ANNUAL CROPS—A RENEWABLE SOURCE FOR CELLULOSE

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SYNOPSIS

Historically, cellulosic materials from annual crops have been of major industrial importance. They predate wood for paper by centuries. As early as 500 B.C., pressed sheets were made in Egypt from papyrus. The technique of papermaking, most closely related to processing now followed, was based primarily on cellulose from such annual crops as cotton, flax, and hemp. Commercially, cellulose is available from annual fiber crops, byproducts, and residues. Typical fiber crops are kenaf, jute, reeds, hemp, cotton, and esparto grass. They may be grown under either cultivated or natural conditions. Byproducts include cereal straws, sugarcane bagasse, oilseed stalks, and similar cellulosic materials normally associated with a principal agricultural crop. Residues represent many different types of materials and are best typified by food and animal wastes. Annual crops have increasing potential as renewable raw materials to meet future requirements for cellulose and cellulose-based chemicals.

INTRODUCTION

The efficiency of U.S. agriculture has advanced so fast that for several decades annual crop production has exceeded market demands, except in times of international conflicts or temporary emergencies. Average farm output per acre has increased about 85% since 1940 because of better yielding seeds and greatly improved farming techniques. This increase has exceeded domestic population growth. Even though less acres are planted to meet domestic needs, more crops are still available for export [1] (see Figs. 1 and 2).

A 1974 USDA study [2] projects that requirements for cropland will remain relatively constant beyond the year 2000 even with increased exports. Undoubtedly, total production from all available land could be consumed throughout the world if all were given away. Methods to carry out such a program within the world economic systems are outside the scope of a technical discussion.

Normally, U.S. agriculture first provides food, feed, and fiber, and these outlets usually bring the highest financial return. This will probably always be true. Almost all annual crops produce large amounts of cellulose either in the crop itself or in the byproduct residues remaining after the primary crop has been harvested.
Much of these high cellulosic materials can be exploited for the production of such manufactured products as paper and paperboard, for use as chemical raw materials, and for a source of energy. They are annually renewable and they will undoubtedly be available for the predictable future. Two types of cellulosic materials will be considered; namely, cellulosic byproducts and residues from annual food, feed, and fiber crops, and annual nonwood crops high in cellulose.

In the United States little cellulose from annual crops is now used to make pulp or to manufacture chemicals. About 1% of North American fibrous raw material is from byproducts—mostly from sugarcane bagasse. Essentially, no annual fiber crops are commercially grown specifically for this purpose. However, existing byproducts are available and do represent a major potential source of fiber. Their use awaits only the economic necessity.

Agricultural fibers as a whole differ characteristically from woods in chemical composition and fiber dimensions as may be expected from the vast number and variety of annual plants. Many exceptions to these generalizations occur. Typi-
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TABLE I

Typical Dimensional and Compositional Characteristics of Selected Pulpwood and Nonwoody Plants

<table>
<thead>
<tr>
<th>Species</th>
<th>Fiber Length, mm</th>
<th>Fiber Width, %</th>
<th>Crude Cellulose %</th>
<th>Alpha-Cellulose %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coniferous woods</td>
<td>2.0-5.7</td>
<td>32-44</td>
<td>60</td>
<td>39-45</td>
</tr>
<tr>
<td>Deciduous woods</td>
<td>0.6-1.9</td>
<td>38-50</td>
<td>45-62</td>
<td>38-49</td>
</tr>
<tr>
<td>Nonwoody plants:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugarcane bagasse</td>
<td>0.3-3.4</td>
<td>9-45</td>
<td>48-58</td>
<td>30-37</td>
</tr>
<tr>
<td>Cereal grain straws</td>
<td>1.1-1.5</td>
<td>9-13</td>
<td>43-54</td>
<td>29-39</td>
</tr>
<tr>
<td>Bamboo</td>
<td>1.1-3.8</td>
<td>12-22</td>
<td>44-62</td>
<td>30-43</td>
</tr>
<tr>
<td>Esparto grass</td>
<td>0.5-3.5</td>
<td>7-18</td>
<td>49-50</td>
<td>33-38</td>
</tr>
</tbody>
</table>

cal dimensional and compositional characteristics of selected woods and annual nonwoody plants are listed in Table I. Note that the cellulosic content of nonwoody plants is usually comparable to, or somewhat lower than, most woods. Of course, there is more variance in the cellulosic content, which ranges from 25 to 60% total cellulose and from 15 to 40% alpha-cellulose. Fiber dimensions are similar. In general, practically all nonwood cellulose from annual crop varieties can serve as raw materials for the manufacture of either paper and paperboard or chemicals.

Of the approximately 2,264 million acres of land used in the 50 states about 475 million acres is classified as cropland (Fig. 3). An additional 604 million acres is classified as grassland. Almost all the idle cropland could be exploited through cultivation to grow annual crops. Possibly some of the grassland could also serve this purpose. On an average, about 300 million acres of cropland has been cultivated for the past two decades. This acreage is slightly lower than that several decades ago. Whether the trend will continue under present world conditions remains to be determined. However, there is now significant unused crop-land available on which to grow cellulosic annual crops and there probably will be for many years to come.

Historically, nonwoody cellulosic annual crops have been of major importance.

![Fig. 3. Land use.](Data Furnished by ERS, USDA)
They were first used in the manufacture of paper, and they predated wood for paper by centuries. As early as 500 B.C. pressed paper-type sheets were made from papyrus in Egypt. The technique of papermaking most closely related to the processing now followed originated about 105 A.D. in China and was based primarily on fibers from such annual crops as cotton, flax, and hemp.

World production of nonwood plant fiber pulp is more than 7 million tons, or about 5% of all pulp production [3]. Nonwoody fiber includes about 1.1 million tons of bagasse, 2.2 million tons of cereal straw, 1.5 million tons of bamboo, and 0.5 million tons of cotton linter. Other commercial pulping operations are based on esparto, sisal, flax, hemp, abaca, reeds, and sabai grass. Total potential world
availability of nonwood plant fibers could now exceed 1.5 billion tons annually, of which more than 200 million tons might be readily collected in the United States alone. Even small percentage would be significant in the world’s pulp supply.

**BYPRODUCTS AND RESIDUES**

The present and potential supply of U.S. cellulosic byproducts from domestic crops is not accurately known. The total certainly exceeds 500 million tons (dry basis) of which potentially collectible cereal straws make up about 130 million tons and bagasse more than 5 million tons. Most cereals produce in the order of 2 lb straw/lb grain. General distribution of cereal straws throughout the various States is pictured in Figure 4.

The importance of raw material collection must be emphasized. Modern farming practices for most annual crops require highly mechanized field processing equipment. Minimum transportation of byproduct materials is involved. Most straws, hulls, stalks, cobs, and other byproducts are left in the field. They have some fertilizer value in certain regions, but in areas where they cannot be plowed under or burned, they cause serious disposal problems. The old familiar straw stacks and corncob piles have essentially disappeared from the landscape. The developing farming techniques that use no-till or minimum-till planting may necessitate some increased removal of byproducts from the fields. There is considerable controversy at present concerning collection of cellulosic materials as a separate operation and also about the amounts that can be economically recovered. Any major increase in the use of straw and other byproducts will require major efforts to collect, handle, transport, store, and deliver them at the plant at a cost so that they will be competitive with such other raw materials as hardwood. This effort will possibly mean major engineering breakthroughs. Bulk handling of bagasse and bulk handling and storage of wood chips typify such techniques. At one time, in the United States alone, there were at least 50 pulp mills based on straw, primarily from wheat (Figure 5). More than 650,000 tons of pulp were produced annually from wheat straw in 1950. Today, only a small amount of flax straw is pulped in the U.S. for speciality uses.

![Fig. 6. Bagasse pulp production worldwide.](image)
TABLE II
New Crop Opportunity

Of the 250,000 botanical species:
From 80-90 produce crops in U.S. worth more than $1,000,000
Only 200-300 used for commercial crops
Past efforts largely agronomic and to generate new varieties
Chemical composition of plant kingdom largely unknown

Bagasse is still available in collection form. In 1939, the first successful bagasse pulp mills started operation. In 1973, bagasse pulp was produced in some 80 mills located in 22 countries (Fig. 6). One paper mill and one board mill are located within the continental United States.

ANNUAL FIBER CROPS

In the U.S., production of annual nonwood cellulosic crops for industrial use has received little attention. Undoubtedly, this situation is changing because extensive research is now in progress.

There are at least 250,000 known plant species in the world (Table II). Almost all of these are nonwoody annual varieties and almost all contain considerable cellulose. The potential for new commercial crops from them is practically unlimit-
ed. Throughout the ages, man has rather arbitrarily selected the plants that best fill his needs for food, feed, and fibers.

Through research, high-yielding annual crops that convert solar energy can undoubtedly be developed. A significant breakthrough would have major effects on land usage and on world economics. Today, solar efficiency of practically all annual crops is less than 1%. Here again, extensive research is under way to develop crops that better utilize this energy. It is renewable energy and should be available for the foreseeable future.

In 1957, the U.S. Department of Agriculture initiated a new crops program. Its primary purpose was to find crops with major plant constituents different from those already available and to emphasize their potential for industrial use. Included was research on fiber crops for the production of pulp and paper. More than 500 species of fiber plants have now been evaluated. Highest rated materials include kenaf, roselle, sorghums, bamboo, and crotalaria.

Kenaf appears to have the greatest potential as a papermaking fiber. Yields in potential growing regions have been much greater than wood with 10 tons of dry matter/acre/year regularly reported. Under the best conditions as much as 20 tons has been reached (Fig. 7 and 8).

Kenaf has been grown as a fiber crop in parts of the world as a raw material from which to manufacture twine and rope. The bast fiber (about 20% of the total dry stalk weight) is used. Labor and handling costs in the U.S. require that modern cultivation and harvesting techniques be followed, and the whole kenaf stalk must be used if kenaf is to become commercially available. This is the basis for current research efforts.

Kenaf is now under intensive agronomic and utilization investigation by government and industry. Undoubtedly, kenaf or similar stem plants, such as roselle,
sorghum, or crotalaria, will become important annual cellulosic raw materials in the U.S. and in developing countries. They may be used either by themselves or as blending pulps for wood or with other nonwoody plant fibers, such as bagasse and straw.

CONCLUSION

This review has described briefly the possibilities for renewable annual crops as cellulosic raw materials. The potential now exists with greatly increased production possible. In 1970, the TAPPI Nonwood Plant Fibers Committee was established in recognition of the growing worldwide importance of this agricultural source.

Annual crops should not be considered as a complete replacement for wood as a source of fibrous raw materials. Rather, they have potential for extending limited wood supplies and for contributing desired characteristics and properties to finished products. Their utilization also provides a means to better utilize agricultural production with major resource and energy savings.

REFERENCES