricultural residue. Unlike bagasse, large quantities of cereal straw, generally, are not available at one location. Storage is accomplished usually by baling. Straws have a high ash content (Table 1), tend to fill fireboxes in boilers, and increase the wear rate on cutting tools. Their high silica content also tends to make them naturally fire resistant (Opel 1992).

Plants exist in several countries to make thick (5 to 15 cm; 0.2 to 0.6 in.) straw panels with kraft paper faces (United Nations Industrial Development Organization 1975). The panels are made by heating the straw to about 200°C, at which point springback properties are virtually nil. The straw is fed through a reciprocating arm extruder and made into a continuous low density (0.25 specific gravity) panel. Kraft paper is glued to the faces and edges of the panels. These panels can then be cut for prefabrication into housing and other structures. The low density of the panels makes them fairly resilient and test data show that housing built using these panels is especially earthquake resistant. In the 1980s, such a plant to produce straw panels from wheat and rye straw was set up in California (Galassco 1992).

Table 1.—Chemical composition of selected lignocellulosic fibers

<table>
<thead>
<tr>
<th>Fiber Type</th>
<th>Alpha Cellulose (%)</th>
<th>Lignin (%)</th>
<th>Ash (%)</th>
<th>Silica (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice straw</td>
<td>28 to 36</td>
<td>12 to 16</td>
<td>15 to 20</td>
<td>9 to 14</td>
</tr>
<tr>
<td>Wheat straw</td>
<td>38 to 46</td>
<td>16 to 21</td>
<td>5 to 9</td>
<td>3 to 7</td>
</tr>
<tr>
<td>Oat straw</td>
<td>31 to 37</td>
<td>16 to 19</td>
<td>6 to 8</td>
<td>4 to 7</td>
</tr>
<tr>
<td>Bagasse</td>
<td>32 to 44</td>
<td>19 to 24</td>
<td>2 to 5</td>
<td>1 to 4</td>
</tr>
<tr>
<td>Kenaf</td>
<td>31 to 39</td>
<td>14 to 19</td>
<td>2 to 5</td>
<td>na</td>
</tr>
<tr>
<td>Cotton stalks</td>
<td>na</td>
<td>22</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Rice husks</td>
<td>38</td>
<td>22</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Softwoods</td>
<td>40 to 45</td>
<td>26 to 34</td>
<td>&lt;1</td>
<td>--</td>
</tr>
<tr>
<td>Hardwoods</td>
<td>38 to 48</td>
<td>23 to 30</td>
<td>&lt;1</td>
<td>--</td>
</tr>
</tbody>
</table>

*a* na is not available; -- is negligible value  
*b* Source: TAPPI 1983  
*c* Source: Fadl et al. 1978  
*d* Source: Govindaraao 1980
Straw can be used to supplement part of the fiber content in particleboard. A large particleboard plant in the United States, located in La Grande, Oregon, substituted straw at a rate of 8% and found no major problems except that the sander dust from the faces deposited additional ash in the boiler. This plant then stopped using straw in the face and used it only in the core. At a rate of 10% or less, the effect on tool wear was not significant (Knowles 1992).

The time of harvest for the straw is important to board quality (Rexen 1977). The quality of the straw is highest when the grain is at its optimum ripeness for harvesting. Under-ripe straw has not yet yielded its full potential and over-ripe straw becomes brittle. A small amount of ryegrass straw particleboard was produced commercially in the United States in Oregon (Loken et al. 1991). The product has a density of 0.6, is quite stiff, and has a Class 3 fire rating (Opel 1992). Some properties of straw composition panels are shown in Figure 2. Specifications for these panels are 97% pulped rice straw, 3% urea-formaldehyde resin, 0.98 specific gravity, and 0.08 in. (2.8 mm) thickness. Thickness swell and water absorption time values are unknown (Fadl et al. 1984).

Corn Stalks and Cobs

Based on the literature search, currently there is no commercial utilization of corn stalks or cobs in composition panel production. A three-layer board having a corn cob core and wood veneer face was produced for a short time in Czechoslovakia after World War II (United Nations Industrial Development Organization 1975). Records show that the process was too labor intensive and was discontinued.

Corn stalks, like many agricultural fiber sources, consist of a pithy core with an outer layer of long fibers. Currently, in the United States, corn stalks are chopped and used for forage, left on the field, or baled for animal bedding. The cobs are occasionally used for fuel.

Figure 2—Some properties of straw composition boards. (Source: American National Standard Institute [for standards] 1989a [Particleboard Standard] and 1989b [American Hardboard Standard]; Fadl et al. 1984 [for data])
Research shows that corn stalks and cobs can be made into reasonably good particleboard and fiberboard (Chow 1974). In the research, corn stalks and cobs were either hammermilled into particles or reduced to fibers in a pressurized refiner. Some panels were laminated with 0.09 in. (3.2 mm) pine veneers, and three-layer panels were made with stalk faces and cob cores. Selected results of this research are shown Figure 3. Specifications for these composition panels are 92% hammermilled and depithed corn stalks, 7% urea-formaldehyde resin, 1% wax, 0.74 specific gravity, and 0.5 in. (16 mm) thickness (Chow 1974).

**Cotton Stalks**

Cotton is cultivated primarily for its fiber used in textiles and little use is made of the cotton plant stalk. Stalk harvest yields tend to be low and storage can be a problem. The cotton stalk is plagued with parasites and stored stalks can serve as a home for the parasites to winter over for next year’s crop. Attempted commercialization of cotton stalk particleboard in Iran was unsuccessful for this reason (Brooks 1992).

If the parasite issue could be addressed, cotton stalks can be an excellent source of fiber. With regard to structure and dimensions, cotton stalk fiber is similar to common species of hardwood fiber (Mobarek and Nada 1975). As such, debarked cotton stalks can be used to make high grades of paper. The stalk is about 33% bark and quite fibrous. Newsprint quality paper can be made from whole cotton stalks. Some properties of composition panels made from undebarked cotton stalks are shown in Figure 4. Specifications for these composition panels are 97% refined undebarked cotton stalk, 3% phenolic resin, 0.82 specific gravity, and 0.08 in. (2.8 mm) thickness. Thickness swell and water absorption time values are unknown (Fadl et al. 1978). Recently (Frazier 1993), Carl Schenk GmbH constructed a plant based on cotton stalks in China (in De Zhou, 300 km east of Beijing). The plant is providing a board meeting or exceeding

![Figure 3.—Selected results of corn stalk composition board research. (Source: American National Standard Institute [for standards] 1989a [Particleboard Standard] and 1989b [American Hardboard Standard]; Chow 1974 (for data)]](image-url)
property specifications for wood particleboard. The plant size is 110 m$^3$ with an 8.2 by 33 ft single opening press. An identical plant is now under construction in Heze in Shandong Province and a third plant is on order.

**Kenaf**

Kenaf is a plant that is similar to jute or hemp. It has a pithy stem surrounded by fibers. The fibers make up 20-25% of the dry weight of the plant (LaMahieu et al. 1991). Kenaf grows well in the southern United States. Growth in the northern United States fluctuates with variations in the growing season. Mature kenaf plants can be 17 ft (5 m) high.

Currently, kenaf is generating a great deal of interest from government and industry. The U.S. Department of Agriculture is promoting kenaf, and other nonfood, nonfeed agricultural crops, because these crops are not subject to subsidies (Alternative Agricultural Research and Commercialization 1992). Historically, kenaf fiber was first used as cordage. Industry is exploring the use of kenaf in papermaking and nonwoven textiles. Kenaf fiber can be used to make letterhead quality paper; whole kenaf stalk can be used to make newsprint grade paper. With the pith removed, kenaf and other fibers can be blended together to make nonwoven textile mats. As a nonwoven textile mat, kenaf can be used for erosion control, seedling mulches, and oil spill absorbents. When a resin is added to the kenaf mats, they can be pressed into flat panels or molded into shapes, such as interior car door substrates.

As an indication of the interest in kenaf, a recent bibliography devoted solely to kenaf had 241 scientific citations (United States Department of Agriculture 1992). Also, the International Kenaf Association is devoted to the study and promotion of kenaf (Taylor 1993). Research on the use of kenaf for composition panels has been somewhat limited, although encouraging. In the literature search, two references contained data on composition panels made from kenaf.

Research at the FPL (unpublished) showed that kenaf can be used to make fiberboard nearly equal or equal to American National Standard Institute, American Hardboard Association, basic hardboard standards. Some properties for kenaf composition panels are shown in Figure 5. Specifications for these panels are 92% depithed kenaf bast fiber, 7% urea-formaldehyde, 1% wax, 0.74 specific gravity, and 0.5 in. (16 mm) thickness. Thickness swell and water absorption values reflect 2 hours of immersion (Chow 1974).

Rice Husks

Rice husks are an agricultural residue that is available in fairly large quantities in one area. Rice usually comes to the plant at about an 8% moisture content level (Vasishth and Chandramoule 1974). Rice husks are quite fibrous by nature and require little energy input to prepare the husks for board manufacture. To make high-quality boards, the inner and outer husks are separated and broken at their “spine.” Resin is applied and the rice husk particles are air laid like other lignocellulosic materials.

Rice husks or their ash are used in cement block and other cement products. The addition of the hulls increases thermal and acoustic properties (Govindarao 1980). Some properties of selected rice husk composition panels are presented in Figure 6. Specifications for these composition panels are 0.94 specific gravity and 0.2 in. (6.2 mm) thickness. Husk and resin content are unknown (Govindarao 1980).

Sunflower Stalks and Hulls

The University of Minnesota was the site of several studies to examine the properties of particleboard made with varying amounts of sunflower stalks and hulls. In Gertjejansen et al. (1972), particleboards from 50% aspen and 50% sunflower hulls were produced. Gertjejansen (1977) focused on sunflower stalks, prepared and depithed in different ways and blended with aspen flakes. The results indicated that most

Figure 5.—Some properties of kenaf composition panels. (Source: American National Standard Institute [for standards] 1989a [Particleboard Standard] and 1989b [American Hardboard Standard]; Chow 1974 [for data])
physical and mechanical properties increased when adding the fibrous sunflower stalks.

The literature search found only one citation for sunflowers outside the United States. Within the United States, two citations were found for hulls and one was found for stalks. At the time of this writing, no commercial use is known for sunflower stalks or hulls in composition panels. Properties of composition boards made from sunflower stalks and hulls are shown in Figures 7 and 8, respectively. Specifications for these sunflower stalk composition panels are 90% depithed sunflower stalks, 10% phenol-formaldehyde resin, 0.74 specific gravity, and 0.4 in. (12 mm) thickness (Gertjejansen 1977). Specifications for these sunflower hull composition panels are 92% sunflower hulls, 7% urea-formaldehyde resin, 1% wax, 0.78 specific gravity, and 0.3 in. (10 mm) thickness. Thickness swell and water absorption values reflect 2 hours of immersion (Chow 1974).

FIBER AVAILABILITY AND ECONOMICS

Knowing that agricultural residues and other nonwood fibers can be used to make panels of comparable mechanical properties, the question is, “are these fibers available and economical to use?” The material that follows will discuss briefly the availability, economics, fiber yield, bulk density, alternative use, and price comparison.

Availability

Considerable amounts of agricultural residues are generated each year in the United States (Table 2). If the unlikely assumption was made that 75 wood composition panel plants decided to change entirely to agricultural fiber and, on average, each particular plant required $135 \times 10^3$ metric tons (t) of fiber a year, the total fiber requirement would be approximately $10 \times 10^6$ t. Relative to the amount of residues generated, more than 30 times as much agricultural fiber would be available as would be consumed. This
Figure 7.—Some properties of sunflower stalk composition panels (Source: American National Standard Institute [for standards] 1989a [Particleboard Standard] and 1989b [American Hardboard Standard]; Gertjejansen 1977 [for data])

Table 2.—Residue estimates of U.S. major crops

<table>
<thead>
<tr>
<th>Crop</th>
<th>Harvested (ha)</th>
<th>Harvested (acre)</th>
<th>Yield per ha (t/ha)</th>
<th>Yield per ha (t/acre)</th>
<th>Residue Weight (×10^6 t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn</td>
<td>26</td>
<td>65</td>
<td>5 to 7</td>
<td>2 to 3</td>
<td>167</td>
</tr>
<tr>
<td>Wheat</td>
<td>24</td>
<td>60</td>
<td>2 to 5</td>
<td>1 to 2</td>
<td>106</td>
</tr>
<tr>
<td>Sorghum</td>
<td>6</td>
<td>16</td>
<td>5 to 7</td>
<td>2 to 3</td>
<td>23</td>
</tr>
<tr>
<td>Oats</td>
<td>6</td>
<td>14</td>
<td>2 to 5</td>
<td>1 to 2</td>
<td>9</td>
</tr>
<tr>
<td>Barley</td>
<td>4</td>
<td>11</td>
<td>2 to 5</td>
<td>1 to 2</td>
<td>11</td>
</tr>
<tr>
<td>Rice</td>
<td>1</td>
<td>2</td>
<td>2 to 5</td>
<td>1 to 2</td>
<td>2</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>318</td>
</tr>
</tbody>
</table>

a Source: Goldstein 1981

calculation of availability does not take into account bagasse or agricultural fibers from non-residue sources like kenaf. Thus, from the viewpoint of potential availability, the amount of residues generated by U.S. agriculture far exceeds present and future composition panel fiber requirements.

However, not all the gross potential supply is freely available. For instance, to participate in Federal farm programs, all farms must have an approved conservation plan by 1995. In some cases, this entails leaving some portion of the residue mass on the ground as cover for soil protection. Also note that these fibers are available only on a seasonal basis. Storage issues for many individual fiber types are addressed in this paper.

**Economics**

In North America, composition panels come primarily from wood residues and secondarily from roundwood obtained from traditionally managed forests. How alternative fiber sources compare in cost with these traditional sources will determine the extent to which they can be considered as a wood fiber substitute. Alternative agricultural fiber comes from two main sources: agricultural crops grown for fiber (e.g., kenaf) and residues of crops grown for other purposes (e.g., wheat, cotton).

**Fiber Yield**

Intensively managed hybrid poplar grown under short rotations can produce yields of fiber ranging from 4 to 6 t/acre (10 to 15 t/ha) per year. Conventionally managed aspen stands yield about 1 t/acre (2.5 t/ha) per year (Dawson et al. 1975, Turhollow 1991). From the viewpoint of maximum yields, kenaf appears to be preeminent. Yields of up to 20 t/acre (50 t/ha) on the best sites were reported (Corkern 1971), although 6 t/acre (15 t/ha) is more realistic. When fiber yields of crop residues were examined, the range of harvestable fibers varied from 1 to 3 t/acre (2 to 7 t/ha), depending on plant species and local growing conditions (Table 2).

**Bulk Density**

A major difference between wood and non-wood fibers is bulk density. One obstacle to agricultural fiber utilization for relatively low-value commodity products, like composite panels, is low bulk density. Low bulk density can increase transport costs significantly. A standard cord contains 128 ft^3 (3.6 m^3) of space of which approximately 76 ft^3 (2.1 m^3) is wood. This yields a gross bulk density (dry basis) of 15 to 20 lb/ft^3 (240 to 320 kg/m^3). The economics of processing and transporting small-diameter timber with such bulk density indicates a practical procurement radius of about 40 miles (65 km) (Vaagen 1991).
In contrast, annual fiber stems of a plant such as kenaf or straw cannot be compacted much beyond 8.4 lb/ft$^3$ (135 kg/m$^3$), which limits the feasible supply basin to a range of 15 to 20 miles (25 to 35 km) (Sandwell 1991). By analogy, similar ranges could be expected to hold for residue fibers as well, if the same high density baling equipment as assumed in the Sandwell study were available. This effectively reduces the availability of fiber to a single plant to an area of approximately 800,000 acres (320,000 ha). Assuming that 70% of this land was devoted to agriculture and fiber-producing plants were planted on one-third the acreage in a given year, the available supply, based on a 2 t/acre (5 t/ha) yield, would be about 375,000 t. This provides a coverage ratio of 2.75 for a typical plant’s needs, based on the previous assumptions.

**Alternative Use**

Not all the fiber produced in U.S. agriculture is valueless by product. For example, uses and markets for baled straw exist where animal bedding needs are high, such as in states where dairying is strong. In Wisconsin and Pennsylvania, two states where the availability of straw relative to the number of cows in dairy herds is small. Baled straw delivered to central auction sites is priced from US$50 to US$90/dry t (Table 3). In North Dakota, straw is generally left on the ground. The small amount of straw that is baled markets for only US$25 to US$35/t. In other areas, although straw is not priced, it plays a valuable role in agriculture as a mulch to retard runoff and soil erosion. The use of straw for these conservation purposes is mandated by Federal farm programs. These conservation purposes must be established by 1995 for a farm to benefit from Federal farm programs. Nevertheless, mulch straw has little economic value and would be available for other off-site uses at low cost.

Corn stalk residue has lower absorbency than does straw and thus, is not as well suited for bedding purposes. Estimates show that corn stalks could be obtained for as little as US$5/t, unbaled (on the stump). Factoring in harvesting and transport costs, such material should be obtainable for US$25/t.

**Overall Price Comparison**

Current costs of pulpwood were used as a frame of reference. Pulpwood in the United

<table>
<thead>
<tr>
<th>U.S. State</th>
<th>Cereal Straw Availability per Year (×10$^6$ t)</th>
<th>Number of Milk Cows (×10$^6$)</th>
<th>Ratio (straw/cow)</th>
<th>Price Range (US$/t)$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kansas</td>
<td>24.5</td>
<td>0.10</td>
<td>250</td>
<td>25 to 35</td>
</tr>
<tr>
<td>North Dakota</td>
<td>23.3</td>
<td>0.09</td>
<td>250</td>
<td>- -</td>
</tr>
<tr>
<td>Washington, Oregon</td>
<td>15.2</td>
<td>0.31</td>
<td>50</td>
<td>- -</td>
</tr>
<tr>
<td>Montana</td>
<td>12.9</td>
<td>0.23</td>
<td>55</td>
<td>- -</td>
</tr>
<tr>
<td>Texas</td>
<td>11.6</td>
<td>0.38</td>
<td>30</td>
<td>- -</td>
</tr>
<tr>
<td>Oklahoma</td>
<td>11.4</td>
<td>0.10</td>
<td>110</td>
<td>- -</td>
</tr>
<tr>
<td>Minnesota</td>
<td>10.2</td>
<td>0.78</td>
<td>15</td>
<td>- -</td>
</tr>
<tr>
<td>Illinois, Indiana</td>
<td>10.2</td>
<td>0.38</td>
<td>25</td>
<td>- -</td>
</tr>
<tr>
<td>California</td>
<td>8.9</td>
<td>1.10</td>
<td>8</td>
<td>- -</td>
</tr>
<tr>
<td>Nebraska</td>
<td>7.6</td>
<td>0.11</td>
<td>70</td>
<td>- -</td>
</tr>
<tr>
<td>Wisconsin</td>
<td>2.2</td>
<td>1.76</td>
<td>1.2</td>
<td>60 to 90</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>1.6</td>
<td>0.77</td>
<td>2.0</td>
<td>50 to 95</td>
</tr>
</tbody>
</table>

$^b$-, price not available
States is usually marketed in terms of cords, thus a conversion to weights, based on species density, was made to facilitate comparison with agricultural residues. The results of the comparison are in Table 4.

Recent pine, mixed hardwood, and aspen pulpwood delivered prices range from US$43 to US$52/cord (3.6 m$^3$). When converted to a weight basis, prices range from US$40 to US$47/t.

Intensively cultivated hybrid poplar plantation prices are estimated at US$60/t, exceeding pine and hardwoods prices. Hybrid poplar estimates assume a 6 t/acre (15 t/ha) yield and two harvest rotations following initial harvest involving coppice regeneration (which eliminates replanting costs).

Among the agricultural fibers, kenaf is generally the highest in estimated price because all cultivation and harvest costs are born by the fiber component of the output. Kenaf calculations are based on 6 t/acre (15 t/ha) yields, and the price is between those of hybrid poplar and pine or hardwood pulpwod. Straw and corn generally cost less than do crops grown specifically for their fiber content because the grain portion of the output bears the expense. An exception to this is where the fiber has value for other uses, such as animal bedding. In those cases, straw prices can be almost twice as high as pulpwood and not currently within economic reach of particleboard producers.

**CONCLUDING REMARKS**

A new era of wildland stewardship is emerging in the United States. Its philosophy is broader than sustained yield and multiple use and it should not reject the contributions and future utility of those concepts and practices that have characterized good land management. In fact, the emerging ecosystem management builds directly on the foundation established by previous policies, concepts, and accomplishments. Because of what prior generations of scientists and resource

<table>
<thead>
<tr>
<th>Pulpwood/Fiber</th>
<th>Stumpage $^b$</th>
<th>Harvested and Delivered</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulpwood</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern Pine</td>
<td>16</td>
<td>20</td>
<td>25</td>
</tr>
<tr>
<td>Southern hardwood</td>
<td>8</td>
<td>9</td>
<td>31</td>
</tr>
<tr>
<td>Lake States</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aspen</td>
<td>13</td>
<td>12</td>
<td>34</td>
</tr>
<tr>
<td>Hybrid poplar</td>
<td>40</td>
<td>na</td>
<td>20</td>
</tr>
<tr>
<td>Kenaf</td>
<td>36</td>
<td>na</td>
<td>19</td>
</tr>
<tr>
<td>Agricultural fiber $^e$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cereal straw</td>
<td>5 to 70</td>
<td>na</td>
<td>20</td>
</tr>
<tr>
<td>Corn stalks</td>
<td>5</td>
<td>na</td>
<td>20</td>
</tr>
</tbody>
</table>

$^a$ Conversions based on 77 ft$^3$ (2 m$^3$) per cord
$^b$ Stumpage is growing cost plus return to land and farmer; for kenaf, straw, and corn, cost of harvest is included in stumpage
$^c$ Prices from Timber Mart South (1992)
$^d$ Aspen prices from Wisconsin and Minnesota state forestry officials; hybrid poplar based on Turhollow (1991); kenaf based on Sandwell and Associates (1991)
$^e$ Based on partial survey of state agricultural extension economists

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managers created, we can now move to land management that considers more than selected resource outputs and single species utilization.

In this paper, the uses of alternative agricultural fibers from a global perspective were explored. Agricultural fibers that have been or could be used in North America were discussed. Also discussed were those issues in which a producer of wood-based composition panels would have the most interest. In summary:

1. There is no global wood fiber shortage. However, several examples of localized supply shortages exist throughout the world.

2. A large amount of literature reports on the satisfactory use of agricultural fibers in composition panels.

3. More than enough agricultural fiber residues are available to support composition panel manufacturing needs within North America. However, the fibers may not be in the right place at the right time.

4. In general terms, composition panels made from agricultural fibers are of somewhat poorer quality than those made of wood, but blending in small amounts of agricultural fibers (10% to 20%) may have no significant impact on quality.

5. Bagasse, cereal straw, and kenaf appear to have the most promise for continued panel development.

ACKNOWLEDGMENTS

We thank Diana Hess for assembling data and constructing Figures 1 to 8 and Table 1.

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