

Jeanne Trombly  
Executive Director

## **II. TECHNICAL PROPOSAL**

### **1. Project Approach/Methodology**

#### **Objectives**

The overall goal of this research is to further the potential for using cereal straw as a supplemental source of fiber for paper-making and to evaluate systems for utilizing straw pulping effluent by chemical recovery or by producing a beneficial soil amendment from the fiber extraction process.

This research proposal builds on a current project that has recently completed an assessment of: 1) morphological properties of Washington State wheat straw fiber related to paper-making; and, 2) the genotypic and environmental variation in these properties to identify optimal cropping systems for generating high quality fiber for paper-making.

The research objectives being proposed for funding from the Washington State Department of Ecology, to supplement the remaining U.S.D.A. National Research Initiative Competitive Grants Program funding, are to: 3) determine the pulping, bleaching and paper-making response of straw from selected wheat cultivars preprocessed in a variety of ways; 4) determine the processing properties of the waste liquor comprised of straw organic by-products and spent pulping chemicals for potential use as a slow-release fertilizer; and 5) complete a report evaluating the commercial potential of utilizing this newly developed pulping technology and value-added by-product generation.

#### **Introduction & Significance**

##### *Environmental Considerations*

Environmental and population growth pressures are contributing to long-range changes in forest land management practices, which are reducing the availability of wood fiber for pulp & paper manufacturing. At the same time, cereal grain crop production in the U.S. generates tremendous quantities of straw each year. In Washington state alone, three million acres of wheat are grown each year, producing approximately 3 tons of straw per acre. While .5 ton of straw per acre must be left on the soil surface for erosion control of steeply sloped ground (Veseth, 1984), there is still abundant quantities of straw left in the field. This excess straw often cause problems for subsequent field operations, such as no-till seeding, and can promote the development of plant fungal diseases. This concern has prompted growers in the region to burn the straw or till it into the soil.

Approximately 200,000 acres of wheat straw were burned in Washington state last year. A recent report estimated that 45,000 tons of particulates, carbon monoxide and other volatile carbon compounds are emitted by wheat straw burning each year in the state of Washington. Recently, there has been public opposition to this air polluting practice by

region citizen action groups, such as Save our Summers. To address this air pollution and human health concern, the Washington State Department of Ecology Agricultural Burning Task Force, in conjunction with the Washington State Department of Agriculture and the Washington Association of Wheat Growers have entered into a voluntary agreement calling for reductions of wheat stubble burning that average 7% each year for 7 years, leading to a 50% reduction by the year 2006.

Establishing a market for cereal crop straw would provide growers with an economically feasible alternative residue management option, straw harvesting, while enabling them to reduce the level of field burning in the region and providing them with additional reliable revenue for a co-product of their grain harvest. Of course, in this scenario, it would be critical to limit the quantity of straw that could be harvested in order to avoid negative impacts on soil quality and to ensure adequate erosion control.

Given the current and future environmental and social pressures to limit the volume of wood harvested from U.S. public forest land, the utilization of cereal crop residues represents a significant fiber substitution opportunity. The pulp produced from cereal grain straw could be used as a substitute for wood fiber in a range of paper and paperboard products. The utilization of previously burned straw residue for the production of value-added products presents an innovative opportunity for sustainable resource management, provides additional income for farmers and contributes to the development of rural economies.

#### *Promoting the Utilization of Straw Fiber*

Fiber Futures seeks to increase the use of agricultural crop residues (ag-residues) and other innovative non-wood fibers as sustainable feedstock resources for manufacturing paper, building materials, textiles and other fiber-based products. As an information resource, Fiber Futures conveys opportunities for using non-traditional fiber resources. As business development specialists, Fiber Futures provides business technical assistance to eligible start-up enterprises and initiates strategic alliances to further uses of non-wood fibers. Fiber Futures has already been funded to conduct the pre-development work and to write a business plan for the nation's first zero-effluent non-wood pulping facility using wheat and grass seed straw from Pacific Northwest farmlands. This closed-loop manufacturing system would utilize the leftover residues from farmer's fields, currently being burned, as a feedstock for paper production. The pulping agents would be chosen based on their potential to produce a non-toxic effluent, capable of being converted into a safe, rich soil fertilizer which would be returned to farmers' fields in the form of timed-release pellets. If successful, this solutions-oriented, collaborative model of environmentally sound paper production could be utilized at other sites in the Pacific Northwest and across the nation.

However, before a widespread transition to cereal crop residues for use as pulp feedstock occurs, it is necessary to develop an improved understanding of wheat straw composition, morphology and preprocessing requirements. It is only with this information that it will be possible to predict the actual potential of crop residues to be used as an input for paper-making given the existing U.S. industry conditions. Furthermore, it is necessary to evaluate the fiber recovery steps (pulping, bleaching and liquor handling) in terms of straw properties. Preliminary work at WSU and UW (described later) on straw

morphology suggests a broader range of straw properties than initially expected from literature reports. Initial research on preprocessing suggests that the option chosen also could have a substantial impact on pulp and paper properties. Consequently, there is potential for cultivar selection, environmental effects and preprocessing to be manipulated in order to enhance paper properties.

The utilization of cereal straw could provide partial replacement of the wood fiber shortfall expected in the upcoming years. Estimates indicate that processing of approximately 10% of the available Pacific Northwest wheat straw would be equivalent to increasing the chip supply in that region by 10% (Timmer, 1993). This is a significant impact, as Washington State is currently a net importer of wood chips for papermaking. Processing this amount of wheat straw would be equivalent to approximately five pulp mills each producing 500 tons of pulp per day from about 10% of the straw produced in a 25 mile growing radius of each mill in irrigated areas or a 50 mile radius in dry land areas.

This concept is not entirely new. In fact, straw-based fiber production occurs in many wood-poor regions of the world. China annually produces 60% of its 5 million tons of paper from straw, mostly from wheat (Haifeng, 1988). The European Economic Community realized a severe shortage of wood-based raw materials more than a decade ago (Rexen, 1984), and have instituted research and development programs to adopt alternative fiber sources for paper production. In Denmark, printing and writing paper contains between 15 to 50% straw pulp. There have been several recent developments in Canada using crop residues for pulp & paper applications. Most notably, Al Wong of Downtown Paper is producing a wheat straw paper composed of 45% wheat straw, 45% recycled PCW paper and 10% chalk. Other developments in Canada are focused on the utilization of flax residue for pulp production.

However, the utilization of cereal crop residues in the United States has several potential limitations which include: 1) small fiber dimensions, which limits the strength of paper products and slows paper machine operating speeds; and 2) high inorganic content which creates problems in conventional chemical recovery systems. Blends of straw and preferably recycled wood pulp offers useful paper properties, increasing the strength of the paper product. Additional limitations include the need for a dedicated straw pulping facility to pulp the wheat straw, since existing wood-pulping facilities use too harsh of chemicals and different operating procedures to effectively pulp non-wood alternatives. Other challenges include the tendency by wood-based industries to stay with the status quo due to high investment costs and market uncertainties. In addition, straw handling issues (harvesting, storage and transportation) issues will greatly influence the economic viability of the straw processing operation. A better understanding of straw properties and potential use of the pulping effluent as a value-added, slow-release fertilizer will be the basis of future developments using significant quantities of this raw material in Pacific Northwest and other U.S. mills.

### **Straw Morphology**

The extent of environment X genotype interactions is not well characterized, but it is critical to understand the nature of these interactions, because wide variations in raw

materials will cause quality control problems in large scale manufacturing operations. A strong environmental influence on variations in fiber quality would suggest the importance of identifying a narrow range of optimal wheat-growing environments for generating straw fiber. On the other hand, a strong genotypic correlation with fiber quality would suggest that there is potential for identifying or developing wheat cultivars that produce superior straw fiber for paper-making.

Wheat breeders have traditionally focused their efforts on improving yield potential and pest resistance in cultivar development, while placing little emphasis on straw characteristics. While Rexen and Munck (1984) suggested that wheat straw pulp exhibits similar papermaking characteristics as hardwood pulp, the range of variability in wheat straw fibers was not explored. Our preliminary characterization studies of six Washington State commercial wheat varieties (Haynes, 1994) revealed a wide range of stem fiber dimensions, implying that there may be significant genetic variation in fiber characteristics, although these studies also suggested that there may be a strong environmental influence. The range of fiber length and diameter vary with cultivar and with environmental factors. Average values of fiber length and diameter for the Madsen variety grown under irrigated conditions approach some commercial hardwoods. Conversely, the poorest papermaking candidates have about 1/2 of those fiber dimensions.

Recent research was performed by Roberta Jacobs, as a graduate student at the University of Washington, characterizing the chemical composition and morphology of wheat straw as it relates to papermaking needs. Jacobs found that both environmental and genotypic variations influence fiber morphology as it affects papermaking (Jacobs, 1999 Pulping Conference). Her research exhibits promise for future efforts toward selecting cultivars and optimal wheat-growing conditions for producing straw with superior papermaking qualities.

### **Preprocessing**

In addition to cultivar selection and environmental conditions, preprocessing of the straw is also an important factor that contributes to pulp and paper performance. Preprocessing removes the less desirable straw components, like leaves and nodes, from the raw material prior to pulping. Other preprocessing methods that will be considered include the removal of less desirable plant and stem materials, like the pith and epidermal, prior to pulping. Research performed overseas comparing the pulping of preprocessed straw to whole straw shows that preprocessed straw produces improved paper strength properties and a higher pulping yield. It was found that in Europe, where straw is mechanically harvested leaving more leaves in the field, there was a higher pulping yield than in China, where straw is hand harvested which incorporates more leaves into the pulping process (J. Jeyasingam, 1999).

Recent research by the University of Washington has provided some preliminary results comparing preprocessed straw to whole straw. Both straw types were pulped using soda anthraquinone pulping. The research initially found that the preprocessed straw, with leaves and nodes removed, led to improved paper properties and pulping yield (Jacobs,

1999). Further research on preprocessing options offers an opportunity to improve the final pulp properties and so will be continued as part of this research project.

## **Straw Pulping**

Large scale pulping of wheat straw residues poses challenging problems. Differences (from wood) in straw chemical and physical properties significantly influence the processes of harvesting, cleaning, pulping, spent liquor processing and papermaking. For example, the higher fines and silica content in leaf nodes would suggest separation in the field of that denser material from the lighter, bulkier stem segments. However, informed decisions on these process steps require more complete assay results to confirm the distribution of these materials in various cultivars, grown over a range of environmental conditions.

Wheat straw has been pulped by many mechanical and chemical processes. Because of the relatively low lignin content and abundance of partially soluble pectin and hemicellulose materials, straw has been successfully converted to rough corrugated and linerboard products by medium shear mixing in boiling water or slightly pressurized reactors (Aronovsky, 1949). Heating to elevated temperatures followed by instantaneous pressure relief (steam explosion) minimizes shive content and improves corrugated and linerboard properties. High shear conditions probably fracture the thin walled, straw fibers and produce small dimension fragments which can retard water removal during papermaking.

In general, acid or alkaline chemical pulping results in better papermaking properties, but lower yield than mechanical processes. These pulps can be bleached to high brightness for incorporation in writing and communication papers (Haifeng, 1988). Wheat straw has been bleached by two to four stages using chlorite, caustic and hypochlorite treatments (Misra, 1987). However, since environmental and health concerns strongly discourage chlorine bleaching in the United States, it is critical for further research on the response of wheat straw pulps to chlorine-free bleaching agents.

Generally, strength properties of alkaline pulps exceed acid pulps, so soda, kraft and alkaline sulfite processes offer the greatest commercial potential for papermaking. However, the chemical recovery system associated with the kraft processes for pulping non-woods is different than for soda anthraquinone pulping. The high inorganic content of annual crop straw and the negative effects on sodium chemical recovery systems is well-documented (Misra, 1987). Small scale commercial pulping (about 1/100 of U.S. production unit size) in developing countries involves land or water disposal of soda-based spent liquors, unacceptable practices in the United States. Alternatively, attempts are made to recover the pulping chemicals with or without silica rejection. The former employs systems unproven for U.S. sized production and the latter is unworkable because of silica scaling of equipment in large U.S. combustion units, which are expected to remain on-line for long periods before shutdown for cleaning.

Clearly, the chemical pulping must depend on the type of paper product and on the quantity of silica entering the pulp facility. Successful mechanical separation of high silica content fractions of the plant stem may permit the use of soda or kraft pulping. But, information is required on the amount and location of silica in the major commercial

cultivars to evaluate mechanical separation systems and to project silica loads in the pulp mill black liquors. If these values exceed about .5% SiO<sub>2</sub> based on dry solids content on the liquor, then silica purge systems (Paassinen, 1968) will likely be required for any sodium-based pulping.

Alkaline sulfite pulping is used in many mills manufacturing bleached fine paper grade pulp. This process is commonly used when pulping hardwoods. Since the fiber morphology of straw is much like that of hardwoods, the alkaline sulfite pulping process should give favorable results. Preliminary investigations have proven that sulfite processes can effectively be used with cereal grains (Li, 1990; Liu, 1988). A number of producers use ammonium sulfite systems and dispose of the spent chemical on agricultural land. Other non-sodium based pulping chemistry may also allow return of liquor to the soil (Wong, 1989). This option is potentially viable in the U.S., but the effects of spent pulping chemicals on soil quality and on crop nutrient availability are still poorly documented. Available information on this topic is discussed in the next section.

### **Spent Pulping Liquor**

Wheat straw contains complex organic compounds, including lignin and carbohydrates. During soda and ammonium sulfite pulping, a portion of these materials are solubilized and the resulting aqueous mixtures eventually are burned in the chemical recovery system. The particular reaction steps and products are important to the extent that they influence final pulp lignin content and black liquor burning properties. However, assuming that ammonium sulfite liquors could be returned to agricultural land to capture nutrient values, the composition of that spent liquor assumes greater importance. Some discussion of the potential use of this liquor is given in the following paragraphs. The organic materials in wheat straw when reacted with ammonia at high temperatures and pressures, will produce organically-bound N forms. Winter wheat straw contains about 15% lignin and 25% carbohydrates that would be separated from the cellulose fibers during pulping (Rexen, 1984). Chemical fixation of ammonium has been demonstrated in soil organic matter, leaf litter, sewage sludge, animal manure, cereal straw and sawdust (Nommik, 1982). Phenolic and carbohydrate hydroxyl groups are sites for simultaneous oxidation and nitrogen fixation to produce organic nitrogen compounds (Bennett, 1949).

A large number of studies are reported on pulping of annual crops by sodium-based alkaline (kraft or soda) or acid, neutral or alkaline sulfite processes for a range of pulp products. Potential silica related problems with large scale combustion of spent liquors from kraft and soda-based processes have already been mentioned. For alkaline sulfite pulping, the use of ammonium or potassium should enhance the characteristics of the spent liquor for use as a soil supplement, which will avoid the combustion problems associated with spent liquor disposal (Li, 1990; Liu, 1988).

Alkaline ammonium sulfite processes applied to annual crops produce pulp at comparable yields and properties to kraft and soda-based processes (Li, 1990; Liu, 1988). The spent liquor from straw pulping will contain approximately one-third spent pulping agents and silica, along with two-thirds organic materials in dissolved and colloidal form. The inorganic nutrient composition of spent pulping liquors can be manipulated by using combinations of ammonium and potassium sulfite or hydroxide for liquor pH control and by neutralizing the spent alkaline liquors with phosphate (Wong, 1989). If the pulping

agents contain ammonium compounds, such as occurs in ammonium sulfite systems, the lignin portion of the liquor solids will incorporate nitrogen in ammonium salt, amine and heterocyclic forms. The exact composition will depend on the severity of the pulping conditions (Gratzl, 1993; Collins, 1987). After field application, this nitrogen will be released to agricultural plants at rates depending on the form, allowing the material to act as a slow-release fertilizer.

The conditions for an agripulp system visualized in the proposed project depart significantly from typical commercial sulfite pulping. Considerable study is required to obtain the proper pulping conditions and to understand the soil, crop and environmental implications for this type of agricultural-manufacturing combination. The study of soil/crop/liquor interactions is described in the work plan.

### **Spent Liquor as a Soil Amendment**

Preliminary studies conducted by M. Mahoney at WSU suggests spent liquor from wheat straw pulping can improve soil physical properties, such as water holding capacity and soil aggregate size and stability. Although commercial fertilizers have provided an expensive and convenient source of plant nutrients for plant production, their widespread use in lieu of organic fertilizers over the last 50 years has resulted in a decline in soil organic matter levels (Rasmussen, 1989; Doran, 1987). In addition, severe soil erosion problems in many areas of the U.S., including the Pacific Northwest, have resulted in a loss of organic matter-rich topsoil. In eroded landscape positions, soil productivity has deteriorated and residue production has declined, which leads to further decreases in soil productivity (Oldenstadt, 1982; Pan, 1992). This downward spiral could conceivably be reversed with the addition of the straw spent liquor to these soils as part of a soil reclamation strategy. Thus, the whole system may involve the harvesting of organic matter from non-eroded slope positions, conversion into a high N, P, K and S organic amendment and application of this material onto eroded slope positions to improve soil productivity. Past studies have suggested that the productivity of eroded slopes improves with the addition of organic matter (Pan, 1992).

Organic nutrient sources such as animal manure often produce grain yields above and beyond those obtainable with inorganic fertilizers (Rao, 1993). Improvement of soil quality by incorporation of organic amendments and residues has been a subject of recent interest. Organic amendments increase soil water holding capacity, improve soil aggregation and structure, and increase cation exchange capacity (Pan, 1992). The addition of organic carbon also stimulates beneficial microbial activity. Green manures improve water infiltration rates (Sarrantonio, 1992) and increase soil aggregate stability (Thorup-Kristensen, 1993). These effects decrease soil erodibility and potentially improve crop productivity (Griffin, 1991; Kay, 1998).

Fertilizer use in intensive crop production potentially deteriorates surface and ground water quality. Phosphorus and nitrogen runoff into surface waters causes eutrophication. Nitrate leaching is a serious problem that may lead to contamination of water supplies. Nitrate levels in Washington wells have increased over the past several years (Erickson, 1990), with many exceeding EPA established levels for safe drinking water. In most

arable soils, ammonia readily oxidizes to nitrate, and thereby becomes susceptible to leaching below the root zone. This reduces the crop recovery efficiency of N fertilizer. There is a need to develop cropping systems based on ammonium nutrition (Bock, 1984) to reduce nitrate leaching and contamination of water supplies. Chemical inhibition of nitrification has been shown to improve N recovery and reduce N losses (Pan, 1992). However, these inhibitors are expensive to use and difficult to handle.

The synchronization of nutrient release from the liquor with the timing of plant demand will dictate whether this product will have a positive or negative effect on the potential for nitrate leaching. It has been well recognized that this synchrony is important for optimizing N uptake in other organic fertilizer systems. For example, legume cover crops preceding a potato crop had poor synchronization of mineralization in relation to the timing of potato nitrogen requirements (Griffin, 1991; Lauer, 1986). Major factors to be considered in synchronizing N availability include the method of incorporation, soil moisture and temperature regimes, the C/N ratio of the residue, and the timing of incorporation (Ladd, 1992; Frankenberger, 1985; El-Haris, 1983; Yaacob, 1980). These environmental relationships with straw liquor reactions in soil must be defined before the material can be reliably used as a fertilizer source.

Clearly, commercial utilization of annual crop straw residues offers potential as a fiber source. Furthermore, in combination with fertilizer systems described above, a number of agricultural problems may be addressed. However, critical areas need clarification before commercial development. Early attempts by our laboratories to achieve ammonium fixation to wheat lignin have had limited success; however, our most recent experiments provide preliminary evidence that the proper conditions have been identified. This is a huge step forward toward our goal of creating a slow-release nitrogen fertilizer from the black liquor generated from wheat pulping.

## **2. WORK PLAN**

### **Research Methods**

The project work plan is organized into two coordinated areas of research to address the issues described above:

- E. Washington wheat straw will be preprocessed in several different manners. The resulting straw material will be pulped by soda anthraquinone and alkaline ammonium sulfite processes. The pulping processes will be initially evaluated based on the fiber morphology measurements determined. Relative performance of the two pulping processes will be compared in terms of yield, lignin content and bleachability of the resulting pulps. Refining studies, water drainage rates, water retention values, and physical properties of handsheet paper samples will also be measured to evaluate the relative performance of the pulps produced.
- F. Chemical characterization of the spent liquors generated from pulping procedures, and evaluation of the viscosity/concentration and scaling tendencies of soda anthraquinone liquors will be performed. The ammonium sulfite liquor will be tested as a soil amendment for improving soil quality and nutrient availability to crops.

### **A1. Preprocessing**

Research on preprocessing will consist of performing the various preprocessing options and then pulping the resulting straw using the two pulping processes being researched. The evaluation of the preprocessing options will be based on the cooking chemicals required and the characteristics of the resulting pulp. The final pulp properties will be compared based on the yield loss, silica balances, fiber length distribution and the pulp handsheet properties (see section I.d.) These characteristics will be evaluated using the following methods: yield (mass balance OD basis), the silica balance (TAPPI Method 244), the fiber length distribution (Kajaani fiber analyzer), and the pulp handsheet properties (TAPPI Method 220).

### **A2. Soda Anthraquinone and Ammonium/Potassium Sulfite Pulping**

The University of Washington will pulp the different pre-processed straw options using two pulping methods, soda anthraquinone and ammonium/potassium sulfite. Sodium-based cooks will use a combination of sodium hydroxide and anthraquinone as the chemical treatments. An alternative which will be evaluated will be the use of potassium hydroxide. The university will also run cooks that utilize potassium instead of sodium, to test the performance of this alternative black liquor as a soil fertilizer. Alkaline sulfite pulping cooks will also be performed. Ammonium sulfite and potassium sulfite will be used as the chemical treatments to evaluate their impacts on the spent liquor characteristics for use as a soil amendment or fertilizer. Additional information on these two pulping methods was discussed in the section on Straw Pulping above.

The pulps will be characterized initially by assessing the fiber morphology by measuring the fiber length using the Kajaani fiber analyzer method. Once a superior variety is selected, additional laboratory tests will be performed to determine the relative performance of the pulping processes in terms of yield, lignin content, bleachability, freeness and water retention values of the resulting pulps. The yield will be measured using the mass balance OD basis. The lignin content will be determined using Systematrix Kappa tester. The bleachability of the resulting pulp can be evaluated from the lignin content and by using elemental chlorine free bleaching sequence. The water drainage rates or freeness of the resulting pulps will be determined using the Canadian standard freeness method, TAPPI Method 227. The water retention values will be evaluated by TAPPI Useful Method 256.

### **A3. Spent liquor generation**

Cooking liquor will be applied between 4:1 and 8:1 liquor to straw ratio. After the cooking is complete, the liquor will be collected. Investigations into steam stripping of the liquor have shown that it is possible to enhance the characteristics of the liquor with this technique. The spent liquor that is generated will be sent to Washington State Univeristy for thorough liquor characterization and soil and crop response testing.

#### **A4. Fiber fractionation and refining**

After the cooking process has taken place, the straw is then exposed to a mechanical action which separates the fibers. The pulp is then washed and screened to remove unwanted shives, uncooked nodes, or any other material that would be detrimental to the production of paper. The method used to fractionate out the fines is Bauer McNett TAPPI Method 233.

The resulting fiber pulp will then be refined using a mechanical process to increase the surface area of the fibers, and thus improve the strength of the resulting paper. The method used to refine the pulp will be the PFI mill method, TAPPI Method 233. The pulp will be refined to four different levels of freeness. Freeness is a standard method that is used to determine the amount of refining done to a given pulp.

#### **A5. Laboratory handsheet testing**

Once the pulp is produced, experimental sheets of paper called handsheets will be made for physical and optical property evaluations. The formation of the handsheets will be developed using TAPPI Method 205, and the subsequent testing will be completed in accordance with TAPPI standard methods. The fiber length of the handsheet pulp will be determined using the Kajaani fiber analyzer and the lignin content will be measured using Systemetrix Kappa tester. The paper properties will be evaluated by measuring the tensile strength, burst strength, tear resistance, brightness and opacity of the handsheets using TAPPI Method 220. These paper characteristics can also be evaluated using individualized TAPPI Methods 496, 404, 432, 451 and 538 to evaluate the various strength properties of the resulting handsheets.

#### **B1. Liquor Characterization**

The utilization of spent chemicals as soil nutrients will very likely require concentrating, pelletizing and storage for application in the normal crop cycles. Design of process steps will require information on viscosity/solids relationships, liquor composition and vapor pressures for volatile gases. The viscosity behavior will be measured by standard TAPPI Information Sheets 0607-04 and 0607-22. Vapor pressures of ammonia and sulfur dioxide are already available from Scott (1964). Tendencies for silica deposit formation will also be measured using TAPPI Methods 211 for the ash and T244 for the silica. Lignin will be measured by TAPPI Method 222. Total N, C, H, S will be measured with dry combustion autoanalysis using LECO instrumentation. Other alkali metals will be determined with atomic absorption spectrometry. Other standard characteristics (pH, EC) will also be determined.

#### **B2. Nitrogen Mineralization, Nutrient Availability & Soil Physical Characteristics**

Soil incubation experiments will be conducted in the laboratory to examine the nitrogen release rates in soils as a function of carbohydrate, lignin composition and heat accumulation units. An infertile Shano silt loam soil (coarse-silty, mixed, mesic Andic Mollic Cambosol) and a Quincy sand will represent the low organic matter soils of east-central Washington. These soils, identified as being low in N and P availability to plants, will serve as a good media for evaluating the nutrient availability of the liquor. In

addition, Palouse silt loam (fine-silty, mixed, mesic Pachic Ultic Haploxerolls) from eroded and non-eroded areas of eastern Washington will be collected.

Soil samples will be treated with varying rates and types of the liquor, and allowed to incubate at a soil moisture level approximating field capacity. The release rates of plant available N, P, and K will be monitored with standard Washington soil test procedures established by our laboratory. The inorganic nitrogen available will be measured with dry combustion autoanalysis using LECO instrumentation. Nutrient release will be related to changes in the inorganic/organic fractions of these nutrient over time. Elemental composition of the soil solutions will be characterized with ion chromatography and atomic absorption spectrophotometry. Electrical conductivity will be measured to check for potential salt toxicity problems.

Spent liquor effects on soil physical properties, such as water holding capacity and soil aggregate size and stability will also be examined. Water holding capacity will be measured using a gravimetric determination. Soil aggregation will be characterized using the hanging column method, and wet and dry sieving procedure will be used to determine aggregate stability.

### **B3. Crop Response to Spent Liquor Application**

From this information, reasonable estimates of liquor amounts can be made to be applied in subsequent greenhouse and growth chamber experiments. These experiments will be conducted to examine crop response to the pulping liquor. Spring wheat will be grown in containers under greenhouse conditions to compare dry matter, morphological development, and nutrient accumulation as affected by the soil amendment. Plant tissues will be analyzed for accumulation of major and minor elements. Rhizotron systems will be established in selected treatments to examine root growth responses to soil amendments. Digitized computer images will be created with portable scanners and root dimensions will be estimated with edge discrimination image analysis. Optimal rates of application will also be used to bioassay for potential phytotoxic organic compounds that may be released during the decomposition of the complex organic fraction of the liquor.

### 3. Schedule

#### Current and Pending Tasks (1999-2001)

	1999				2000				2001			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
I. Wheat Straw Characterization												
a. Morphology & Chemical Content of Commerical Cultivars												
Leaf, stem, node mass												
Chemical composition												
Fiber isolation and assay												
b. Publication of Morphology & Chemical Content Research												
II. Pulp Response												
Soda Anthraquinone cooks												
Ammonium/Potassium sulfite pulping												
Spent liquor generation for use in III.												
Fiber fractionation and refining												
Laboratory handsheet testing												
III. Soil and Crop Response to Spent Liquors												
Liquor Characterization												
Soil incubations												
Crop response to spent liquor												
IV. Deliverable: Identify most successful pulping process, develop slow-release nitrogen fertilizer from pulp effluent, and produce essay describing commercial potential of this research.												

### 4. Deliverable

The deliverable of this research project will be the identification of the patentable technical process for successfully pulping wheat straw, while producing a usable effluent that can be returned to farmers as a slow-release nitrogen fertilizer. Fiber Futures will develop a report summarizing the commercial potential of this straw pulping research and effluent fertilizer development. This essay will be utilized in the business plan to rationalize the economic potential of the development of a straw pulping facility in eastern Washington.

In future years, the universities plan to field test the fertilizer over the course of 2-3 years in order to evaluate the success of the product during various weather conditions. This data will be used to determine the success of the value-added fertilizer in the field and to further interest potential buyers in marketing the fertilizer by-product.

### III. MANAGEMENT PROPOSAL

#### II. Project Management

##### 1. Project Team Structure/Internal Controls

##### 1. Project Team

<i>Fiber Futures Project Team</i>	<i>Universities Sub-Contractors</i>
Jeanne Trombly (1/4 time) Project Director Fiber Futures	William T. McKean Professor, Paper Science & Engineering Dept. College of Forest Resources University of Washington
Kristen Martinez Project Coordinator Fiber Futures	Mark Lewis Manager of Program Operations College of Forest Resources University of Washington
Michael Jackson and Roberta Jacobs On-Call Technical Consultants Fiber Futures	William L. Pan Professor, Soil Science Department of Crop and Soil Sciences Washington State University
Nancy Hurwitz Project Associate Fiber Futures	

##### 2. *Team Structure*

Jeanne Trombly of Fiber Futures will be responsible for submitting the final report and initial commercial analysis of the research that will be conducted. Fiber Futures has already been funded to conduct the pre-development work, perform the economic analysis and write a business plan for the nation's first zero-effluent non-wood pulping facility using wheat and grass seed straw from Pacific Northwest farmlands. The development of an effective straw pulping technology and soil amendment from the pulping effluent compose the critical Research & Development components of the pulping project. For these project tasks, Fiber Futures will be subcontracting to the University of Washington and Washington State University who are already working on the development of this pulping technology and exploring value-added opportunities such as a slow-release nitrogen fertilizer derived from the pulping effluent. Fiber Futures will also bring on two highly qualified technical pulp & paper consultants, Michael Jackson and Roberta Jacobs, to assist and review the work of the universities and provide assistance with the report writing once the research is complete.

##### 3. *Organization Chart*

The organizational chart is attached as a Power Point document.

### **Division of Research Responsibility**

Wheat will be grown and sampled for straw at Washington State University (WSU) by Bill Pan. Straw fiber preprocessing and pulping will be conducted at the University of Washington (UW) by Mark Lewis and Bill McKean. The chemical characterization of the spent liquor will be conducted jointly by the UW and WSU researchers. Soil and crop responses to the soil application of the spent liquor will be conducted at WSU.

### **4. Internal Controls**

Jeanne Trombly, Executive Director of Fiber Futures, will be the project manager, ensuring that the team stays on schedule and creates timely reports. She will work mostly with Mark Lewis and Bill Pan, who will be conducting many of the scientific experiments together under the guidance of Bill McKean.

The standard procedure at the University of Washington and Washington State University is to have the research manuscripts, where data is reported and analyzed, submitted to a peer review process by other university faculty. This procedure will act as an internal control to verify that the data and analysis was derived using appropriate scientific methodology and laboratory testing.

Additionally, Mike Jackson and Roberta Jacobs, who are technical consultants to Fiber Futures, will conduct an independent analysis of the technical conclusions made by the university researchers for Fiber Futures and contribute to the final report. Ms. Trombly will write the final report, described above as the deliverable.

## **2. Staff Qualifications and Experience**

### *5. Jeanne Trombly, Project Director*

Ms. Trombly founded Fiber Futures, a non-profit consulting group established to further the commercial viability of alternative fibers and agricultural residues in the paper, building materials and textile industries. In this position, Ms. Trombly brings considerable experience in the community economic development field with a special emphasis on providing business technical assistance to start-up ventures. Her work in non-traditional fibers started when she was funded to help a maverick paper scientist launch a wheat straw pulp mill. In this capacity, she helped convince a multi-national paper company complete a pilot run of ag-residue pulp for major California's newspapers. In 1997, she co-founded Fiber Futures '97, a conference which drew over 150 attendees interested in commercial solutions and successful examples of alternative fiber uses.

She brings over 10 years of experience working in community economic development after having served as the Program Director for the Materials for the Future Foundation. In this capacity, she researched and designed an award-winning community revolving loan fund targeting high-risk recycling businesses in Alameda County, California. In addition, she provided general business technical assistance and helped launch a building materials reuse company in San Francisco. Ms. Trombly has a B.A. in International Affairs/Communications from George Washington University. She has completed the Economic Development Finance Professional certification program from the National Development Council.

**Kristin Martinez, Project Coordinator**

Kristin Martinez is founder and principal of Sound Point Ventures, LLC, in Seattle, Washington, providing private equity services and innovations, including mission related investing and venture philanthropy, to individuals and institutions. Current projects include creating and capitalizing an acquisition fund investment vehicle for a nonprofit organization, working with individual and venture fund clients to identify private equity opportunities, and assisting early stage companies and enterprising nonprofits with strategic financial advice and venture financing. Kristin is a co-founder of New Vantage Partners, LLC, a private equity investment advisory firm in the Mid-Atlantic where she co-produced two venture fairs each year for the Investors' Circle, a national group of investors working to grow the social venture capital industry. She was an advisor to two recently formed venture funds, the \$30 million Women's Growth Capital Fund and the \$25 million Telecommunications Development Fund. Her experience includes eight years in the energy industry, most recently as Vice President of Operations and Treasurer at Pepco Services, Inc., an energy services startup in Washington, D.C. that has grown to over \$25 million in sales. Additionally, she spent three years as Executive Director of a private, non-profit economic development corporation in central Vermont, where she established and managed a \$2 million regional loan fund portfolio. Kristin is a member of the Advisory Board of the Avalon Trust Company in Santa Fe, New Mexico. She holds a B.S. degree from Boston University and an MBA degree in finance and investments from The George Washington University.

**Michael Jackson, Technical Advisor, On-Call Consultant**

Michael Jackson has over thirty five years experience in the pulp and paper industry involving process design, process development, and process optimization in pulping systems. He is familiar with a wide range of process technology in pulping, bleaching, and stock preparation. He has specialized in fiber processing, related operations, and pulp requirements in paper products. His technical work includes over a dozen published papers. Recent projects have focused on feasibility studies, process improvement, and product opportunities in a wide range of pulp and paper mills. He has worked on sulfite and kraft process development, dissolving pulp, mechanical pulping, stock refining, and pulp and paper product requirements. He is an active member of TAPPI being involved in the Sulfite and Mechanical Pulping Committees and he is currently Chair of the Nonwood Fiber Committee and undertakes projects in the nonwood area. He has a B.S. and a M.S. in Chemistry from Manchester University in England, and a Ph.D. in Chemistry from the University of British Columbia, Canada.

Specific projects in the nonwood area include:

- Design and feasibility studies on alternatives for bagasse utilization in paper
- Preliminary evaluation of wheat straw pulping at Northwest U.S. mills
- Design of straw pulping facility for unbleached board and assistance in operating pilot plant
- Process evaluation for a novel agricultural residues pulping facility
- Cooperation and assistance to NACO International on marketing a pulping process for nonwood material

### **Roberta Jacobs, Technical Consultant**

Roberta Jacobs is currently an Assistant Professor of Paper Science at the University of Wisconsin at Stevens Point. Prior to this, she was working as a Research Assistant, Teaching Assistant and Instructor in the Paper Science and Engineering Department at the University of Washington, under Bill McKean. In 1994, Jacobs worked as a Graduate Student Intern for the Weyerhaeuser Research Center in Tacoma, Washington on the Newsprint Business Support Team examining the potential impact of raw material changes. As part of her extensive professional affiliations, Jacobs is a member of the TAPPI (the Technical Association of the Pulp and Paper Industry) Nonwoods Committee and has been an active TAPPI member since 1988. She has made numerous presentations at TAPPI pulping conferences and has published extensive articles, often jointly with Bill Pan and Bill McKean, on fiber morphology, chemical composition, and other topics relating to wheat straw utilization. She has recently completed research evaluating the environment and genotypic impacts on fiber morphology and chemical composition, as well as preliminary research on the impacts of preprocessing on final pulp properties. She has been working jointly with Bill McKean and Bill Pan to evaluate the performance of non-wood pulping processes and to generate a suitable black liquor to be used as a soil amendment or fertilizer. Jacobs received a B.S. in Paper Science and Engineering at the University of Washington, a M.S. in Chemical Engineering at the University of Maine, and a Doctorate in Philosophy in Paper Science and Engineering at the University of Washington. Her dissertation, completed in Spring 1999, was entitled, "The Papermaking Properties of Washington State Wheat Straw."

### *Nancy Hurwitz, Project Associate/Researcher*

Nancy Hurwitz brings organizational, communication and computer skills, along with a substantial background in agriculture, natural resource management and economics to Fiber Futures. Ms. Hurwitz has developed its web site, refined its database, conducted extensive research for clients, and identified opportunities for network building. Prior to this, she worked with the Oregon State Public Interest Research Group to train and mobilize student volunteers in the skills of leadership, public interest research and advocacy. Ms. Hurwitz worked as events coordinator for the Second Annual Northeast Regional Student Activist Conference. As a Conservation Assistant for the Northwest Ecosystem Alliance in Washington, she researched and published articles on resource conservation issues. She received a B.A. in Environmental Science and Public Policy from Harvard University.

### **Subcontractors**

#### **William T. McKean, Professor, Paper Science and Engineering, University of Washington**

William T. McKean has been a Professor of Paper Science and Engineering, and of Chemical Engineering at the University of Washington, College of Forest Resources for the past 20 years. Previous to that, he served as a Senior Research Engineer and Manager of Fiber Sciences for Weyerhaeuser Company, and as a Professor of Wood & Paper Science at North Carolina State University. In addition to his extensive

professional experience, he is a Member of the TAPPI Board of Directors from 1993-1996, and has taught at numerous seminars, lectures and short courses on pulping, bleach recovery and paper-making topics. He has published numerous scientific articles on fiber morphology, pulp and paper properties, modified batch cooking and other related pulp & paper technology. His project team recently received a grant from the National Research Initiative for three years of funding to work on the development of this non-wood pulping technology. Professor McKean received his B.S. in Chemical Engineering from the University of Colorado and his Ph.D. in Chemical Engineering from the University of Washington.

**W.L. Pan, Professor and Soil Scientist, Washington State University**

Dr. William Pan has been a Professor and Soil Scientist for Washington State University Department of Crop and Soil Sciences for the past 15 years. Dr. Pan has conducted soil fertility and agronomic research over the past 22 years, specializing in nutrient cycling and rhizosphere ecology. Dr. Pan is also a member of several professional societies in his field, including the American Society of Agronomy, the Soil Science Society of America, the American Society of Plant Physiologists and the Far West Fertilizer and Agrichemical Association. He has published several book chapters and numerous scientific articles on soil science, nutrient uptake and availability and fertilizer management. For the past five years, Drs. Bill Pan and Bill McKean have collaborated to evaluate the potential for utilizing wheat straw for papermaking in the Pacific Northwest. For the past three years, they have been funded by a USDA/NRICGP grant to examine genetic and environmental factors affecting paper making properties of wheat straw fiber, and to evaluate pulping processes for generating suitable black liquors that would provide stock for soil amendments and fertilizers. The results indicate wheat straw has promise for supplementing traditional hardwood fiber sources in papermaking. Recently, progress has been made in identifying conditions required to fix ammonium to lignin of wheat straw, which may lead to the development of a slow-release N fertilizer. Professor Pan received a B.S. in Biochemistry from the University of Wisconsin, a M.S. in Soil Science from the University of Missouri and a Ph.D. in Soil Science from North Carolina State University.

**Mark Lewis, Manager, Program Operations, University of Washington**

Mark Lewis currently works as the Manager of Program Operations and the Director of the Paper Science and Engineering Cost Center at the University of Washington. He has over 20 years of experience in the pulp & paper industry, including 11 in Research and Development. In the past, he served as Papermaking Research Manager for GK Carbonate, a division of English China Clays. Lewis has performed laboratory work with many different ag-fiber sources to evaluate their fiber morphology, and to determine the optimal pulping conditions for each type of ag-fiber.

*Resumes*

Resumes for the staff, consultants and subcontractors listed above are attached.

*B. Experience of the Applicant*

1,2. The project team, consultants, and subcontractors have substantial experience in the following areas:

Community Economic Development  
Business Technical Assistance  
Financing  
Research & Analysis  
Soil Fertility  
Plant Nutrition  
Nutrient Cycling and Rhizosphere Ecology of Agricultural Systems  
Site-specific Nutrient Management  
Computer Imaging of Plant Root Systems  
Pulping, Bleaching and Recovery Process Technology, Flowsheets & Material & Energy Balances  
Papermaking Processes and Laboratory  
Pulp and Paper Unit Operations  
Pollution Abatement in Forest Products Industry  
Process Design and Process Economics of pulping systems  
Process Development and Optimization of pulping systems  
Fiber Processing and Pulp Requirements in Paper Products

3. ***Relevant Contract References for the University of Washington***

a. Ernett Altheimer or Dick Macintee

Nile Fiber  
P.O. Box 1114  
Tacoma, WA 98401  
253-627-3756 phone  
253-627-5259 fax  
nilefiber@seanet.com

**Current**

b. Bill Snyder

Universal Pulping  
P.O. Box 11586  
Eugene, OR 97440  
541-484-5312 phone  
541-484-0657 fax  
[bsnyder@rio.com](mailto:bsnyder@rio.com)

**Current**

c. Michael Jackson, Ph.D.

Consulting for the Pulp & Paper Industry  
P.O. Box 169  
Tolovana Park, OR 97145  
503-436-2110 phone  
503-436-9256 fax  
[mjackson@seasurf.com](mailto:mjackson@seasurf.com)

## **Current**

- d. Lee Snipes  
Asten  
3506 NW 114<sup>th</sup> St.  
Vancouver, WA 98685  
360-608-6913 voice mail  
360-576-7795 home office  
email: not available  
**1998-1999**

### **3. Relevant Contract References for Fiber Futures**

- a. Ernett Altheimer or Dick Macintee  
Nile Fiber  
P.O. Box 1114  
Tacoma, WA 98401  
253-627-3756 phone  
253-627-5259 fax  
nilefiber@seanet.com  
**Current**
- b. Bill Thompson  
Agricultural Development Technologies, Inc.  
Des Moines, IA  
515-472-4543 phone  
515-472-0018 fax  
thompson@lisco.com  
**Current**

### **C. References**

- 1. Chris Churchill, President & CEO  
FiberTech USA  
Sacramento, CA  
916-849-6667 mobile  
Mailing:  
2626 Cole #400  
Dallas, TX 75204  
phone: (214) 922-0291  
fax: (214) 880-7588  
email: cchurch@ibm.net  
Service: Provided business TA, helped raise \$50,000 from angel investor.
- 2. Dave Eakin, Founder  
Northwest Strawboard  
Spokane, WA

Phone: (509) 372-4869

Fax: (509) 372-4868

Email: Not available

Service: Analyzed business plan, introduced entrepreneur to investors, currently conducting market analysis.

3. Jeff Gain, Chair

U.S.D.A. Alternative Agricultural Research & Commercialization Corporation

P.O. Box 607

Hardin, IL 62047

phone/fax: (618) 576-9392

email: not available

Service: Organized Fiber Futures conference with AARC sponsorship.

D. Related Information – Items 1, 3, and 4 are not applicable.

2) Subcontractors Professor Bill Pan (WSU), Chairman William McKean (UW) and Manager Mark Lewis (UW) are currently state employees at the University of Washington and Washington State University. Bill Pan is a Professor of Crop and Soil Science at Washington State University, William McKean is Chairman of the Paper Science & Engineering Department at the University of Washington College of Forest Resources, and Mark Lewis is the Manager of Program Operations for the Paper Science & Engineering Department at the University of Washington College of Forest Resources.

E. OMWBE Certification – Both Fiber Futures and Kristen Martinez are in the process of applying for the Washington State Office of Minority and Women-Owned Business Certification.

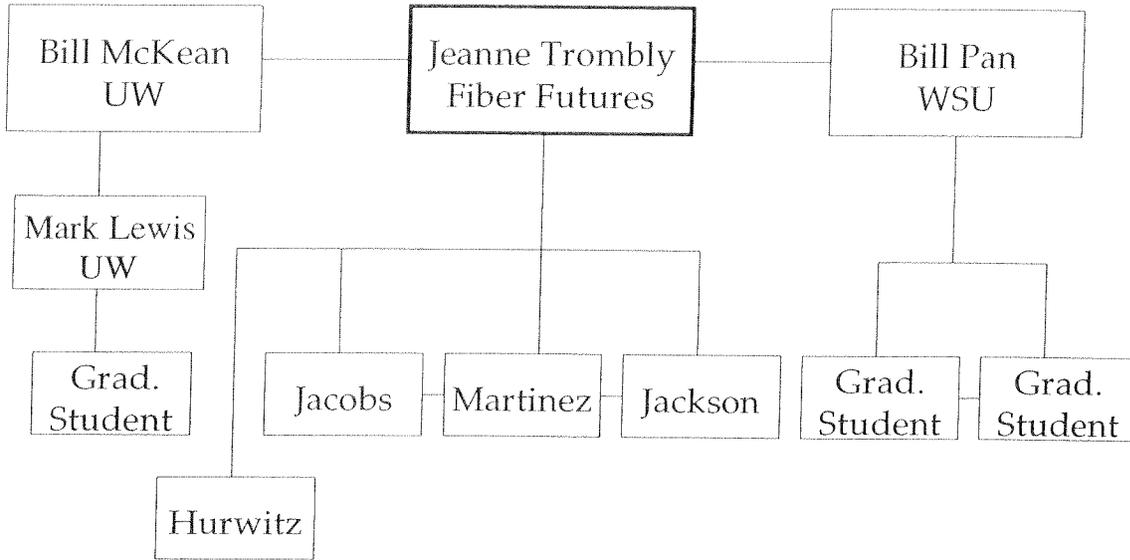
## Line Item Budget for University Research

Budget Item	Expense	Notes
Staff Salaries and Benefits		
University of Washington	<b>\$9,000</b>	
Bill McKean	\$1,000	15 hrs.
Mark Lewis	\$5,000	100 hrs.
Graduate Student	\$3,000	300 hrs.
Washington State Univers	<b>\$8,000</b>	
Bill Pan	\$0	400 hrs. (University covers salary & benefits)
Graduate Student	\$4,000	400 hrs.
Graduate Student	\$4,000	400 hrs.
One-time Expenses		
Laboratory Supplies	<b>\$5,000</b>	\$2,500 for each university
Equipment Usage	<b>\$4,000</b>	\$2,000 for each university
Travel	<b>\$4,000</b>	\$2,000 for each university for trips around WA state
<b>TOTAL</b>	<b>\$30,000</b>	

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Budget Income	Amount
WA Dept. of Ecology	\$25,000
Fiber Futures	\$5,000
<b>TOTAL</b>	<b>\$30,000</b>

*Project Team Structure*



Prime Responsibility and Final Authority



# Jeanne Trombly

Presidio Box 29363  
San Francisco, California 94129  
415/561-6524 • -6474 fax • jtrombly@jgc.org

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## QUALIFICATIONS

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- Thrives on challenges, organized and independent while acting as a catalyst to produce desired results.
- Maintains vast knowledge of success stories, issues and opportunities related to non-traditional fibers.
- Experience with traditional and alternative sources of debt and equity financing.

## WORK EXPERIENCE

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current

*Fiber Futures, San Francisco, California and Seattle, Washington*

**Founder and Executive Director (current)**

Ms. Trombly has built Fiber Futures as a non-profit networking and consulting organization established to further business uses of non-traditional fibers and agricultural residues. Fiber Futures has helped raise money, provided business technical assistance to start-ups and expanding businesses and served as a general resource. In 1997, Ms. Trombly co-produced a conference called Fiber Futures '97, drawing over 150 attendees, 30 vendors and 24 speakers.

1992 - current

*Materials for the Future Foundation, San Francisco, California*

**Revolving Loan Fund Administrator (PART-TIME, 1997-1998).**

Oversee unique \$1.25 million revolving loan fund targeting community based businesses in the recycling and materials conservation industries. Market the fund. Qualify businesses. Conduct outreach to alternative lending community. Provide business technical assistance.

**Program Director (1994-1996).** Nurtured and launched new projects for nonprofit organization specializing in recycling and community economic development. Oversaw grantmaking program and provided general business technical assistance to recycling companies starting-up or expanding. Prepared fundraising strategy and grant request proposals. Acted as Board liaison. Special accomplishments include having:

- Researched, designed and successfully bid on a contract to operate a revolving loan fund targeting recycling businesses.
- Assessed product development opportunities and market development trends for specific materials such as tires and reclaimed old growth wood. Prepared business feasibility studies where appropriate.
- Developed unique technical assistance program for Sacramento area businesses making products utilizing rice straw.

**Outreach Coordinator (1992-1993)** Prepared information and outreach publications. Developed grantmaking program structure. Established resource library. Researched funding leads, wrote proposals and progress reports. Set up networked computer system and designed databases to track clients. Served as Program Co-chair for annual California Resource Recovery Association conference.

(continues)

- 1989 - 1992      *Resource Management Associates, Napa, California*  
**Project Manager.** Designed specialized recycling planning reports and environmental education material for clients including private businesses and public agencies. Supervised research team, analyzed and summarized data, monitored project budget, wrote and edited reports, developed graphics and oversaw publication production. Prepared marketing materials.
- Organized a successful plastics recycling conference.
  - Prepared recycling plans for the Cities of Napa, Vallejo, Benicia and Pleasant Hill, California; and Kansas City, Missouri.
  - Quantified recycled glass and end-markets in New York State.
- 1988 - 1989      *California Energy Markets, San Francisco, California*  
**Assistant Editor.** Wrote several articles each week for newsletter analyzing business trends in the electric utility industry. Investigated filings and covered regular sessions of the California Public Utilities Commission.
- ongoing          **Freelance Science Writer.** *San Francisco, California*  
Wrote articles for publications including Environmental Science & Technology, San Jose Mercury News, Home Energy, BioCycle, Resource Recycling, Equinox and Pacific Discovery. Actively explored critical intersection between science and environmental issues.

**EDUCATION**

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- 1986              George Washington University, B.A. International Affairs/Communications
- 1993 - 1994      National Development Council,  
Economic Development Finance Certification Program
- 1992 - 1996      University of California at Berkeley - post graduate studies in business and environmental studies

**RELEVANT EXPERIENCE**

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- current          Board Member, Amazon Watch
- 1995-1997      Special Advisor, Wood Use Reduction Campaign launched by the Turner Foundation
- 1997              U.S. liaison for *Green Volunteers*, an international network of organizations and oppor in support of environmental conservation and activism.

1994-1995 Board Member, Urban Ecology

## William L. Pan

revised 7/99

Department of Crop and Soil Sciences  
Washington State University  
Pullman, WA 99164-6420  
TEL 509-335-3611  
FAX 509-335-8674; wlpan@wsu.edu

### FACULTY APPOINTMENT

Professor and Soil Scientist, Department of Crop and Soil Sciences; 60% research/40% teaching; appointed 12/84;  
Adjunct Professor, Program in Environmental Science; appointed 5/94.

### AREA OF SPECIALIZATION

Soil Fertility, Plant Nutrition, Nutrient Cycling and Rhizosphere Ecology of Agricultural Systems, Site-specific Nutrient Management; Computer Imaging of Plant Root Systems

### EDUCATION

1983 Ph.D. Soil Science, North Carolina State University, Raleigh, NC

1979 M.S. Soil Science, University of Missouri, Columbia, MO

1976 B.S. Biochemistry, University of Wisconsin, Madison, WI

### PROFESSIONAL EXPERIENCE

1996 - present Soil Scientist/Professor of Soil Science

Dept. of Crop and Soil Sciences, Washington State University

1991 -1996 Associate Soil Scientist/Associate Professor of Soil Science,

Dept. of Crop and Soil Sciences, Washington State University;

Adjunct faculty in the Environmental Science Program (5/94-present)

1984 - 1991 Assistant Soil Scientist/Assistant Professor of Soil Science,

Dept. of Crop and Soil Sciences, Washington State University

1983 -1984 Post-doctoral Research Associate, Department of Soil Science,  
North Carolina State University, Raleigh, NC

1979-1983 Graduate Research/Teaching Assistant; Department of Soil  
Science, North Carolina State University, Raleigh, NC

1977-1979 Graduate Research/Teaching Assistant in Soils; Department of Agronomy, University  
of Missouri, Columbia, MO

### PROFESSIONAL AND HONORARY SOCIETIES

American Society of Agronomy

Sigma Xi

Soil Science Society of America

Gamma Sigma Delta

American Society of Plant Physiologists

Far West Fertilizer and Agrichemical Association

### PUBLICATIONS

#### *Computer programs*

Hermanson, R. H., A.C.S. Rao, and W.L. Pan. 1995. Manure Nutrient Balancer. Decision support software for land application of animal waste in Washington state. Washington State Cooperative Extension.

#### *Book Chapters*

Camberato, J. J. and W. L. Pan. 1998. Bioavailability of calcium, magnesium, and sulfur. In M. E. Sumner (ed.), Handbook of Soil Science, CRC Press, Boca Raton, FL. **In press.**

Pan, W. L., D. R. Huggins, G. L. Malzer, and J. L. Smith. 1997. Variable soil-plant relationships: implications for site-specific nitrogen management. p. 81-100. In, F. J. Pierce and E. J. Sadler (ed.) The state of site-specific management for agriculture. ASA, CSSA, SSSA, Madison, WI.

Hergert, G. W., W. L. Pan, D. R. Huggins, J. H. Grove, T. R. Peck, and G. L. Malzer. 1997. The adequacy of current fertilizer recommendations for soil specific management. p. 283-300. In, F. J. Pierce and E. J. Sadler (ed.) The state of site-specific management for agriculture. ASA, CSSA, SSSA, Madison, WI.

***Professional articles, refereed***

Pan, W. L., R. P. Bolton, E. J. Lundquist, and L. H. Hiller. 1998. Portable rhizotron and color scanner system for monitoring root development. Plant Soil 200: 107-112.

Gao, S., W. L. Pan and R. T. Koenig. 1998. Wheat root growth responses to an enhanced ammonium supply. Soil Sci. Soc. Am. J. 62: 1736-1740.

Gao, S. and W. L. Pan. 1998. Integrated root system age and nutrient uptake capacity. Agron J. 90: 505-510.

Rusan, M., W. L. Pan, and A.C. Kennedy. 1998. Seasonal mycorrhizal colonization of winter wheat and its effect on wheat growth under dryland field conditions. Mycorrhiza: In press.

Pan, W.L. 1996. Role playing and mind mapping issues in nitrate contamination. J. Nat. Resour. Life Sci. Educ. 25: 37-42.

Koenig, R. T. and W. L. Pan. 1996. Calcium chloride enhancement of ammonium nutrition in spring wheat. Soil Sci. Soc. Am. J. 60: 498-505.

Koenig, R. T. and W. L. Pan. 1996. The influence of calcium on ammonium quantity-intensity relationships and ammonium availability in soil. Soil Sci. Soc. Am. J. 60: 492-497.

Mohammad, M., W. L. Pan, and A. C. Kennedy. 1995. Wheat responses to VAM inoculation of soils from an eroded toposequence. Soil Sci. Soc. Am. J. 59:1086-1090.

Fiez, T. E., W. L. Pan, and B. C. Miller. 1995. Nitrogen efficiency analysis of winter wheat among landscape positions. Soil Sci. Soc. Am. J. 59: 1666-1671.

Pan, W. L., J. J. Camberato, R. H. Moll, E. J. Kamprath, and W. A. Jackson. 1995. Altering source-sink relationships in prolific maize: consequences for N uptake and remobilization. Crop Sci. 35:836-845.

Fiez, T. E., B. C. Miller, W. L. Pan. 1995. Winter wheat yield and grain protein across varied landscape positions. Agron. J. 86:1026-1032.

Doty, J., A. C. Kennedy, and W. L. Pan. 1995. A rapid bioassay for inhibitory rhizobacteria using digital image analysis. Soil Sci. Soc. Am. J. 55: 1699-1701.

Sowers, K. E., W. L. Pan, B. C. Miller, and J. L. Smith. 1995. Nitrogen use efficiency of split applications in soft white winter wheat. Agron. J. 86:942-948.

Sowers, K. E., B. C. Miller, and W. L. Pan. 1995. Optimizing yield and grain protein in soft white winter wheat with split N applications. Agron. J. 86: 942-948.

Fiez, T. E., B. C. Miller, W. L. Pan. 1994. Assessment of spatially variable nitrogen fertilizer management in winter wheat. J. Prod. Ag. 7: 86-93.

Huggins, D. H. and W. L. Pan. 1993. Component analysis of cropping system differences in nitrogen use efficiency. Agron. J. 85: 898-905.

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## Michael Jackson

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2223 Pacific  
P.O. Box 169  
Tolovana Park, OR 97145  
Phone: 503-436-2110  
Fax: 503-436-9256

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### EDUCATION

Ph.D. (Chemistry), University of British Columbia, Canada, 1959  
M.S. (Chemistry), Manchester University, England, 1956  
B.S. (Chemistry), Manchester University, England, 1955

### PROFESSIONAL AFFILIATIONS

Technical Association of the Pulp and Paper Industry (TAPPI)  
Co-chair, TAPPI Sulfite and Semi-Chemical Pulping Committee (1991/92)  
Chair, TAPPI Nonwood Plant Fiber Committee, (officer 1993 to present)  
Member, TAPPI Mechanical Pulping Committee  
Member, Canadian Pulp and Paper Association (CPPA), Technical Section

### EMPLOYMENT SUMMARY

- Twelve years at mill sites in technical and process/product development and group management capacities
- Six years at chemical cellulose processing plant in development capacity
- Mechanical pulping process development, design and start-up beginning in 1973; including CTMP market pulp, newsprint, directory and LWC mills
- Ten years at central technical in pulp process/product development, market pulp customer technical service and management capacity
- Twelve years consulting in process design engineering, process improvement, problem solving and feasibility assessments.

1987 to Date

Consultant

1978/87

Weyerhaeuser Paper Company  
Technical Center  
Tacoma WA  
Process and product development

	Dissolving pulp, fluff pulp, LWC paper, newsprint
1969/78	Weyerhaeuser Paper Company Everett, WA Sulfite pulp mill and CTMP mill Process and product development
1963/69	Celanese Corporation Rock Hill, SC Cellulose acetate plant Process development
1959/63	Columbia Cellulose Company Prince Rupert, B.C. Sulfite Pulp Mill Process and product development

**PROJECT EXPERIENCE**

**Daishowa America  
Port Angeles, Washington**

Review of the quality and costs of separate rejects refining compared to alternative schemes for rejects treatment in a TMP/RMP system.

**Stone Container  
Missoula, Montana**

Audit benchmarking and improvement opportunity identification for stock preparation systems in unbleached board mill.

**Confidential**

Audit and evaluation of a bleached kraft market pulp production line for potential cost savings in raw material, energy, chemicals and operations.

**Kimberly-Clark  
Everett, Washington**

Evaluate impact of alternative bleaching sequences on fiber and product characteristics and performance. Modifications included peroxide bleach stage alternatives and chlorine dioxide to reduce AOX generation.

**Boise Cascade  
Portland, Oregon**

Prefeasibility study for wheat straw pulping line at existing mill.

**St. Laurent Paperboard Inc.**

**La Tuque, Quebec**

Mill audit; responsible for statistical data analysis, evaluation of process performance and analysis of relationships between pulp production and paper quality parameters. Led brightness reversion reduction program related to bleach plant and machine conditions.

**Rainy River Forest Products  
West Tacoma, Washington**

Feasibility study of TMP system optimization, modernization of refiners and energy reduction.

**Boise Cascade Corp.  
Wallula, Washington**

Technical lead for feasibility and detailed design for the installation of an M&D digester system moved from North Carolina for the pulping of hybrid cottonwood.

**Smurfit Newsprint Corp.  
Newberg and Oregon City, Oregon**

Responsible for design and specifications for feasibility estimates for new and modified process systems including TMP line capacity expansion, resin control and removal, deink stock peroxide bleaching.

**Boise Cascade Corp.  
Wallula, Washington  
St Helens, Oregon**

Technical/engineering interface for evaluation of polysulfide kraft cooking including recausticizing system analysis.

**NACO International  
Foggia, Italy**

Technical representative for process technology sales in North America for oxygen delignification system for use in pulping of straw and bleaching of OCC.

**Boise Cascade Corp.  
Wallula, Washington**

Data analysis and system sizing for mill expansion and optimization and related environmental permit application.

**Pope & Talbot  
Halsey, Oregon**

Provided statistical analysis for optimization of M&D digesters operating on softwood and hardwood chips and sawdust.

**Weyerhaeuser  
Springfield, Oregon**

Responsible for process design for a prefeasibility study of the utilization of grass straw in the production of linerboard including design and optimization of a pilot operation. Made preliminary economic assessment.

**Kraftanlagen Heidelberg  
Germany**

Responsible for evaluating and assisting in the scale-up for the North American commercialization of the alkaline sulfite anthraquinone with methanol (ASAM) pulping process, developed and demonstrated in Germany.

**James McClaren Inc.  
Thurso, Quebec**

Evaluate the position of Thurso pulp grades in the market and identify means of extending opportunities of specialty grades.

**Western Pulp  
Port Alice, British Columbia**

Developed design criteria for modified dissolving pulp bleach sequence to incorporate one hundred percent ClO<sub>2</sub> substitution and peroxide bleaching.

**Weyerhaeuser  
Everett, Washington**

Responsible for coordination of a process audit to meet an environmental permit and identify production capacity to increase capabilities from chip through drying machine, including the recovery loop, in the bleached market pulp kraft mill.

**Fibreco Pulp  
Taylor, British Columbia**

Pulp brightness optimization for high consistency peroxide bleach system identifying points of brightness loss in the CTMP market pulp system to attain high target brightness levels at the mill.

**Daishowa America  
Port Angeles, Washington**

Responsible for major portion of audit of mechanical pulping system, development of improvement alternative in chip conditioning, refining, bleaching, and white water and of mechanical pulp systems for directory grade paper production.

**Daishowa America  
Port Angeles, Washington**

Responsible for process design definition for PGW and bleaching systems for detailed scope and estimate for a greenfield integrated mill producing newsprint and directory goods.

**Smurfit Newsprint  
Oregon City, Oregon**

Jointly responsible for mill audit, improvement alternatives analysis, and recommendations for pulp quality targets for specialty paper grade production for process audit and upgrade to produce pulp quality for specialty groundwood grades.

**Boise Cascade  
St. Helens, Oregon**

Responsible for pulp mill process audit, chip through digesters including Kamyr, batch, and Pandia sawdust digesters.

**Weyerhaeuser  
Longview, Washington**

Responsible for coordination of chips through bleached pulp areas and preparation of final report for process capability and major profitability opportunities scoping bleached kraft and semichemical products complex. This project led to the design and construction of a new kraft fiber line.

**Hawaiian Commercial & Sugar Company  
Puunene, Maui, Hawaii**

Responsible for process design concepts and economic analysis for prefeasibility study of soda bagasse pulp mill.

**Papeles Venezolano  
Venezuela**

Responsible for raw material assessment for newsprint from Caribbean pine for pilot trials in Sweden and Norway.

**Confidential**

Raw material availability, quality assessment, and process design for greenfield CTMP/newsprint mill in the Northwest.

**DuPont**  
**Wilmington, Delaware**

CTMP process review and market projections in United States.

**Weyerhaeuser Company**  
**Process Engineer/Scientist**

Mechanical pulping process, quality, and properties for newsprint, LWC, and fluff pulp.

**Weyerhaeuser Company**  
**New Product Development Manager**

Sought, analyzed, evaluated, and proposed new product alternatives for paper.

**Weyerhaeuser Company**  
**Manager, Market Pulp R&D**

Process and product development in kraft, sulfite, and TMP pulp for market sales.

**Weyerhaeuser Company**  
**Senior Scientist**

- Raw material studies on western and southern wood species in kraft and mechanical pulping processes.
- NSAQ and ASAQ pulping process evaluation for feasibility and product requirement suitability for southern pine.
- Evaluation of pressurized groundwood process for LWC paper production.
- Dissolving pulp product and process development.
- Fluff pulp product and process development.

**Celanese Fiber Company**  
**Senior Engineer/Group Leader**

Dissolving pulp production pilot evaluation, acetate manufacturing development.

**PUBLICATIONS**

Eight papers based on thesis work in biochemistry and carbohydrate chemistry.

Pulp and paper related articles:

Jackson, M., "Fluff Absorbency Testing and Related Wood Pulp Properties" TAPPI Testing/Paper Synthetics Conference Preprints, 1974.

Jackson, M., "Behavior of Wood Pulps in Nonwoven Structures – Moisture Effects" TAPPI Paper/Synthetics Conference, 1976.

Atack, D., Fontebasso, J., Stationwala, M.I. and Jackson, M., "Pressurized Grinding of Loblolly Pine" TAPPI Journal, 66, No. 6, 1983.

- Jackson, M., "Interaction of Juvenile Loblolly Pine with the Thermomechanical Pulping Process" TAPPI Pulping Conference, 1984.
- Jackson, M. and Veal, M., "Pressing Chips Before TMP Pulping of Softwoods" TAPPI West Conference, 1985.
- Jackson, M. and Megraw, R.A., "Impact of Juvenile Wood on Pulp and Paper Properties" Forest Product Research Society, Pacific Northwest Conference, 1985.
- Veal, M., Marrs, G.R. and Jackson, M., "Control Over the Quality of Loblolly Pine Chips" TAPPI Journal, 70, No. 1, 1987.
- Jackson, M., "The Impact of Technological Developments of the Production of High-Yield Pulps" University of Washington Symposium – Global Issues and Outlook in Pulp and Paper, 1987.
- Veal, M.A. and Jackson, M., "A Review of Methods of Characterization of Mechanical Pulp for Papermaking" TAPPI Journal, 70, No. 10, 1987.
- Strand, B.C., Mokvist, A. and Jackson, M., "Improving the Reliability of Pulp Quality Data Through Factor Analysis and Data Reconciliation" International Mechanical Pulping Conference, Helsinki, 1989.
- Tantalo, L. and Jackson, M., "The Effect of Screening System Configuration on End Use Properties" TAPPI Pulping Conference, Seattle, 1989.
- Jackson, M., "Designing Peroxide Bleach Plants for Maximum Efficiency" TAPPI Pulping Conference, Toronto, 1990.
- Jackson, M., "Process Developments in Designing High Yield Pulping Facilities" ESPRA Conference, Syracuse, 1990.
- Hentges, R.A., Jackson, M., and Hunter, W.D., "The ASAM Process - A Concept for Environmentally Friendly High Quality Pulps" TAPPI Pulping Conference, Atlanta, 1993.
- Jackson, M., "Technological Developments in the Production of High Yield Pulps" PAPFOR Conference, St. Petersburg, Russia, 1993.
- Jackson, M., Croon, L.C., and Nardi, F., "Bleached Fiber from OCC" TAPPI Journal, 77, No.9, 153-159 (1994).
- Jackson, M., "Small Tree Utilization in Pulp and Paper Manufacturing" Forest Pruning and Wood Quality, Pub. College of Forest Resources, University of Washington, Seattle, 1995.
- Jackson, M., "The Interaction of Wood Species and Wood Quality with the TMP Process – A Review" TAPPI Pulping Conference, 455 (1998).

## CURRICULUM VITAE

### Roberta Jacobs

Assistant Professor, Paper Science  
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#### Education

- Doctorate in Philosophy, Spring 1999. Paper Science and Engineering, University of Washington. "The Papermaking Properties of Washington State Wheat Straw" W. T. McKean (206) 543-1626.
- Master of Science, May 1995. Chemical Engineering, University of Maine. "The Specific Bond Strength of High-Yield Pulp" Joe Genco (207) 581-2277 and Barbara Cole (207) 581-1188.
- Bachelor of Science, June 1992. Paper Science and Engineering, University of Washington.

#### Mill and Research Experience

- **Research Assistant, Teaching Assistant, Instructor.** Paper Science and Engineering. University of Washington, W. T. McKean (206) 543-1626. Managed research projects. Supervised undergraduate research assistants. Used student's data to write progress reports. Taught the pulping and bleaching analytical chemistry class, PSE 306. (Winter 1995 – Spring, 1999)
- **Graduate Student Intern.** Weyerhaeuser Research Center. Tacoma, Washington. Newsprint Business Support Team, Mike McCaw, Development Scientist, (253) 924-6162. Participated in a refining and blending studies. Examined the potential impact of raw material changes. (May 1994 - December 1994)
- **Research Assistant & Graduate Student.** Chemical Engineering, University of Maine. (Fall 1992 - Spring 1994)
- **Graduate Student Intern.** Weyerhaeuser Technology Center. Tacoma, Washington. Fiber Sciences Group. Pete Lancaster, Senior Scientist (253) 924-6688. Examined the ultrasonic treatment of pulp. (Summer 1992)
- **Undergraduate Research Assistant.** Paper Science & Engineering, University of Washington. W. T. McKean (206) 543-1626. Examined the processing of OCC to bleached paper. Developed an image analysis method for measuring stickies (1991 - 92 Academic Year). Used image analysis to measure glass fiber lengths and wrote programs for dirt count (1990-91). Studied the effects of water and sodium chloride content on the conductivity of paper (1989-90).
- **Chemical Engineering Intern.** James River Corporation, Camas, Washington. Henry Chen (360) 834-8181. Determined the brownstock screening efficiency. Calculated a mass balance around a paper machine. (Summer 1991)
- **Chemical Engineering Intern.** James River Corporation, Camas, Washington. Henry Chen (360) 834-8181. Designed a beater curve data gathering program. Studied variations in black liquor solids determinations. (Summer 1990)

- **Engineer's Assistant.** Longview Fiber Company, Longview, Washington. (360) 425-1550. Analyzed wetting agents and defoamers for creping heavy paper. Proposed and examined manufacturer's glue lap testing methods. (Summer 1989)

### Professional Affiliations

- **TAPPI**
  - National Member 1989-present
  - Nonwoods Committee 1996-present
  - Pacific Section Member 1990-present
  - Lake States Section Member 1999-present
  - UW Student TAPPI Member (1995-present, 1988-1992), Staff Advisor (1997-1999), Outstanding Student TAPPI Member (1992), President (1991-1992), Treasurer (1989-91)
  - UMO Student TAPPI Member (1992-1994)
- **Alumni and Student Affairs Committee,** Washington Pulp and Paper Foundation (1995-present) *Coordinator of the Big Brother/Big Sister Mentor Program and the Industrial Mentor Program. Coordinate seminars and educational activities.*

### Presentations and Publications

- Jacobs, R. S., W. L. Pan, W. S. Fuller, W. T. McKean, "Genetic and Environmental Influences on the Chemical Composition of Washington State Wheat Straw" 1999 Pulping Conference, Orlando, Florida, November 1-4, 1999.
- Jacobs, R. S., W. L. Pan, W. T. McKean, "Papermaking Potential of Washington Wheat Straw" 54<sup>th</sup> Northwest Regional Meeting, American Chemical Society, Portland, Oregon, June 20-23, 1999, Abstract 254.
- Jacobs, R. S., W. L. Pan, W. S. Fuller, W. T. McKean, "Washington Wheat Straw: Variations in Fiber Properties" 1998 Pulping Conference Proceedings, TAPPI Press, Atlanta, pp. 477-483.
- Jacobs, R. S. and W. T. McKean, "Refining Wheat Straw Pulp: A Comparison with Hardwoods" 1997 Pulping Conference Proceedings, TAPPI Press, Atlanta, pp. 667-672.
- Jacobs, R. S., B. Miller, W. S. Pan, R. A. Allan, W. T. McKean, "Pacific Northwest Wheat Straw: Glance at the Fiber Morphology" 1996 Pulping Conference Proceedings, TAPPI Press, Atlanta, pp. 237-242. (accepted for publication in *TAPPI Journal*)
- Pan, W. L., R. S. Jacobs, B. C. Miller, R. A. Allan, W. S. Fuller, and W. T. McKean. "Prospects for Utilizing Wheat Straw from the Pacific Northwestern United States in Paper Production" U. S. - Egypt Manufacturing Technologies Workshop, sponsored by NSF, Egypt NRC, December 6-9, 1996.
- McKean, Bill, Roberta Jacobs, and Bill Pan, "Straw Pulp Utilization: Implications for Cropping Systems, the Environment, and Emerging Fiber Markets" *Wheat Life*, 38(11): 43(1995).
- Jacobs, R. S., B. J. W. Cole, J. M. Genco, "The Relative Bonded Area (RBA) of High-Yield Pulps" 1994 TAPPI Pulping Conference Proceedings, TAPPI Press, Atlanta, pp. 427-434.

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## **EDUCATION**

1980-86 Paper Science and Engineering Graduate Studies. University of Washington.  
1980-86 Worked on Ph.D. Research: Pressure/Temperature Diffusion in Hot Nip Presses;  
Master's Thesis: The Effects of Load Cycling in Tension on Young's Modulus  
1977 B.S. Wood Science and Technology. Colorado St University, 1977.

## **WORK EXPERIENCE**

**Manager, Program Operations.** University of Washington Paper Science & Engineering Dept.  
Responsible for managing the laboratories and all contract service work.  
Currently doing research in utilizing existing deinking technology to process cereal straw.

**Regional Manager.** Penford Products.  
Responsible for sales and service to West Coast paper mills.  
Provided on machine technical support in the area of wet end chemistry and coating

**Territory Manager.** Vinings Industries.  
Providing technical support to both pulp and paper mills. Areas of concentration:  
ECF bleaching in mechanical mills, and wet end chemistry on paper machines

**Paper Making Research Manager.** GK Carbonate.  
Responsible for managing the wet end and physical testing labs.  
Developed a state-of-the-art laboratory for doing research into Alkaline Paper Making

**Scientist.** Weyerhaeuser Company.  
Managed the testing facilities in the central research building.  
Worked in the Papermaking Research Group on press section developments.

## KRISTIN K. MARTINEZ

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Kristin Martinez is founder and principal of Sound Point Ventures, LLC, in Seattle, Washington, focusing on private equity services and innovations, including mission related investing and venture philanthropy. Current projects include creating an acquisition fund for a Seattle nonprofit organization, working with several individual and venture fund clients to identify private equity opportunities, and assisting early stage companies and enterprising nonprofits with strategic financial advice. She is a member of the Seraph Capital Forum, a recently formed network of women angel investors in Seattle.

Kristin is a co-founder of and investor in New Vantage Partners, LLC, a private equity investment advisory firm in the Mid-Atlantic. Her major responsibilities while serving as an active partner in the firm from 1997-1998 included client services, investment review, and operations. She assisted in producing two venture fairs each year for the Investors' Circle, a national group of 175 family and institutional investors working to grow the social venture capital industry. She was an advisor to two recently formed venture funds, the \$30 million Women's Growth Capital Fund and the \$25 million Telecommunications Development Fund.

Immediately prior to starting NVP, Kristin was founder and President of Equilibrium, a consulting firm that provided strategic and financial planning for new and emerging businesses and enterprising nonprofits. Clients included startup Avalon Trust Company, the Center for Human Resources at Brandeis University, and Potomac Electric Power Company. Her experience includes eight years in the energy industry, most recently as Vice President of Operations and Treasurer at Pepco Services, Inc., an energy services startup that has grown to over \$25 million in sales. As a member of the Pepco Services team, Kristin developed and managed key supplier and vendor relationships, developed external financing sources, and identified investment opportunities in new, energy-related technologies.

Additionally, she spent several years as Executive Director of a private, non-profit economic development corporation in central Vermont, where she established and managed a \$2 million regional loan fund portfolio. Kristin is a member of the Advisory Board of the Avalon Trust Company. She holds a BS degree from Boston University and an MBA degree in finance and investments from The George Washington University.

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### EDUCATION

**Harvard-Radcliffe University**, Cambridge, MA 1993-1997 Cum Laude B.A. in Environmental Science and Public Policy, June 1997. John Harvard and Elizabeth Cary Agassiz scholar for highest academic achievement. Coursework included: Ecology, Biology, Environmental Geochemistry and Geology, Environmental Justice, Ecophilosophy, Programming in C, Computer Applications, Economics and a field trip studying Venezuelan tropical ecology.

**School for International Training**, Queensland, Australia Fall 1995  
Coursework included: Rainforest Ecology, Marine Ecology, Aboriginal Studies, Methods and Techniques of Field Study and an Independent Study practicing and evaluating a permaculture site.

**Byram Hills High School**, Armonk, NY 1989-1993  
Valedictorian. National Merit Scholar. National Cum Laude Society. IBM T.J.Watson Scholar. N.Y. State Byrd Scholar. University of PA Award for Academic and Extracurricular Achievement. N.Y. State Finalist in Mock Trial. Hugh O'Brien Youth Ambassador.

### WORK EXPERIENCE

**Program Associate, Fiber Futures**, San Francisco, CA & Medford, OR 10/98 -present

- Perform extensive research for start-up companies.
- Update and maintain information and resource database.
- Develop and maintain website.
- Perform fundraising responsibilities for Fiber Futures and research entities.
- Identify opportunities for network building.

**Campus Organizer, OSPIRG**, Lewis and Clark College, SW Portland, OR 1997- 4/98

- Recruited, trained and mobilized student volunteers in the skills of leadership, public interest research and advocacy.
- Assisted students in organizing research projects, educational events, and grassroots lobbying on environmental and consumer campaigns.
- Coordinated press conferences and publicity events to build awareness and support for the State PIRGs' positions on issues.

**Campaign Support, Progressive Campaigns**, Portland, OR Fall 1997

- Educated the public and gathered signatures for state ballot initiative efforts.

**Conservation Intern, Northwest Ecosystem Alliance, Bellingham, Washington** Summer 1996

- Assisted Conservation Director in the daily management of the organization.
- Served as a Liaison to the Washington State Rally Coordinating Committee on the anniversary of the Salvage Logging Rider.
- Composed and published newsletter and magazine articles and letters to the editor, Congressional Reps. and the President.
- Researched and compiled technical information for projects and publications..
- Provided administrative and office services.

**Intern, Dorchester Garden Lands, Dorchester, MA** Spring 1996

- Organized and taught composting techniques in a workshop for community gardeners.

**Office Worker, Database Publishing Group, Cambridge, MA** Fall 1996

- Performed data entry, proofreading and editing of Alumni publications. Provided administrative and office services.

**Programming Support Assistant, Prodigy, White Plains, NY** Summer 1994

- Tested new releases of Prodigy applications. Recommended improvements to program designers.

**Teacher Assistant, SAT Prep. Course** 1993

**Tutor for high school students** 1992

## **VOLUNTEER EXPERIENCE**

**Teacher, Peace Games, Cambridge and Boston, MA** 1993-1997

- Taught a conflict resolution and violence prevention curriculum to elementary students.
- Guided students in weekly hands-on science experiments.

**Teacher, Environmental Education, Boston, MA** 1995-1997

- Developed creative curriculum and taught environmental education to inner-city youth.

**Coordinating Committee, UNITE!: Campus Alliance for Social Change, Harvard University**  
1996-1997

- Developed mission statement and constitution, planned for future events and organized outreach and publicity.

**Events Organizer, Act '97 Student Activist Conference, Harvard University** Spring 1997

- Recruited speakers, organized schedules, and coordinated outreach, publicity and logistics.
- Facilitated environmental justice discussion group.

**Member, Direct Action Environmental Committee, Harvard University** 1995-1997

- Performed research, letter-writing and actions on local, national and international environmental issues addressing forestry, wilderness, and environmentally responsible purchasing and investment.

## **TECHNICAL SKILLS**

Proficiency in:

Claris Home Page, HTML coding, FileMaker Pro., Microsoft Office 98, including Microsoft Word, Microsoft Excel and Microsoft Powerpoint; Adobe Acrobat Reader, Adobe Illustrator and Adobe Photoshop; ThumbsPlus, Fetch, NCSA Telnet, "C" Language, BASIC, Unix, Windows, Word Perfect, LOTUS 1-2-3, dBASE.

Paper Manufacturing  
Using Agricultural Residues  
From Pacific Northwest Farmlands

FINAL

prepared for the

Washington Department of Ecology  
Air Quality Program

by

Fiber Futures, Inc.

in collaboration with

University of Washington

and

Washington State University

March 2001

# PAPER MANUFACTURING USING WHEAT STRAW FROM PACIFIC NORTHWEST FARMLANDS

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- A Glossary
- B Straw Resource Data
- C Letters of Market Interest
- D Research Results

## 1. EXECUTIVE SUMMARY

This report is being submitted to the State of Washington, Department of Ecology (DOE), Air Quality Program, as a result of a \$25,000 grant for scientific research that was awarded to the University of Washington and Washington State University. Fiber Futures, a non-profit environmental and economic development consulting group, has prepared this summary of the university research which examined the use of wheat straw as a pulping fiber for paper production. The report also identifies a theoretical scenario for developing the nation's first pulp mill that could use readily available agricultural residues as an alternative to wood chips. The conclusion identifies the steps and costs necessary to further this effort.

Although Fiber Futures was not a recipient of grant monies from the DOE, Fiber Futures was able to leverage its resources and contribute to this discovery process thanks to funding received from several conservation-based foundations, including the Brainerd Foundation and the Northwest Fund for the Environment.

Detailed research summaries are shown in Appendix D, provided by the recipients of the DOE grant. The funded research was conducted by the University of Washington's Paper Science and Engineering Department, represented by Professor William McKean and Mark Lewis, as well as the Crop and Soil Sciences Department at Washington State in Pullman, represented by Professor William L. Pan.

The submission of this report has a dual purpose: 1) to present the university research findings, part of which were orally presented to the Agricultural Burning Practices and Research Task Force during the summer 2000; and 2) to stimulate discussion about developing a non-wood pulp mill by presenting findings and related cost estimates to a non-wood pulping technology.

Target Region The Project Team agrees that the Pacific Northwest is a prime region to site a non-wood pulp mill for several reasons:

- ◆ The area's growing regions are host to prolific sources of agricultural residues – primarily wheat straw and grass seed stubble. Alfalfa and barley straw are also available, although to a lesser degree. Quantities of this material can be found on the web at [www.fiberfutures.org](http://www.fiberfutures.org), where state and county maps are featured.
- ◆ Much of this material is subject to a mandatory burning phase-out. At the same time, they are proven resources for papermaking. Ag-residues and some on-purpose fiber crops have a long history as papermaking fibers, and were used in the U.S. as recently as the 1950s. Today, they are still the primary materials for papermaking in China and India.
- ◆ These raw materials are within proximity to an existing, mature paper industry in need of new sources of raw material and innovative environmental technologies.

- ◆ Researchers from the University of Washington and Washington State have spent several years conducting R&D on the pulpability of fibers generated from ag-residues in Washington State.
- ◆ The State of Oregon and Universal Pulping, a private company, have financed initial engineering studies that indicate that grass seed stubble and wheat straw pulp are excellent raw materials for producing a corrugated linerboard grade.
- ◆ Fiber Futures is working with the AgFiber Association in several counties in eastern Washington and Oregon to assist in setting up the collection and processing infrastructure for ag-residues. This is necessary to ensure both quantity and quality of raw material.

Market Interest Interest has been conveyed by several large pulp purchasers including Brownville Specialty Papers, Procter & Gamble and other smaller manufacturers of fine printing and writing papers (see appendix C). Representatives from these companies conveyed interest in testing a significant quantity (at least one ton) of non-wood pulp made from wheat straw or grass seed stubble in simulated conditions that would mimic those in a full scale pulp mill.

To date, it has been difficult to garner interest in the pulp from entities located within the Pacific Northwest region. Members of the project team attempted throughout the project period to solicit interest from the region's pulp & paper mills, which frequently contract with the University of Washington to conduct research. Mill operations managers from both the Boise Cascade plant and the Ponderosa plant in Wallula, Washington reportedly conveyed guarded interest, but not strong enough to commit any company resources. Fiber Futures and the University of Washington met with the operations manager at the Ponderosa recycled paper plant in Wallula, who asked to be kept abreast of non-wood pulping possibilities as more specific data and proposals are developed. The Wallula plant was shut down in February 2001 due to operational and financing difficulties.

In general, it can be assumed that the level of interest from regional paper companies will depend on the cost and availability of wood-chips, which has not risen significantly enough to warrant local paper company involvement in funding or participating in a test run of ag-residue pulp.

Pulping Research Results For several years, the University of Washington (UW) has initiated research on wheat straw composition, and further investigated the viability of several types of pulping processes. These processes include neutral sulfite (NSSC), and a process called universal pulping (UP), which is a newer and more innovative approach. The DOE grant enabled UW to further work that had been previously funded through a National Science Foundation grant.

From this early stage R&D, both the NSSC and the Universal Pulping processes show strong potential for effectively and efficiently pulping wheat straw and grass seed.

However, only the UP process underwent an economic and engineering analysis as a result of a State of Oregon grant provided to a start-up company. For this reason, Fiber Futures included this preliminary cost data and chose to focus on UP to further assess the next steps needed to site a mini-mill in eastern Washington.

UP technology reportedly has several technological advantages. It produces a relatively high yield pulp – 70% – compared with 50% for other materials including wood chips. It utilizes a process that is relatively low cost because the agricultural residues can be cooked at a lower temperature and pressure, and with fewer chemicals, compared to wood-based pulping. Unlike other conventional pulp mills in the area which are facing tougher environmental requirements, this state-of-the-art pulping approach provides an opportunity to turn the effluent into a co-product, such as a soil amendment or a fertilizer that can be sold back to the farmers.

Soil Research Results Washington State researchers received from the University of Washington black liquor samples from both the NSSC and the UP straw pulping processes. The goal of WSU's efforts were to analyze the chemical composition of the pulping effluent in order to determine the potential for developing a soil amendment from the by-products of pulping. Dr. Pan, who led the research, reports that the UP pulping liquor has a far more favorable impact on wheat seedlings compared with the NSSC effluent, which reportedly severely inhibits wheat seedling growth. Additionally, Dr. Pan has had discussions with Agrium, a fertilizer company, which has indicated interest in participating in any future tests. (See Appendix C.)

Initial Feasibility The initial engineering study focused on a theoretical 200 ton per day pulp mill that would use wheat straw, grass seed stubble and other ag-residues from Pacific Northwest farmlands to produce an unbleached pulp. Capital costs are estimated to be between \$20 - \$28 million for a pulp mill sited adjacent to an existing paper mill. Initial operating cost estimates for producing an unbleached pulp from ag-residues indicate that a competitive pulp can be produced for \$125 - \$130 per ton. This price is significantly lower than a comparative pulp which, over the past four years, has sold for an average of \$336 per ton.

A Pacific Northwest-based non-wood pulp mill producing 200 tons per day would require an annual feedstock of 110,000 – 150,000 tons of wheat straw or other ag-residue. This is a tiny fraction of what is available in the eastern Oregon/Washington and Idaho region, whose combined tonnage of available straw exceeds 4,000,000 tons each year.

Recommendations This report reflects the conclusion of Fiber Futures based on conversations with, and reports submitted by project Team Members, as well as opinions solicited from key advisors.

It is recommended that the UP pulping approach be tested on a larger scale, in order to provide enough raw material to send to large pulp buyers and further garner their interest. This recommendation is based on research results from sound technology, yet unproven on the large scale. Enough market interest has been obtained from large buyers to lead to the next phase.

It is recommended that the project proceed to Phase Two at a cost of approximately \$475,000, outlined in the last section. These steps would be required for any pulp and paper manufacturing endeavor irregardless of the raw material. First and foremost, it is necessary to conduct a large scale trial run using the new pulping technology to produce 30 tons of the non-wood pulp. This pulp would be tested by potential future buyers. Phase Two also involves commissioning a Class 20 engineering study, which, upon completion, would place the project within a range of 20% accuracy and is standard for siting a major manufacturing facility. A more detailed market analysis would also be pursued in the next phase and include efforts to obtain letters of intent from major paper companies and pulp brokers to purchase the finished non-wood pulp product.

Conclusion Currently, there is no state of the art pulp mill, which uses ag-residues, makes use of its effluent, is low cost and is of an appropriate scale that makes sense for bioregionally beneficial economic development efforts in rural areas. Yet U.S. and international experts are without hesitation in agreeing that the technology for such a mill is viable. Existing mills that use ag-residues are operating around the world, yet their environmental compliance would not meet U.S. standards. Other efforts are underway in Australia and England which would utilize wheat straw for pulping.

While straw pulp development projects are being pursued by private entrepreneurs in different parts of the western world, there is little or no significant push in the United States to launch a non-wood pulping enterprise. The "mini-mill" concept, designed for bioregionally appropriate ag-residue pulping has garnered little interest from traditional pulp & paper representatives, it is within reason for a non-traditional entity to continue pursuing it. The traditional wood-focused pulp and paper industry is not likely to take first steps in innovating non-wood pulping due to preference for massive centralized manufacturing plants and their significant investment in wood resources.

Based on a year's worth of discovery and predevelopment work, Fiber Futures has determined that a successful straw pulp mini-mill, able to produce a relatively cost-effective pulp for the corrugated medium sector, is within reach. This conclusion is based on the target region's available straw fiber, the research results, the synergistic need of farmers to dispose of their straw, the regulators' need to improve air quality, tangible market interest, and consumer demand for paper which is considered environmentally preferable. This vision, however, will not take shape without a dedicated implementation team and significant financial resources to take the project through Phase Two.

## 2. INTRODUCTION

This report provides an overview of the research results from a Washington Department of Ecology grant to several Washington-based universities pursuing the utilization of wheat straw for pulp. Also included is a section on market interest, a background discussion of the paper industry, a summary of non-wood pulping in the rest of the world, the results from an engineering study and a set of recommendations describing the next steps to further non-wood pulping in the Pacific Northwest.

### Project Team

Fiber Futures, a non-profit environmental advocacy and economic development consulting group, teamed up with the University of Washington and Washington State University to explore how to further research on straw pulping and the effect on the pulp effluent on soil. Additionally, opinions and advice were garnered from a broad set of advisors, listed below.

The following Project Team members, shown below, share the common view that the Pacific Northwest holds tremendous potential for siting a small to medium-sized pulp mill which can provide non-wood pulp as a supplementary material to existing papermaking operations.

Jeanne Trombly, Fiber Futures

Dr. William McKean, Professor, University of Washington

Mark Lewis, Paper Science Laboratory Manager, University of Washington

Dr. Bill Pan, Professor of Soil Science, Washington State University

### Contributors and Advisors

Hank Bisner	<i>Industra Engineering</i>
Medwick Byrd	<i>North Carolina State U.</i>
Lou Edwards	<i>University of Idaho</i>
Tim Gruner	<i>Critical Resources Fund</i>
Mike Jackson, Ph.D.	<i>Pulp &amp; Paper consultant</i>
Roberta Jacobs	<i>University of Wisconsin</i>
Jim Jessernig	<i>Washington State Dept. of Agriculture</i>
Mike Meredith	<i>Jacobs Engineering</i>
Tom Miles	<i>Ag-Fiber Association</i>
Frank Riccio	<i>Danforth International</i>
Keith Romig, Jr.	<i>PACE International Union</i>
Cynthia Rowland	<i>Coblentz, Patch and Duffy &amp; Bass</i>
Bill Snyder	<i>Universal Pulping</i>
William Sommers	<i>Cybus Venture Capital</i>
Laurie Valeriano	<i>Washington Toxics Coalition</i>
Gertjan van Roekel	<i>Rijnconsult</i>

Members of this team had conducted prior research to develop a modern ag-residue pulping process. Both the University of Washington and Washington State University had received government grants and some private support to study the viability of pulping processes and soil impacts specific to the wheat grown in the region. At the same time, an independent for-profit Oregon start-up had received a state grant to further a non-wood pulping process, with a special emphasis on grass seed stubble. That company also contracted with the University of Washington to further the research potential of this process. In this final report, Fiber Futures weaves together these two separate, yet overlapping approaches because their respective outcomes impact the current state of non-wood pulping in the Pacific Northwest.

## **Objectives**

The overall goal of the research conducted by the University of Washington and Washington State was to further the potential for using cereal straw as a supplemental source of fiber for paper-making and to evaluate systems for utilizing straw pulping effluent by chemical recovery or by producing a beneficial soil amendment from the fiber extraction process.

This research proposal built on previously funded work that had analyzed the: 1) morphological properties of Washington State wheat straw fiber related to paper-making; and, 2) the genotypic and environmental variation in these properties to identify optimal cropping systems for generating high quality fiber for paper-making.

The DOE-funded portion was intended to build on the knowledge from steps one and two and: 3) determine the pulping, bleaching and paper-making response of straw from selected wheat cultivars preprocessed in a variety of ways; 4) determine the processing properties of the waste liquor comprised of straw organic by-products and spent pulping chemicals for potential use as a slow-release fertilizer; and 5) complete a report evaluating the commercial potential of utilizing this newly developed pulping technology and value-added by-product generation.

Although the \$25,000 grant, split between UW and WA State was not sufficient to thoroughly complete tasks #3 - 5, it enabled sufficient research and dialogue to determine that the research and commercialization efforts should not cease.

## **Significance**

Approximately 200,000 acres of wheat straw were burned in Washington state in 1998, which could have otherwise made available millions of tons of available residues. A recent report estimated that 45,000 tons of particulates, carbon monoxide and other volatile carbon compounds are emitted by wheat straw burning each year in the state of Washington. Lawsuits challenging the air polluting practice of burning have been filed by regional citizen action groups, such as Save our Summers. To address this air pollution and human health concern, the Washington State Department of Ecology Agricultural Burning Task Force, in conjunction with the Washington State Department of Agriculture and the Washington Association of Wheat Growers, entered into a voluntary agreement

calling for reductions of wheat stubble burning that average 7% each year for 7 years, leading to a 50% reduction by the year 2006.

While wheat straw regulation represents a gradual phase down, more stringent measures have been enacted on grass seed stubble burning. The state of Washington implemented an outright ban in 1999.

The sheer abundance of a particular resource has often been a catalyst to target a particular material for industrial manufacturing. In the mid - 19<sup>th</sup> century, U.S. policy makers were gleefully establishing laws that encouraged the use of the country's vast resources – land, minerals, forests and water. Today, the abundance factor has shifted to the leftover biomass from critical agricultural crops. It is difficult to ignore the availability of ag-residues and their potential to provide a source of fibers, especially when these materials are otherwise burned.

Environmental and population growth pressures are contributing to long-range changes in forest land management practices, which are reducing the regional availability of wood fiber for pulp & paper manufacturing. At the same time, cereal grain crop production in the U.S. generates tremendous quantities of straw each year. In Washington State alone, approximately three million acres of wheat are grown each year, producing approximately 3 tons of straw per acre. (For a specific break-down of quantities see Appendix B; for resources mapped by county, see Available Residues under [www.fiberfutures.org](http://www.fiberfutures.org).) Even with a half ton of straw per acre left on the soil surface for erosion control of steeply sloped ground (Veseth, 1984), there is still abundant quantities of straw left in the field. This excess straw often causes problems for subsequent field operations, such as no-till seeding, and can promote the development of plant fungal diseases. This concern has prompted growers in the region to burn the straw or till it into the soil.

## **Engineering Analysis**

In a parallel development in the 1999/2000 research timeline, the Universal Pulping (UP) process which had been analyzed and verified by the University of Washington, underwent an economic and engineering analysis as a result of a State of Oregon grant provided to a start-up company called Universal Pulping. Neither the AQ or the NSSC processes (further described in Research Results) has undergone the basic engineering analysis which is needed to provide cursory capital and operating cost information. For this reason, along with the favorable UP soil results, Fiber Futures chose to summarize UP's preliminary economic potential in Section Five of this report and present the next steps needed to site a mini-mill in eastern Washington in the last section.

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### **3. RESEARCH RESULTS**

This section provides a concise synopsis of the research included in Appendix D. The research focusing on wheat straw pulping was conducted by the University of Washington's Paper Science and Engineering Department, represented by Professor William McKean, Mark Lewis and several graduate students. The research focusing on soil was conducted by Professor William L. Pan and a graduate student from the Crop and Soil Sciences Department at Washington State in Pullman.

#### **Pulping Results**

For several years, the University of Washington (UW) has researched the viability of pulping regional wheat straw and grass seed stubble for potential incorporation into the area's paper manufacturing facilities. These processes include neutral sulfite (NSSC), soda anthraquinone (AQ) and more recently, universal pulping (UP). Besides pulping processes, UW has examined straw morphology - essentially which parts of the wheat straw are best suited for pulping.

For this project, straw from both wheat and alfalfa in the Wallula area was pulped in a two month timeframe using a neutral sulfite semi-chemical pulping process (NSSC). This data was compared with earlier tests of alkaline ammonium/potassium sulfite pulping process conducted in December 1999. Approximately 12 hand sheets were prepared representing different fiber types, pulping types and temperature cooks. Specific data regarding yield, lignin content and bleachability of the resulting pulps are shown in Appendix D.

In general, the highest brightness was reached using the alfalfa straw. Wheat straw showed a yellower brightness, without extensive use of bleaching chemicals and a non-pressurized cooking method. This is significant, because lowering bleaching and cooking requirements also reduces capital and operating costs for a potential mill.

The results indicate that these pulps might be appropriate for use at the Boise Cascade mill in Wallula, which produces a corrugated linerboard. Additionally, the data would suggest that the Wallula Ponderosa recycled mill might be slightly modified to handle such a non-pressurized cooking approach. Effluent from the NSSC and UP processes were sent to Washington State University to be examined for their impact on soil.

From this early stage R&D, both the NSSC and the UP processes show strong potential for effectively and efficiently pulping wheat straw and grass seed. The results of the effluent impact from both the NSSC and UP processes are further described below.

#### **Soil Impact Results**

Wheat straw black liquor samples from the University of Washington were sent to Dr. Bill Pan, a soil scientist at Washington State in order to undergo chemical analysis and soil incubation/plant response experimentation. The goal of this effort was to analyze the

chemical compositions of the pulping effluent in order to determine the potential for developing a soil amendment from the byproduct of pulping.

Two pulping processes were evaluated for their effects on soils and plants: universal pulping (UP) and neutral sulfite (NSSC). Conclusions from these two processes were incorporated in a final report which also included the results from a lignin solution, isolated from an Egyptian rice straw pulping operation (obtained from a separate source). The lignin data was added so that the report could provide a more comprehensive overview of different effluent performances on soil.

Samples were analyzed for carbon, nitrogen, and silica with a Leco dry combustion analyzer. Separate subsamples were digested and prepared for multi-elemental analysis with intercoupled plasma spectroscopy (ICP) for potassium, calcium, magnesium, iron, aluminum, and silica. The lab acquired this instrumentation in late 2000, and it proved to be invaluable for these tests.

A soil incubation and plant growth chamber experiment on these two black liquor samples was initiated in early November 2000. Quincy sand soil from Prosser, Washington was treated with UP and NSSC pulping liquors and incubated for six weeks at field capacity moisture content at 20 C.

The soil was also treated with inorganic fertilizers supplying N and P. Wheat seeds (cv Scarlet) were presprouted in distilled water for 2 days and 10 seeds per pot were transplanted. Plants were then thinned to a maximum of six plants per pot, 4 replicates per treatment.

Preliminary observations indicate the NSSC liquor severely inhibits wheat seedling growth compared to UP liquor, Egyptian rice straw lignin and inorganic fertilizer. Plants were harvested in mid-January and analyzed for biomass, N, K, Ca, Mg, Na, Al and Si accumulation. Soils were analyzed for soil aggregate size and stability, organic C, N, S.

Pulp liquors from the NSSC and UP processes aided in soil aggregation, which could ultimately help with erosion. The NSSC process had a negative impact on wheat growth and the UP process had a minor positive impact on growth, but increased the soil pH and enhanced aggregation.

#### 4. PAPER INDUSTRY BACKGROUND

The United States, the nation of innovation and opportunities, is also the land of the greatest paper production, consumption and waste. The United States paper and forest products industry is a behemoth player in the top ten line-up, producing over \$200 billion in shipments each year. In this sector, paper and paperboard counts for about 85% of industry revenues; wood products represent the remainder. The industry directly employs about 1.6 million people in the United States and maintains about one third share of the total worldwide sales.<sup>1</sup>

U.S. paper consumers are also a significant faction. As published in a recent World Resources Institute report, the U.S. accounts for 30% of the world's consumption of paper - close to 90 million metric tons out of a total global appetite of nearly 300 million metric tons. Per capita consumption in the U.S. in 1997 is 335 kilograms per person (897 lbs) compared with an average for industrialized nations of 164 kilograms (439 lbs) and a global average of 51 kilograms (137 lbs) per person.

To feed this paper demand, the U.S. paper industry relies mainly on virgin wood sources for the majority of its papermaking. Despite the widespread availability of agricultural residues and recycled fibers for manufacturing pulp for the paper industry, total domestic paper production continues to rely on the virgin wood supply for almost 70% of its total fiber input. This number climbs to over 90% when considering only printing and writing paper.<sup>2</sup>

It is not surprising that virgin wood fiber is the preferred feedstock for the pulp and paper industry. Long distance transport of wood chips is cost effective, enabling larger and more centralized manufacturing facilities to evolve. As shown in Table I, most of the top ten companies have invested in vast tracts of forest lands.

**Table I: Forest Land Owned by US Paper Companies**

Company	Land Owned
International Paper	14.8
Kimberly-Clark Corp.	1.0
Georgia-Pacific Corp.	4.7
Mead Corp.	2.1
Weyerhaeuser Co.	5.3
Westvaco Corp.	1.5
Willamette Industries Inc.	1.7
Abitibi-Consolidated Inc.	3.2
Temple-Inland Co.	2.2
Consolidated Papers Inc	0.7
Boise-Cascade Group	2.0
<b>Total area</b>	<b>39.2</b>

Source: *Fiber Futures 2000*

Less than one percent of all of the paper produced for U.S. consumption uses any non-wood fiber. This is in sharp contrast to other parts of the world. In certain regions of Asia, for example, up to 80% of domestic paper produced uses non-wood fibers from agricultural practices. According to a 1994 FAO study, the primary fibers that represent the approximately 400,000 metric tons used are cotton linters, hemp, kenaf, sugarcane bagasse and some post-industrial rags.<sup>3</sup> Non-wood fibers are mainly used for high-end specialty papers containing cotton, hemp, bamboo and kenaf that hold only a tiny market sliver. For instance, US banknotes and cigarette paper are made of flax fiber.

### Non-wood Fiber Use Overseas

On a global scale, non-woods contribute 16.5 million metric tons of fiber for paper production,<sup>4</sup> amounting to 10% of the overall fiber used on a worldwide basis. As shown in Table II, straw is the most common non-wood fiber used today, and its use predominates in China (12 million metric tons), India (1.8 million metric tons) and other Asian countries. An ancient Chinese adage "eat first, then make paper" especially applies. In China, straw accounts for 46% of the fiber used in total paper production, followed by bagasse (14%); bamboo (6%) and a variety of others.<sup>5</sup>

**Table II: Non-wood Fiber for Worldwide Papermaking**

Raw Material	Total Papermaking Pulp Capacities (1000 metric tons)					
	1985	1988	1990	1993	2000	2010
Straw	6,166	5,260	7,623	9,566	12,318	17,014
Bagasse	2,339	2,267	2,646	2,984	3,516	4,387
Bamboo	1,545	1,674	1,468	1,316	1,137	807
Miscellaneous*	3,302	6,366	6,870	6,870	10,168	14,276
Total Non-wood Papermaking	13,352	15,567	18,607	20,736	25,832	35,624
Total Paper Production	178,558	225,887	238,939	250,359	312,056	397,780
Percentage Non-wood	7.4%	6.9%	7.8%	8.3%	8.3%	9.0%

\*cotton, reeds, sisal, jute, hemp, abaca, kenaf, flax

Source: FAO 1997

### Meeting Future Global Fiber Demand

Global fiber demand is expected to increase yet another 32% by the year 2010,<sup>6</sup> and experts are conjecturing just where the material will come from. Admittedly, like energy conservationists will insist, a deliberate focus on paper reduction strategies would uncover immense supplies of fiber, at least in the U.S. However, the greatest growth curves are expected to take place in developing countries where paper use is already at bare minimal levels (see Global Paper Market Trends, below). If industry is determined to retain intact and biologically diverse forests, non-woods and plantation forests will have to meet future fiber needs. Whether the added capacity to meet future demands comes from wood or non-wood fibers is going to depend on a myriad of factors including:

- pace at which post-consumer paper recovery programs are put in place
- increased infrastructure for using recycled and non-wood fibers
- WTO determinations of fair trade practices for wood chips
- growth of forest farms and associated siting of integrated pulp and paper mills

- increase in availability of certified wood chips for papermaking

Add to this the recent developments in US environmental protection, and it becomes apparent that the US paper industry will have to address the issue of fiber supply sooner than later. In doing so the industry has four options: import wood chips, increase recycling, grow fiber from tree plantations, and utilize non-wood fiber.

## Plantation wood

Although large poplar plantations in Wallula have not met high quality expectations, the paper industry anticipates that massive wood plantation pulp mills will help meet the growing fiber appetite of much of the world. The availability of eucalyptus pulpwood, primarily *E globulus*, is expected to surge in the coming decade due to extensive planting in Australia, Brazil, Chile, Uruguay and Thailand. A significant portion of this planting has been initiated by Japanese pulp and paper companies.<sup>7</sup> In Thailand, a third 2000 ton per day eucalyptus pulp mill is under construction and expected to produce pulp mostly for export.<sup>8</sup> Latin America, notably Chile, Brazil, Argentina and Mexico, has moved into the lead as far as planned paper and paperboard capacity additions.<sup>9</sup> When much of this plantation wood enters into the U.S., the material is subject to fumigation, often with methyl bromide, at the border.

Whenever vast acreage of one crop is cultivated – whether beets, trees or corn - the area is prone to severe and sudden insect infestations and a host of other natural and manmade disasters. In 1999, for instance, more than 500,000 acres of a forest farm in China's Liaoning province were destroyed by an onslaught of insects that thrived in the young, uniform trees.<sup>10</sup> Moreover, tree farms usually require chemical inputs, including herbicides and fertilizers to maintain their yields.

People often ask whether cultivating trees is smarter than growing other on-purpose fiber crops, such as kenaf and hemp. The short and simple answer is, there is no short and simple equation. Bioregional factors such as climate, growing cycle, soil, economic conditions and regional pulping capacity all contribute to a final selection of appropriate fibers. A detailed life cycle assessment, which is currently being conducted by Yale University, is expected to reveal which fiber sources requires more energy, chemicals and water. When comparing on-purpose fiber crops with plantation wood, the debate is subject to more viewpoints. When comparing ag-residues that are otherwise burned with plantation wood, however, ag-residues emerge as the clear environmental winner.

## Potential for Non-woods

The Pacific Northwest annually produces about 4 million tons of wheat straw, which is available for papermaking at the cost of collecting and processing. Non-wood fiber is just as cheap a raw material for papermaking than trees, it is the transport to the pulp mill that introduces a higher cost for non-wood fiber, since it is much bulkier. This factor limits the transport radius for economic operation of a non-wood based pulp mill, and therefore the scale at which such a mill can run at market-conform operational cost. Growth of non-woods used in the pulp and paper sector will depend on developing smaller scale manufacturing facilities that can be sited for less than the astronomical capital costs associated with wood-based pulping systems. The paper products industry caught in the

inertia of the investment legacy attributable to conventional technology and wood fiber. There is little incentive for innovation on the small scale, especially because engineering companies that are paid on a percentage-of-project basis are more motivated to site behemoth pulp and paper mills, which often exceed \$1 billion to build. These large enterprises reap massive economies of scale, but not without environmental consequences.

## **Pacific Northwest Trends**

Current trends indicate that wood fiber will be in abundance in some parts of the world and severely lacking in other parts. In recent years, the pulp & paper sector has realized a contraction in Pacific Northwest wood chip supplies as a result of legislation restricting logging. As a result, many pulp mills have planted vast tracts of fast-growing poplar trees. However the pulping quality of the area's poplar has proven to be less than optimal. Other plants have shut down and production has moved north to Canada. Yet others have increased the quantity of wood chips that are being imported from large overseas tree farming operations. Georgia Pacific has imported low-cost eucalyptus pulpwood chips from Chile for its mill in Bellingham, Washington. Yet that option is not ideal for existing paper companies facing high costs and environmental criticism for toxic fumigation requirements. Before wood chips can be unloaded at a U.S. port, the material must first be fumigated with methyl bromide, an EPA-designated cancer-causing chemical. A methyl bromide "bomb" is dropped into a containership containing exotic wood chips.

It is not surprising that paper officials see opportunity in using more overseas wood. The wood chip supply in the Pacific Northwest has contracted due to the 1990 ruling by the U.S. Fish and Wildlife Service to list the northern spotted owl as a threatened species. This decision eliminated timber harvesting from about nine million acres of land in the Pacific Northwest where the owls reside.<sup>11</sup>

Top paper industry officials are openly expressing their concerns. Gaylord Corporation Chairman and CEO Marvin Pomerantz commented that fiber availability, either for woodchips or recovered paper, appears as a central issue that could act as a "restraint on capacity." Weyerhaeuser Co. Chairman, President, and CEO Steven Rogel identified the government pressures on wood production, and described the softwood markets in the U.S. South as "stressed for woods and chips" and that there was "limited availability" for chips in the Pacific Northwest. He suggested that Southern pine softwood grown in Uruguay and Brazil could become an important resource for making linerboard.<sup>12</sup>

On top of fiber supply concerns, environmental pressures will increasingly weigh on the minds of pulp and paper managers. Over 50 wood-based pulp and paper mills in the Pacific Northwest (including Canada) utilize chlorine compounds in their bleaching processes. According to advocacy group Reach for Unbleached!, at least six mills in the region have had to close down as a result of not meeting increased environmental regulations or having outdated equipment or not being able to access adequate fiber supply. As citizen groups in the Pacific Northwest – mobilized by the Washington Toxics Coalition – continue to raise public awareness, the region may face difficulties on several fronts meeting continued environmental regulations.

## **5. NON-WOOD PULP MILL CONCEPT**

This section describes the broad framework for establishing a non-wood pulp mill utilizing the universal pulping process. It covers size, scale, site, raw material availability and the pulping technology. The majority of assumptions are based on findings from an initial Class 40 engineering study, conducted by Oregon-based engineer, Mike Jackson, Ph.D.

### **Cost and Capacity**

According to the Class 40 engineering study it is estimated that the capital costs for completing the construction and initial start up of a pulp mill sited next to an existing paper mill are between \$20 - \$28 million. The proposed pulp mill would produce 200 tons per day of market pulp. To achieve this capacity, it would be necessary to have a supply of 300 - 400 tons per day of wheat straw or other ag-residues delivered to the mill.

### **Grade and Potential Uses**

Initial results indicate that the pulp would be adequate for producing nonbleached corrugating medium and linerboard. The plant could be upgraded at a cost of roughly \$15 - 20 million to handle a second stage process to produce a brighter pulp for the printing and writing sector, as well as the tissue and towel market.

### **Potential Sites**

In Washington, one optimal site is in Wallula at the location of the recently shut down Ponderosa recycled paper plant. Next to it is the existing Boise Cascade kraft plant, which manufactures approximately one half million tons of pulp and paper each year from virgin wood chips for corrugated box manufacture, uncoated fine papers and bleached softwood kraft market pulp. This location is ideal because Boise may be facing wood fiber shortages, and the Ponderosa facility could be modified, as it has some of the infrastructure that would be required.

Siting at an existing paper manufacturing compound provides numerous benefits, mostly related to cost savings of infrastructure. Energy, steam and water availability is in place, along with familiar regulatory and building permit officials, as well as an accepting community. This south central Washington location is near major highways and rail lines. Moreover, this site is in Walla Walla County, where farmers each year need a market for over 228,000 tons wheat straw. Walla Walla is just north of the Columbia River of Oregon's Umatilla County, which also produces close to 259,000 tons of wheat straw each year.

Mill managers from both the Boise Cascade plant (and the former Ponderosa plant) have expressed guarded interest. Fiber Futures and the University of Washington met with the operations manager at Ponderosa, who asked to be kept abreast of possibilities as more specific data and proposals are developed.

## Siting Criteria

The primary criteria for evaluating potential sites are: (1) an adequate source of raw materials in close proximity to the pulp mill; (2) proximity of pulp end users; (3) adequate infrastructure including water supply, energy supply and transportation routes; (4) the impact of anti-burning regulations, as well as economic incentives available in certain development zones, or other federal, reservation, state, or local economic incentives.

Raw Material Supply The Palouse region, encompassing eastern Washington and northwestern Idaho, was carved out by ancient receding glaciers, creating soil and climate conditions that later became optimal for growing abundant food crops. Today, the area supports some of the highest producing wheat fields in the country where the density of wheat grown is approximately three times greater than other wheat growing areas in the U.S. In addition, abundant crops of blue grass seed, fescue seed, alfalfa, barley and corn are cultivated in nearby agriculture basins. All of these crops produce agriculture residues that are suitable as fiber for pulping. Wheat, in particular, can produce up to three tons per acre of straw.<sup>13</sup> See Appendix B for a complete tabulation of available ag-residues in the Pacific Northwest. These maps illustrate quantities that are only 25% of what is totally available, as to account for the need to plow some organic matter back into the soils.

For purposes of this project, a non-wood pulp mill producing 200 tons per day would require an annual feedstock of 110,000 - 145,000 tons of wheat straw or other ag-residue. This is a tiny fraction of what is available in the eastern Oregon/Washington and Idaho region, whose combined tonnage of available straw from wheat-growing alone exceeds 4,000,000 tons each year.

Regional Markets Project Team representatives from the University of Washington as well as an advisor from Jacobs Engineering conducted an informal phone survey of the area's wood-based paper mills. At that time, none expressed strong interest in testing non-wood sources of pulp. Since the survey, the cost of wood-chips has climbed upwards, and one project team member reports that the Boise Cascade mill in Wallula is experiencing difficulty in finding economically viable wood chips. Boise Cascade has expressed cautious interest further described in the Markets section.

To date, the market interest that has been identified has been generated mainly from paper companies and major pulp buyers that exist outside of the Pacific Northwest. They are listed in the Markets Section.

Infrastructure The region's pulp & paper industry infrastructure already has helped spur and benefited from rail lines, shipping ports, low cost sources of energy, significant sources of water and local regulators who are familiar with permitting issues involving pulp and paper mills.

The specific site requirements that have been identified for a 200 tpd mill are: a) 100 acres of land; b) clean water of 150,000 - 250,000 gallons per day (some of this would come from the recycled effluent); c) electricity supply of 2.1 megawatts. The next project phase would need to verify site-specific costs.

Regulatory Environment Today, the area's high volume straw resource base is, for the most part, underutilized. Some of it is shipped to Canada for mushroom growing. Much of it is needed by the growers as organic matter for the soil. Yet plenty of it is wasted through field burning as farmers routinely set their fields afire after harvest. Some farmers have started incorporating the straw back into the ground to avoid burning, yet many complain that this prohibits no-till farming, which is the preferred method when trying to prevent soil erosion and excessive weeds.

In Washington state alone, close to 250,000 acres of wheat straw stubble has traditionally been burned. To address the air pollution and human health concerns associated with wheat straw burning, the Washington State Department of Ecology Agricultural Burning Task Force, in conjunction with the Washington State Department of Agriculture and the Washington Association of Wheat Growers, entered into a voluntary agreement calling for reductions of wheat stubble burning that average 7% each year for 7 years, leading to a 50% reduction by the year 2006. This situation has prompted the state Governor to deem a future development of a straw manufacturing facility as a project of Statewide Significance, meaning that the permitting and financing would receive high priority attention by all of the regulatory agencies.

### **Ag-residue Feedstock – Attributes and Limitations**

A continuous supply of quality and uniform material is a prerequisite of any manufacturing facility, and is especially pertinent to a potential straw pulp facility that could face expensive temporary plant closures for equipment cleaning. In a typical wood-based pulp facility, a plant shut down can cost over \$100,000 per day.

For years, straw and other ag-residues were considered inferior in their ability to be stored and preserved for later use. In contrast to wood, which can be stored and delivered year round, straw is typically collected once a year, sometimes twice, and has a faster degradation rate. Today, with improved harvesting and bale technology, along with a preprocessing step, large-scale straw manufacturing plants are handling 150 plus tons per day, proving that systems greater than cottage industry are viable.

The quality and uniformity of product from a modern straw manufacturing facility will depend on a carefully crafted design for collection and storage, and a pre-processing step for the raw material. This section touches upon the most important considerations for collecting, storing and using ag-residues from the Pacific Northwest. Valuable information was extracted from a \$200,000 study funded by the state of Oregon Department of Agriculture in conjunction with Weyerhaeuser Corporation. The study carefully calculated relevant capital and operating costs and equipment needs, and it examined a preprocessing step that substantially improved the quality of the feedstock.

### **Costs**

The cost of straw delivered to a manufacturing facility depends on transportation, machine, labor costs and any preprocessing. Cost estimates ranging from \$15 per ton to over \$55 per ton delivered are found in various studies and business plans. Additional

factors would depend on the formation of a farmers' cooperative that would have access to low interest loans and USDA grants.

For purposes of this report, it is assumed that delivered straw costs \$35 per ton. Yet, if a preprocessing step is added, the delivered straw can cost as much as \$58.<sup>14</sup> At this higher amount, the operating costs to produce one ton of pulp would increase from approximately \$125 to \$170 per ton. Whether this cost can be recovered would depend on the quality of the higher grade pulp that could compete in paper markets that command a premium price.

Differences in Varieties Straw in irrigated lands showed an average fiber length of around 0.1mm longer (20%) than straw grown in dryland conditions. Out of the six commercial wheat cultivars that are grown in Washington, the Madsen variety showed the highest potential for pulping. Its internode mass was as high as 80% in one test conducted by the University of Washington.<sup>15</sup> The Weyerhaeuser study found some, but not sufficient significance among different varieties of seed grass.

Harvesting The best possible scenario is for the grain to be harvested, with a large amount of stubble remaining. The second harvest captures the straw that is still standing, as opposed to having been chopped and resting on the earth. This so-called stripper harvesting is accomplished simply by setting the cutter heights to the appropriate level.

Baling There are several ways to bale ag-residues, from large to small, compact to loose, square to cylindrical. Bales can be stacked and stored; tighter bales better withstand harsh weather. Cylindrical bales are the densest, yet the large square bales are convenient for trucking and stacking. If the bales are stored using barns, a Freeman baler is adequate, saving a bit of money (\$22.50 per ton). If bales are stored using tarps or field stacked, a Hesston large baler would be used at \$24 per ton.

Storage The annual nature and short harvesting time frame associated with grain crop harvesting puts storage at the top of the list of quality control factors. The pulp mill needs to be able to draw off of a well-designed storage facility that protects the feedstock resource base year round. Central to this debate is whether the straw is stored on site at several farmers' locations, or at a central facility at or near the plant.

In the 1980s, the state of Oregon provided fiscal incentives to fund the construction of pole barns in the Willamette area where farmers were under intense pressure to stop their burning practices. The mere existence of the pole barns was yet but one step in the chain of solutions, but it provided an incentive for farmers to get their ag-residues under cover, where the material eventually found markets in Asia. Today, farmers in western Oregon export practically all of their grass seed straw.

Stacked bales that are left uncovered are prone to lightning-induced fire. A fire was one of the contributing factors that led to the recent demise of a strawboard plant in Alberta, Canada. Yet permanent shelters for storing straw bales are close to 10 times more expensive than in-field storage. Settling on how much moisture the straw can tolerate and lightning risk resulting from inexpensive storage will be carefully considered in the final business plan.

Preprocessing A considerable amount of research and development has been applied towards understanding the improved quality of the straw feedstock as a result of preprocessing. A preprocessing step can remove nodes, which inhibit superior pulping results, as well as leaves, dirt and other contaminants. For the Weyerhaeuser demonstration plant, a one-of-a-kind disc machine developed in Denmark was used to remove nodes and contaminants, and create straw "chips," providing a yield of over 80%. The remaining material was compressed and deemed to be a superior material for feeding livestock, potentially offsetting some of the preprocessing costs.

### Technical Considerations

The general characteristics that can be used to identify the suitability of ag-residues for papermaking are as follows:

1. Fiber length - the average and range of length of fibers
2. Fiber diameter or coarseness - most critical in terms of its relationship to fiber length. This property affects fiber flexibility and the ability of the fiber to form a dense or less dense sheet.
3. Freeness – the ability of fibers to drain water. The freer they are, the easier it is to form paper.
4. Opacity – the see-through characteristics. When non-opaque, one can print on both sides. Book paper has the highest opacity whereas toilet paper and newsprint have much less opacity.
5. Strength (tensile, tear and burst) – the ability for the paper to withstand force in the plane of the paper, important in packaging; tear is the resistance to the propagation of a crack; burst is the ability of the paper to withstand force in direction perpendicular to the plane of the paper. Puncture resistance. More applicable for cardboard boxes.
6. Porosity – how much air passes through the sheet of paper, the ability of the paper to respond effectively to machinery.

The wheat plant contains several properties, not all of which are ideal for undergoing pulping. As shown in Table II, the internode accounts for the majority of the bulk of the wheat by weight. It is this internodal material that is ideal for pulping, not the leaves, nodes and fines. Nodes contain more fines and less long fibers than the internodes, and the nodal material tends to resist penetration by the pulping chemicals, so nodes tend to clog up the process. Leaves tend to contain high amounts of silica that can be disadvantageous. Separating the nodes and leaves from the straw has proven to be a vital step in creating a high quality pulp.<sup>16</sup>

**Table III: Wheat straw components**

Wheat Components	Mass Percent
Internodes	68.5
Leaves-sheaths	20.3
Leaves-blades	5.5
Nodes and Fines	4.2
Grain and Debris	1.5

Source: Ernst et. al, 1960 Tappi Journal 42(1)

## Comparisons with Wood

It is unrealistic to assert that non-wood ag-residue fibers are an across-the-board replacement for wood fibers. Softwood fibers from northern coniferous forests are very different than hardwood fibers from southeastern forests, and are used for completely different applications. Likewise, within the world of ag-residue fibers and even on-purpose crops, there are unique attributes and weaknesses that need to be understood by the business development and engineering team.

Although sweeping generalizations are difficult, compared with soft- and hardwood fibers, most non-wood plant fibers differ in the following areas:

- higher in ash (silicate)
- lower in lignin
- similar in cellulose
- higher in pentosan (hemicelluloses)

Traditionally, the lower lignin content has been a positive for greater fiber yield and the need for fewer chemicals and energy. Yet the higher ash content has been hazardous for ruining expensive machinery. When silica gets into a chemical recovery unit, it can cause a glassy build-up of minerals around the vats and boilers. Mill operators are then forced to shut down the plant for maintenance, which is an extremely inefficient and expensive process for a mill that is supposed to run 24 hours a day, year round.

Wheat straw pulp has a broader fiber length distribution than hardwood pulp and a broader distribution in length to diameter ratio than hardwood and softwood pulps. Pulps from most annual crops have mean fiber diameters far less than softwood pulps and slightly less than hardwood pulps.<sup>17</sup>

In general, many of the problems associated with non-wood fibers are in the context of applying them for use in technology that is designed for wood pulping. In fact, non-woods show greater flexibility in the required pulping chemicals, enabling some creative processes that result in effluents as co-products instead of troublesome waste. For example, the potassium content of wheat straw is higher than that typical of wood. Although potassium will not affect the pulping and chemical recovery of wheat straw, it will have a negative impact on chemical recovery as it is traditionally practiced in soda/AQ pulping processes. Yet with other pulping processes, it can be a plus. For this reason, it is necessary to apply an innovative design to capture an opportunity to convert the effluent containing the potassium into a value-added soil amendment. Ag-residue effluent can show high amounts of nitrogen as well.

## Universal Pulping Technology

This section describes the technology and advantages behind the universal pulping process. UP was invented by Eric Prior, an Oregon-based scientist who spent most of his professional life working in the pulp & paper industry in Europe. Prior and his partner, Bill Snyder, formed the company Universal Pulping, which is a recipient of grant funds from the state of Oregon through grass seed burning funds. Universal Pulping contracted with the University of Washington to verify and validate the patented UP process. This

work followed on the heels of other positive R&D results from a top non-wood pulping researcher at North Carolina State University.

This R&D led to a Class 40 engineering study on applying the UP non-wood pulping approach to the production of packaging grade papers. This initial engineering step, which places the estimates within a 40% accuracy range, is necessary to bring a R&D project out of the academic arena and into the realm of realistic estimations.

The Class 40 report confirmed the validity of the Single Stage process (described below) in pulping Oregon annual rye grass seed in which a mixture of sodium hydroxide, nitric acid and alum catalyst was used. Commercial mill conditions were simulated, providing enough information for preliminary estimates of chemical, capital and energy requirements. The study confirmed that the pulp produced is suitable for use in the production of corrugating medium. An early cost estimate of \$20-28 million for a 200 tons per day integrated mill was determined for capital requirements; the estimated cost of pulp production, excluding capital depreciation, was deemed to be \$125-130 per bone dry short ton (BDST).

As the precursor to commercialization, a Class 20 study must be commissioned at an approximate cost of \$115,000 focusing on the raw material from a target location. One bid has been received by Mike Jackson and backed by The Harris Group, a Seattle-based engineering firm with substantial experience in working within the pulp and paper sector. Such a study would take painstaking detail into account to provide technical and cost data for a final business plan with pro forma financial projections. The Class 20 study would focus on land and site selection and improvements; energy capacity and requirements; plumbing, engineering and layout design; transportation infrastructure needs; water source and effluent treatment considerations; all code and permitting requirements. The accuracy of the Class 20 study is so critical that it is generally required by any development and finance company for a construction and engineering guarantee.

## **Process Overview**

UP uses a low temperature, non-pressurized, dilute chemical process that is environmentally benign. This more simplified one-stage process is designed to gently and effectively separate ag-residue and on purpose plant fibers via a method that does not require the astronomical capital costs typically associated with wood-based pulp mills.

The Universal Pulping process is extremely versatile compared with most large-scale virgin wood pulping technologies. It can handle a variety of non-wood fibers, as well as produce several types of pulp that would be targeted for sale to different grades of the paper industry. In its simplest single-stage step, UP can produce pulp for the largest sector packaging and paperboard market. Yet the Universal Pulping Process, unlike most wood-based pulping processes, can be scaled up to a two-stage (acid/alkaline) process to produce a bleachable pulp or alpha cellulose, hemicellulose and lignin. This two-stage process would be required for manufacturing the higher grades of paper - the household/sanitary paper sector, as well as the fine printing and writing category.

### Single Stage Process

Once the uniformly cut straw is pre-treated with an initial dilute spray of nitric acid, it is then introduced into a digester (the pulping vat) with water and 0.5% nitric acid, and cooked for less than one hour at no greater than 86°C. Neither high concentrations of chemicals, high pressures nor high cooking temperatures are used. In contrast, wood would require high pressure (175 psi), high temperature (375°F) and a 25% concentration of chemical. After this initial step, the cooking liquor is recovered for reuse on the next batch, and the straw is washed with the wash water returning to be used during the pretreatment stage.

### Two-stage Process

Following the single-stage steps, nitric acid is again introduced in an amount to trigger a reduction in pH to 6.0, which precipitates the lignin and other insolubles. The removal of the lignin produces a lighter pulp, and the lignin has a market within the chemical industry. It is used for animal feed, adhesives and other products.

The UP process uses chemicals that are recoverable and reusable for additional pulping. The byproducts that are available once the fiber is separated from the lignin have qualities that could produce several products, such as a soil amendment. Nitrogen-rich fines from wheat straw that would be removed from the straw during pre-processing could be mixed with the effluent to be marketed as a soil amendment.

## **Past Barriers and New Developments**

Universal pulping is a novel process that solves several challenges that have traditionally held non-wood feedstock out of the realm of modern paper manufacturing. In general, non-woods hold many advantages over their wood counterparts – mainly, they do not require the same pulping conditions that are designed to separate lignin from woody fibers, characterized by harsh chemicals, and bleaching systems which produce toxic byproducts, as well as long cooking times in pressurized vessels. Yet UP offers several unique advantages.

Traditionally, one of the greatest barriers to widespread acceptance of ag-residue pulping has been the problem with silica, a mineral that shows up in higher concentrations in non-wood fibers. While non-wood fibers tend to have less lignin, which provides advantages in using less energy and fewer bleaching chemicals, their greater silica content has been problematic. When silica-laden material is pulped in high temperature digesters, there is a danger of building up a glassy substance in the machinery, requiring technicians to frequently shut down the mill for cleaning. UP uses low temperature pulping, so silica build-up in boilers is not problematic.

Another barrier has been the challenge of storing and shipping large quantities of ag-residues to meet the feedstock demands of a full scale modern pulp & paper mill. Today, however, large-scale strawboard companies are demonstrating newfound confidence in the collection, processing and storage of annual crop fibers. The largest of such mills is based in Manitoba, Canada, consuming over 150 tons per day and producing 144 million square feet per year, drawing from a radius of 75 miles.

## 6. MARKET OPPORTUNITY

This section describes the immediate market interest in, and the long-term market potential for the non-wood pulp to be produced from a 30 ton pilot manufacturing run. It also includes an overall discussion of pulp & paper types and markets, as well as a general discussion about why non-wood pulp and paper can hold a market advantage in certain instances over standard wood-based pulp and paper.

### Market Interest

At this point, Fiber Futures has identified market *interest* from several pulp users and paper companies. Yet in order to secure conditional market *commitment*, companies need to test a large batch - generally minimum one ton - of the designated material.

Six companies have formally expressed their interest in testing an upcoming batch of non-wood wheat straw pulp using the Universal Pulping process. These include:

- ◆ Procter & Gamble – tissue and towel
- ◆ New Leaf Paper – printing and writing
- ◆ Brownville Specialty Paper – paperboard
- ◆ Living Tree Paper – printing and writing
- ◆ Crane Paper – printing and writing
- ◆ KP Products/Vision Paper – printing and writing

Market interest is conveyed in letters shown in Appendix C. If the letter is absent, the interest was conveyed verbally or by email.

A 30 ton test is necessary to produce ten tons each of:

1. unbleached pulp for paperboard, specifically corrugating medium;
2. bleached and unbleached pulp for tissue and towel;
3. bleached and unbleached pulp for fine printing and writing.

The whitening process applied for the tissue/towel and printing/writing would not use any chlorine bleach. The pilot test run would take place at an existing site which can simulate the required low pressure, low temperature conditions necessary for the Universal Pulping process. The mill would be leased out for the sole purpose of producing such pulp. Costs for the pilot trial were obtained from Mike Jackson and Harris Engineering.

### Market Potential

The entire capacity of a proposed 200 tpd wheat straw pulp mill in the Pacific Northwest could provide a paper giant, such as Procter & Gamble, with only a fraction of its pulp needs. This approach would enable P&G to lock in a predictable supply and price of pulp, compared to dealing with the whims of market volatility of the open market for wood pulp. It would also enable the project to more easily obtain financing, provided that P&G were able to sign a conditional take-out contract.

Although P&G is less committed to the green marketing advantages of a "tree-free" or "forest-free" pulp, Crane, New Leaf, KP Products and Living Tree are small, yet fast-growing paper companies which target environmentally choosy consumers. New Leaf Paper Company custom manufactures high post-consumer recycled content papers; Living Tree custom manufactures a printing and writing grade that contains a blend of hemp, flax and post-consumer recycled fibers; Crane carries lines of hemp, kenaf and cotton papers and KP Products manufactures a kenaf/post-consumer recycled blend.

These companies appeal to consumers who are dedicated enough to go through the trouble of finding and buying the paper directly from the source, over the internet, from particular printers or specialty catalogs, as none of their products are found at mainstream office supply stores. Most of these companies make their paper by leasing time on pulp mills or buying reliable sources of pulp. (Crane is the exception with in-house pulp and paper manufacturing capabilities.) Their combined production is less than 1000 tons per month.

Brownville Specialty Papers is a pulp and paper company that was rescued by its former operations director, now president, who in the early 1990s was ordered by Boise Cascade to shut down the plant, lay off the workers and sell off the equipment. Instead, he orchestrated an employee buy-out of the mill and turned it into a profitable venture. Today, Brownville specializes in specialty and commodity paperboard products, and the owner welcomes innovative opportunities to experiment with materials that have a social story and can potentially provide a regular supply of affordable pulp.

These companies have expressed initial interest for a variety of reasons, whether it is concern over rising wood pulp prices and future supplies, or for an added environmental statement that the business can convey to its paper buyers. The interest demonstrated by this small number of companies is likely indicative of a wider breadth of interest by companies that inevitably share the same concerns and market positioning.

The remainder of this section includes anecdotes and vignettes of market trends that can not formally be extrapolated for market research, but certainly provide a sense of the market's varying dimensions. Overall statistics of the domestic and world markets for paper and non-wood fibers are found in Section Four.

## Recent Market Indicators

American consumers, for the most part, are oblivious to the environmental issues surrounding their paper use. Rapidly established curbside recycling programs that were set up in the 1980s and 1990s have left the average person assuming that s/he is doing the right thing, and that the recycled paper will automatically be used in making new paper. Actually, in the late 1990s, recycled paper content used in paper manufacturing declined from its high of 10% to its current rate of just barely 8%.<sup>18</sup>

Paper companies assert that consumers have stopped requesting recycled paper at the stores and recycling companies claim that they can get better prices by selling the scrap paper to overseas countries lacking in forest resources. The United States still stands as the largest exporter of recovered paper, shipping close to 7 million metric tons per year.<sup>19</sup>

While the average consumer awareness for recycled paper has slipped, there has grown a tiny, yet determined minority of people who refuse to use paper made with "dead trees" as many of them would call virgin wood paper. A handful of these cultural creatives are willing to pay higher prices for a ream or a carton of paper, particularly so they can draw attention to a "tree-free" tag line at the bottom of the page.

Although non-wood cotton bond papers have been on the market since the dawn of modern papermaking, the term "tree-free" paper erupted just about the time a maverick entrepreneur introduced a line of 100% kenaf paper called Vision Paper. The \$12 per ream price tag that it commanded (compared to less than \$3 for virgin paper) kept the product out of mainstream office supply outlets, yet by 1996, KP Products of New Mexico was producing just under 100 tons per month of printing and writing grade paper.<sup>20</sup> Vision Paper is now less expensive and offers paper varieties which contains some post consumer recycled fiber content along with kenaf, an annual plant fiber grown mainly in the south.

It is no secret that non-wood papers, now produced by a half dozen small companies whose combined market share is less than \$10 million<sup>21</sup>, are still far more expensive than virgin wood-based paper, and even 100% post-consumer recycled paper. Yet this can gradually change, given a growing awareness of the chemical emissions of wood-based paper mills coupled with reduced logging and a contraction in chip supplies as a greater number of large corporations, such as Home Depot and Lowes, pledge to stop buying products made with old growth trees.<sup>22</sup>

One can conjecture that consumers' choice of ecological paper will follow similar paths of market expansion seen by the organic food movement and even solar power generation. Both have reached sufficient critical mass after decades of dogged determination but practically stagnant growth. Today, these sectors are booming, and demonstrating that enough people were willing to pay a higher percentage to eventually ensure that the demand would have a favorable impact on the economies of scale, which is now reducing their costs.



## 7. STRUCTURING A DEAL

This section assumes that, at least in the near term future, a traditional pulp & paper industry representative is not likely to initiate a non-wood pulp mill in the Pacific Northwest. Yet the information provided in this report indicates that the research is ready for a demonstration phase, given that there is sufficient market opportunity, combined with an innovative cost-competitive process. The potential therefore could be shopped to potential developers through economic development personnel of Washington state, as well as county economic development officials.

### Potential Deal Structure

A significant challenge for this project would be to structure it in a way that it will attract the necessary leadership and financing for the construction and start-up of the mill. Several possible structures could involve equity participation by a farmers' cooperative, a Native American tribe and other entities that could stand to benefit. Ultimately, it would be necessary to retain the expert financial advisors, with the benefit of a Class 20 study, to assess the business, accounting, legal and tax implications of the various options.

One possible deal structure, shown below, could combine unique sources of capital available specifically to each organization. The background considerations for pursuing such a type of structure are further described in this section.

\$6,000,000 Entrepreneur/Developer  
\$3,000,000 Farmers' Cooperative  
\$3,000,000 Strategic Partner (Paper Company or Native American Tribe)  
\$12,000,000 Total Equity  
\$12,000,000 Tax exempt bond financing  
**\$24,000,000 TOTAL PROJECT START-UP COSTS**

### Potential Partners

Agricultural Cooperative Involvement The historically rich significance of agriculture cooperatives in furthering rural economic development serves as a compelling model for considering how to structure a non-wood pulp mill utilizing ag-residues. About thirty percent of farmers' products in the U.S. are marketed through cooperatives. And more than 20 cooperatives have annual sales in excess of \$1 billion.<sup>23</sup>

A unique straw particleboard plant in Minnesota received about 1/3 of its start-up financing through a joint partnership with a farmers' cooperative. In Kansas, Prairie Forest Products is almost entirely owned by three farmers' cooperatives. Strawboard plants are typically capitalized at start-up costs of \$3 - \$7 million.

Several ethanol plants in the mid-west were financed through cooperative involvement. In one instance, a grower would buy into a coop at a minimum of 5000 shares at \$5 per share. For each share the farmer owns, he must deliver a bushel of corn at market price.

At the end of the year, each farmer receives a dividend, which is calculated according to the profit made by the plant that year. One farmer estimates that 10 million bushels are delivered, so it is possible that initial financing amounted to \$10 million.

Preliminary and planning grants are made available through the USDA to help entities finance complex projects. Such examples under the Rural Business Cooperative Service have included a \$200,000 grant to set up a revolving loan in Northeast Alabama and a \$50,000 grant which led to a \$14 million low interest loan to help construct new electrical lines for a community in Jonesboro, Arkansas.

Inquiries have been initiated with the USDA in Washington about whether this project might be eligible for a preliminary grant to help set up a straw collection and processing coop. Fiber Futures has been encouraged to apply. State contact names have been obtained and the proposal process is underway.

Strategic Partner Involvement. At least two of the paper companies that have expressed interest in this project have indicated that investment monies are available should the pilot tests prove positive and should long-term take-out contracts be agreed upon.

Besides a paper company partner, several Native American reservations are located on or close to rich agricultural areas in the Pacific Northwest. Some of these reservations are in great need of economic development due to high unemployment rates. Recognizing this, many tribes have adopted some sort of plan to direct their economic development. These plans often focus on the need to develop environmentally sustainable businesses.

Precedence has been set for a nearby tribe's involvement in a straw utilization project. On the Coeur D'Alene Reservation in Plummer, Idaho, the Tribal Council elected to divert casino shares for an economic development opportunity involving a grass straw pulp mill. The tribe formed a partnership with SEEDS Inc., a blue grass grower, and Pacific Northwest Fiber, a company that operated oriented strand board mills. The partnership built a mill that produces particleboard using blue grass straw. It was necessary to structure the deal so that at least 50% of the partnership was owned by the tribe, and at least 50% of the employees at the mill were residents of the reservation. Apparently SEEDS initiated the project in an effort to find some way to dispose of its blue grass straw without burning it, a practice that has been severely restricted in Idaho. SEEDS brought the idea to the tribe's Planning and Development Corporation, which oversaw feasibility studies, hired engineers, and assisted in finding investors. SEEDS and the tribe contacted several possible partners before choosing Pacific Northwest Fiber.

In addition to development incentives that may be provided by individual tribal governments, there are many tax incentives for tribal ventures. These include an exemption of federal income taxation and certain excise taxation exemptions; access to tax exempt financing, exemption from local taxes including license, consumption and use taxes; deductions and credits against state income tax and more.

## 8. CONCLUSIONS AND RECOMMENDATIONS

Worldwide, there is no state of the art pulp mill, which uses ag-residues, makes use of its effluent, is low cost and is of an appropriate scale that makes sense for bioregionally beneficial economic development efforts in rural areas. Nevertheless, U.S. and international experts are without hesitation in agreeing that the technology to design such a mill is viable. At least one pilot mill is in existence in Canada, although it produces only a tiny amount – one ton per day. Other efforts are underway in Australia and England involving state-of-the-art wheat straw pulping.

Results from this modest research project could lead to the development of a non-wood pulp facility that would set new standards and break down old paradigms that have created economic stagnation in rural communities, and environmental frustration within the traditional pulp and paper industry. Yet the project's promising innovation is not enough. Without adequate leadership mobilizing the resources to shape the next phase, the research and market potential will fail to propel into a mature development project.

In order to proceed into the Second Phase, the following steps need to be taken at a combined cost of approximately \$475,000:

1. Commission Class 20 Engineering Study by a reputable engineering firm;
2. Conduct 30 ton pilot test run using Universal Pulping at existing pulp mill;
3. Conduct a market study; secure additional letters of market interest;
4. Finalize site, obtain costs, coordinate with a farmers' cooperative and/or a local tribe; secure financial incentives;
5. Conduct lab tests necessary to develop soil amendment from effluent and determine need for further field testing;
6. Conduct final bleaching tests necessary to determine marketability for other grades;
7. Write business plan complete with pro formas using Class 20 data;
8. Seek project development partner.

These eight steps would be expected to take sixteen months to complete. Assuming their results are favorable, a Third and final Phase would involve raising approximately \$1 million to hire the final project engineer and developer with guarantees on the construction and design, to raise total project financing, to obtain necessary permits, and to structure the deal with professional legal assistance.

While straw pulp development projects are being pursued by private entrepreneurs in different parts of the western world, there is little or no significant push in the United States to launch a non-wood pulping enterprise. Although the "mini-mill" concept, designed for bioregionally appropriate ag-residue pulping has garnered little interest from traditional pulp & paper representatives, it is within reason for a non-traditional entity to continue pursuing it. The traditional wood-focused pulp and paper industry is not likely to take first steps in innovating non-wood pulping due to preference for massive development projects and significant investment in wood resources, as shown in Section four.

Fiber Futures, with research assistance from the University of Washington and Washington State University, is positioning an important food crop residue to help the world meet its future fiber needs. It has chosen a "closed loop" technology that will produce an effluent co-product as a soil amendment, instead of dealing with the wastewater as a costly burden. This model for new century pulp and papermaking could provide paper manufacturers and pulp brokers with a steady supply of low cost unbleached pulp for the corrugated medium market, while showing great potential to provide market pulp for higher grades – namely, tissue and towel and fine printing and writing papers.

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## APPENDIX A. GLOSSARY

### DEINKING

*The process of removing ink from wastepaper so that the fiber can be recycled*

### DIOXIN

*A hazardous chemical believed to be carcinogenic that is formed as a byproduct of bleaching pulp with chlorine gas*

### ECF

*Elemental Chlorine Free  
A bleaching process that avoids chlorine gas and reportedly reduces dioxin emissions*

### FAO

*Food & Agriculture Organization*

### FINES

*Very small, or fine, pieces of fiber*

### GREENFIELD MILL

*A pulp or paper mill built from scratch where none has been before*

### HARDWOOD

*Wood cut from deciduous trees – produces short fibers for papermaking*

### KAPPA NUMBER

*Value indicating the lignin content of pup. The lower the kappa number the greater the bleachability.*

### KRAFT

*Heavy paper or paperboard made from unbleached kraft pulp which is made by boiling wood chips in a sodium and sulfate solution.*

### LIGNIN

*“nature’s glue” – a substance that combines with cellulose to form the woody cell walls of plants*

### MARKET PULP

*Pulp that is sold to a company*

### NBSK

*Northern Bleached Softwood Kraft  
A bellwether pulp used to gauge market prices*

### SOFTWOOD

*Wood cut from coniferous trees such as spruce, fir and pine – produces long fibers for papermaking*

### TAPPI

*Technical Association of Pulp & Paper Industry*

### TCF

*Totally Chlorine Free  
When a non-chlorine bleaching process is used to whiten pulp, such as ozone delignification and hydrogen peroxide*

### TPD

*Tons Per Day*

### TPY

*Tons Per Year*

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*Tons Per Year*

## APPENDIX B. STRAW RESOURCE DATA

### WASHINGTON BARLEY - 1999

<b>COUNTY</b>	<b>Harvested Acres/ Year</b>	<b>Available Residue Tons/Year</b>	<b>25% Harvest Rate Tons/Year</b>
Adams	11,400	21,660	5,415
Asotin	12,400	23,560	5,890
Benton	0	0	0
Columbia	22,900	43,510	10,878
Douglas	0	0	0
Franklin	0	0	0
Garfield	39,400	74,860	18,715
Grant	9,300	17,670	4,418
Klickitat	10,000	19,000	4,750
Lincoln	131,200	249,280	62,320
Okanogan	0	0	0
Spokane	42,000	79,800	19,950
Stevens	5,700	10,830	2,708
Walla Walla	25,800	49,020	12,255
Whitman	0	0	0
Yakima	168,500	320,150	80,038
All Other Counties:	10,400	19,760	4,940
<b>TOTAL:</b>	<b>489,000</b>	<b>929,100</b>	<b>232,275</b>



## WASHINGTON GRASS SEED - 1999

<b>COUNTY</b>	<b>Harvested Acres/ Year</b>	<b>Available Residue Tons/Year</b>	<b>25% Harvest Rate Tons/Year</b>
Adams	4,500	24,300	6,075
Asotin	0	0	0
Benton	0	0	0
Columbia	0	0	0
Douglas	0	0	0
Franklin	3,500	18,900	4,725
Garfield	1,900	10,260	2,565
Grant	5,500	29,700	7,425
Klickitat	0	0	0
Lincoln	0	0	0
Okanogan	0	0	0
Spokane	26,600	143,640	35,910
Stevens	0	0	0
Walla Walla	11,000	59,400	14,850
Whitman	3,100	16,740	4,185
Yakima	0	0	0
All Other Counties	22,900	123,660	30,915
<b>TOTAL:</b>	<b>79,000</b>	<b>426,600</b>	<b>106,650</b>

## WASHINGTON WHEAT-1999

<b>COUNTY</b>	<b>Harvested Acres/ Year</b>	<b>Available Residue Tons/Year</b>	<b>25% Harvest Rate Tons/Year</b>
Adams	297,500	815,997	203,999
Asotin	24,400	66,926	16,731
Benton	105,600	289,645	72,411
Columbia	71,800	196,937	49,234
Douglas	200,000	548,570	137,142
Franklin	122,900	337,096	84,274
Garfield	70,500	193,371	48,343
Grant	182,600	500,844	125,211
Klickitat	44,000	120,685	30,171
Lincoln	318,000	872,226	218,056
Okanogan	10,200	27,977	6,994
Spokane	113,500	311,313	77,828
Stevens	5,700	15,634	3,909
Walla Walla	209,200	573,804	143,451
Whitman	456,100	1,251,013	312,753
Yakima	45,000	123,428	30,857
All Other Counties	13,000	35,657	8,914
<b>TOTAL FOR STA</b>	<b>2,290,000</b>	<b>6,281,123</b>	<b>1,570,281</b>

**APPENDIX C. LETTERS OF MARKET INTEREST**

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# Procter & Gamble

The Procter & Gamble Company  
Winton Hill Technical Center  
6105 Center Hill Avenue, Cincinnati, Ohio 45224-1788

September 5, 2000

Jeanne Trombly  
Executive Director  
Fiber Futures  
Presidio Box 29363  
San Francisco, CA 94129

Dear Ms. Trombly,

Thank you for meeting with our Tissue and Towel division to further examine the potential for incorporating some non-wood pulp into our operations here in the US and abroad.

As I mentioned, P&G sold off all of its pulp mills in the 1990s. We purchase all of our pulp on the open market and would be interested in any cost comparative non-wood fibers that meet our quality specifications. The majority of pulp that we currently purchase is NBSK, NBHK, and Eucalyptus. We also use small amounts of recycled fiber in our T/T products.

We have considered non-wood pulp in the past but have not been able to obtain sufficient quantities in order to determine compatibility with our product mix. If your team conducts a pilot test run of wheat straw pulp or other non-wood fibers, we would ideally like to purchase at market price approximately one ton for further testing.

Our final determination about whether to sign a long term purchase contract would be based on price and quality specifications.

I look forward to further consideration of these non-wood pulps that could help P&G meet its future fiber needs.

Regards,



Mary E. Kostolansky

c: Dale G. Kavalew  
Scott V. Truncellito

# Agrium



**Agrium Inc.**  
13131 Lake Fraser Drive  
Calgary, AB  
T2J 7E8  
Phone 403-225-7000

Tom Jensen  
Agronomist

Direct Line 403-225-7232  
Facsimile 403-225-7618  
e-mail: tjensen@agrium.com

19-June-2000

Dr. William L. Pan  
Department of Crop and Soil Sciences  
Washington State University  
171 Johnson Hall  
Pullman WA 99164-6420

Dear Dr. Pan:

Regarding: Development of Technology to Use Small Grain Crop Residue as a Source of Fiber for Pulp and Paper.

This letter is to show Agrium's interest in participating in a research program into developing technology to use small grain crop residue as a source of fiber for the pulp and paper industry.

Agrium is a major producer of fertilizer products, with nitrogen, phosphorous, potassium and sulfur production plants in the United States and Western Canada. Our primary markets are the Pacific North West (PNW) and California, the Northern and Central Great Plains, and Western Canada.

We at Agrium are interested in the Proposed research program you are developing for a number of reasons. **First**, the development of an industry that would use excess straw or crop residue from small grain production in the PNW would assist grain producers by allowing them to gain an alternate source of cash income by the sale of straw. **Second**, the baling off and use of excess crop residues could help make no-till cropping systems more feasible in the PNW. **Third**, there is significant potential to use the by-products from using crop residues for pulp production to be combined with fertilizer products such as ammonia (NH<sub>3</sub>), and make new controlled release fertilizers. Controlled release fertilizers can be used to allow increased efficient use of fertilizers to maximize crop yields and net grower returns, while minimizing the environmental footprint of using fertilizers.

We would be interested in participating in the proposed research both in a monetary way (i.e. up to \$5000 per annum) and in allowing a graduate student to conduct some research at one of our fertilizer plant facilities.

Yours truly,

Thomas L. Jensen, Ph.D.  
Agronomist.



**Brownville Specialty Paper Products, Inc.**

Bridge Street  
Brownville, NY 13615

(315) 782-4500 • FAX (315) 782-3964 • 800-724-0299

October 18, 2000

Ms. Jeanne Trombley, Executive Director  
Fiber Futures  
Presidio Box 29363  
San Francisco, CA 94129

Dear Jeanne,

I was pleased to get your phone call regarding the progress on the non wood pulps.

As you know we are extremely interested in this project and are anxious to incorporate these pulps into our products. We feel that these new pulps would be ideally suited for our needs.

In total we purchase about 4000 - 5000 tons a year of various grades of pulps. They include Northern and Southern Bleached Krafts, Unbleached Kraft, BCTMP and Groundwood. We also use a considerable amount of recycled fibers.

We would like to do some trials as soon as the pulps are available.

Please keep us informed.

Sincerely,

Gene Rood  
President

GR/na

pc: Jim Robinson, Mill Manager  
Steve Moore, Technical & Quality Manager





TREE-FREE & RECYCLED PAPERS

September 20, 2000

Jeanne Trombly  
Executive director  
Fiber Futures  
Presidio Box 29363  
San Francisco, CA 94129

Dear Ms. Trombly:

I am pleased that you have narrowed in on a pulping technology for small-scale bioregionally appropriate nonwood fibers. Living Tree Paper Company has been using nonwood fibers (flax and hemp) in our paper blends for the past 7 years. At this juncture we are forced to import our nonwood pulps from Europe due to lack of availability here in North America.

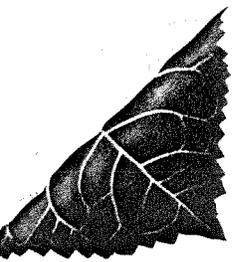
We would be interested in a feedstock of straw pulps especially if it is from the Pacific Northwest region. Once the pulp test run is complete, we would be interested in having you ship 20 tons of pulp to our mill in the East Coast for a papermaking trial. I will give you exact specifications when you are ready to actually make the pulp. If we are satisfied with the trial we would be using from 1000 to 10,000 tons annually for our paper products.

Please keep me posted on your progress. I look forward to being in touch with you this fall and meeting up with you in San Francisco in October.

Sincerely,

A handwritten signature in cursive script, appearing to read "Carolyn Moran".

Carolyn Moran, President  
Living Tree Paper Company



# NEW LEAF PAPER

## Our Mission

The mission of New Leaf Paper is to supply our customers with the most environmentally responsible paper to meet their business needs.

Our goal is to inspire ~ through our success ~ a fundamental shift toward environmental responsibility throughout the paper industry.

**New Leaf Paper** is a nationwide paper distributor based in San Francisco and New York. We distribute office and printing papers with superior environmental qualities. We have custom developed our papers to perform and be priced comparably to other fine printing and office papers.

## Our Primary Objectives

**Service**—New Leaf Paper provides hands-on service and effective quality control, focusing exclusively on environmental papers. Our customers consider us a valuable partner in determining which papers best suit their business needs and environmental initiatives.

**Benefit**—By specifying our custom made recycled grades, you are choosing ultra-high post-consumer waste content, a chlorine-free bleaching process and recycled or non-wood fibers. Our papers can help your company minimize its impact on the environment while communicating a clear message to clients about your environmental commitment. Selecting New Leaf Paper products pays dividends to your environmental bottom line.

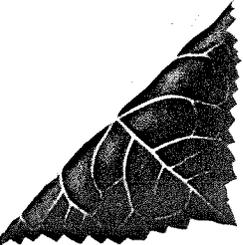
**Quality**—We unconditionally guarantee that our paper products measure up to the quality standards of the NPTA (National Paper Trade Association) and are comparable to competing grades in performance and price.

**Environment**—We can provide an **Eco-Audit** to illustrate the minimized impact on the environment a New Leaf Paper purchase has in comparison to paper made with virgin fiber. It shows the amounts of effluent, water, energy, trees and landfill space saved.

## Our Clients

- Apple Computer, Inc.
- Earth Island Institute
- Gap & Old Navy
- Herman Miller, Inc.
- Hewlett-Packard Company
- Metreon, a Sony Entertainment Co.
- Mitsubishi Electric America
- Natural Resources Defense Council (NRDC)
- Nike, Inc.
- Patagonia
- The Environmental Defense (ED)
- World Wildlife Fund

Printed 17-Aug-00 on New Leaf Paper Everest Writing 24# ~ 100% post-consumer waste, processed chlorine-free



**NEW LEAF**  
PAPER

August 15, 2000

Jeanne Trombly  
Fiber Futures  
Presidio Box 29363  
San Francisco, CA 94129

Dear Jeanne,

I am very interested in the work that you are pursuing in the Pacific Northwest to analyze the technical and economic feasibility of wheat straw pulp. The hand sheets that you have sent from the University of Washington show promising signs.

If you decide to move forward with a major pilot run of the wheat straw pulp, New Leaf Paper would be interested in purchasing it at a fair market value price. I estimate that we would need approximately 20 tons to fully determine if it works in our product mix.

I have enclosed some information sheets on New Leaf Paper for your reference. We rely on the web for comprehensive company information at [www.newleafpaper.com](http://www.newleafpaper.com).

Please keep me abreast of the progress of this very exciting work.

Sincerely,

Jeff Mendelsohn  
President

## APPENDIX D. RESEARCH RESULTS



# Effect of Black Liquors from Universal Pulping and Neutral Sulfite Pulping on Soil Properties and the Growth of Wheat

C. Xiao and W. L. Pan , Washington State University  
Mark Lewis and Bill McKean, University of Washington  
March 28, 2001

## Abstract

Pulping liquor and lignin are produced during the production of pulp and paper making, and these products could be used as potential soil amendments to enhance soil productivity of agricultural land (Camberato et al., 1997). A 4 week wheat growth experiment was conducted to evaluate rice straw-derived lignin from an Egyptian pulp mill and two wheat straw-derived pulp liquors, neutral sulfite semi-chemical (NS) and universal pulping (UP) as potential soil amendments for enhancing soil properties and crop growth. The results indicated (1) rice straw-lignin decreased soil pH and increased soil EC, aggregate formation >2 mm in diameter and macro-aggregate stability of >2 mm, 2-1 mm, 1-0.5 mm and 0.5-0.25 mm aggregates, (2) lignin increased wheat shoot biomass by 29.3% and 11.5% over no amendment and 0 N controls, respectively, but when compared to the corresponding N rates of 100 and 200 mg N kg<sup>-1</sup> soil of (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, lignin at the low rate reduced wheat shoot growth by 16.4 %, while lignin at the high rate significantly increased the shoot weight by 38.6%. (3) NSSC pulp liquor in combination with (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> significantly inhibited wheat growth, possibly due to increased EC and Na availability. The UP liquor with (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> did not affect shoot biomass compared to the (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> alone, and was the only amendment to raise soil pH (4) All three pulping byproducts improved large soil aggregate formation. These results suggest the the pulp byproducts could be potential soil amendments but

potential adverse effects of Na, soil acidification and elevated EC should be taken into account in the pulping chemistry design.

Keywords: wheat straw, rice straw, lignin, pulp liquor, soil properties, soil aggregation, wheat growth

### **Introduction**

Organic matter is an important component for the improvement of soil fertility, soil structure and crop productivity because it regulates both soil physical and chemical properties. Various materials have been used to increase the soil organic matter, including straws, manures, sewage sludge and composts (Raviv et al., 1986). Lignosulfonate (LS) and other waste lignins are produced in great amounts during the production of pulp and paper (Haider and Kladvko, 1980), and they could offer other potential sources of soil amendments. Studies have shown that lignosulfonate (LS), a soluble lignin derivative product from the sulfite pulping process of paper manufacturing, can be used as a soil amendment to enhance productivity of agricultural systems while maintaining high environmental quality standards (Haider and Kladvko, 1980). Owing to characteristics, LS can increase soil structure (Mahoney, M. K. 1998) and soil organic matter (Xie et al., 1994).

Some studies have shown that this material inhibited the urea hydrolysis and nitrification (Meier et al., 1993; Xie et al., 1993) thus reducing the potential for denitrification and leaching loss. This means this material can increase the efficiency of urea- or ammonia-N fertilizers for crop production. Previous studies have focused primarily on the effects of LS or  $\text{NH}_4^+$ -LS from sulfite pulping on soil properties and the crop growth (Meier et al., 1993; Buylov et al., 1979; Mahoney, 1998; Xie et al., 1993,

Xie et al., 1994), but there are very limited reports on the utilization of lignin of black pulp liquor or pulp liquor from Kraft or soda pulping process in above respects (Sudirjo et al., 1991). This study was conducted (1) to evaluate the effect of pulp liquors from paper making and lignin precipitated by acidifying on soil organic carbon and nitrogen, pH and electrical conductivity, and nitrogen mineralization, soil aggregate in the soil size distribution and water-stable aggregation using incubation experiment, and (2) investigate the growth response of theirs on wheat by chamber experiment.

### **Materials and Methods**

*Pulping byproduct characteristics.* Three waste products from paper manufacturing were used for the experiments. Rice straw lignin) was obtained from a pulp mill in Egypt, and its main ingredient was lignin, which was precipitated by acidifying pulp black liquor. The other two products, neutral sulfite semi-chemical (NSSC) and universal pulping (UP) liquors were prepared by Mark Lewis at University of Washington. Some chemical properties of these three products are shown in Table 1.

Table 1. Selected properties of pulping byproducts (expressed on a wet matter basis)

Parameters	Lignin	UP	NS
PH	3.24	11.62	10.42
EC (ds/m)	-	16.78	31.88
Moisture (%)	85.4	95.8	95.8
NH <sub>4</sub> <sup>+</sup> - N (ppm)	350	0.00	0.00
NO <sub>3</sub> <sup>-</sup> - N (ppm)	1.70	0.00	0.00
Organic N (g kg <sup>-1</sup> )	4.51	0.529	0.00
Total N (g kg <sup>-1</sup> )	4.86	0.529	0.00
Total C (g kg <sup>-1</sup> )	79.5	17.0	6.39
C/N	16.3	32.2	-
Total S (g kg <sup>-1</sup> )	3.09	0.00	0.71
Na (g kg <sup>-1</sup> )	0.64	6.60	12.5
K (mg kg <sup>-1</sup> )	131	127	99.7
Ca (mg kg <sup>-1</sup> )	246	4.0	11.8
Mg (mg kg <sup>-1</sup> )	33.0	7.3	7.8
P(mg kg <sup>-1</sup> )	99.0	12.6	8.4

A Quincy sand (0-15 cm) was collected from the IAREC, Washington State University at Prosser, WA after wheat harvest in July of 2000 for use in the growth chamber experiment. The soil was fine-silty, mixed, mesic with pH 6.38, organic C 0.64%, total N 0.070%, Olsen P 10 ppm, Olsen K 163 ppm, NaOAC-K 122 ppm, NaOAC-Ca 6.4 ppm, and NaOAC-Mg 0.04 ppm, and water capacity 11.8% (ml water/100 g soil).

**Growth chamber experiment.** Soil and wheat growth responses to these three pulping byproducts were evaluated by in a growth chamber experiment. The following treatments with 4 replications were arranged in a randomized block design: (1) control (no amendment), (2) 0.0 mg N/kg soil, (3) 100 mg N/kg soil from (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, (4) 200 mg N/kg soil from (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, (5) 100 mg N/ kg soil from rice-straw lignin-N (3.06 g

lignin  $\text{kg}^{-1}$ ), (6) 200 mg N/ kg soil from lignin-N ( $6.12 \text{ g lignin kg}^{-1}$ ), (7) UP black liquor at a rate to provide the same amount of total C as treatment 6, and (8) NSSC black liquor added in the same volume as treatment 7. Since the N concentrations of NSSC and UP were very low, 200mg N/ kg as  $(\text{NH}_4)_2\text{SO}_4$  was added to treatments 7 and 8. Ca  $(\text{H}_2\text{PO}_4)_2$  was added to each treatment at rate of 50 mg P/kg soil. Ca as  $\text{CaCl}_2 \cdot \text{H}_2\text{O}$  and K as KCl were added to treatments 2, 3, 4, 5 and 7 to provide the same amount of Ca and K as treatment 6. (7) NSSC with the same amount of ml as treatment 8, and (8) UP with same C as treatment 6. Distilled water was added to individual pots daily to maintain soil water holding capacity. The various treatments were prepared by mixing 1.2 kg of sieved ( $<2 \text{ mm}$ ) soil with their corresponding amounts of amendments into pots. The pots were lined with plastic bags to prevent any loss due to leaching. Based on the N release rate of rice straw-derived lignin determined in a preliminary incubation experiment, all the treated soil was incubated under  $23^\circ\text{C} \pm 1^\circ\text{C}$  in dark chamber for 4 weeks, and then 10 seeds of spring wheat (cv Scarlet) seeds was sown into each pot and thinned to 6 plants per pot. The pots were placed in a growth chamber in a randomized complete design under 16/8 h light/dark cycle. Illumination was provided by alternating metal halide and sodium vapor lamps with a photon flux density of 350 to 400  $\mu\text{E m}^{-2} \text{ s}^{-1}$ .

After 4 weeks of growth, the plants were harvested, cut at their base, and number of tillers and leaves were counted. The plants were dried in a  $60^\circ\text{C}$  oven for 4 days, and weighed to determine dry plant matter and N. The dried plant was ground in a Wiley Mill to pass a 20-mesh screen. In order to maintain the integrity of the aggregates, the plant roots were not taken out from the soil. A separate soil samples were taken for analysis of pH and EC,  $\text{NH}_4^+ - \text{N}$  and  $\text{NO}_3^- - \text{N}$ .

**Methods of analysis.** Total C, S and N content of three waste products was determined with a dry combustion gas analyzer (LECO). Ammoniacal-N was determined with a modified version of the Kjeldahl method. Organic N was calculated as the difference between total N and ammoniacal N. The amendment pH was measured using an Orion Research digital pH meter. The digestion solution of three waste products was made for determination of Na, K, P, Ca and Mg by ion coupled argon plasmeltry atomic emission. The moisture percentage was determined by oven-dried at 85°C for overnight.

Soil pH was determined on a saturated paste after a 30-minute equilibration (Orion Research, Boston, MA). The soil solution was extracted from the saturated paste and an electrolytic conductivity (EC) was measured as the concentration of dissolved salts in the soil solution by EC meter (Jansen, 1993). Total soil C and N and total plant N were determined on a LECO dry combustion analyzer (Leco Corp., St. Joseph, MI). Since no carbonates were present in the soil, total soil C represented total soil organic C. Mineral N ( $\text{NH}_4^+$  - N and  $\text{NO}_3^-$  - N) was determined in 1 M KCl extracts (1:10 soil/extractant) and measured colorimetrically using the phenate and cadmium reduction-diatotization methods with flow-injection autoanalyzer (Alpkem). Soil aggregation size distribution was measured on a mechanical flat sieve shaker with 2-minute shaking. A 150 of soil samples for incubation experiment and 250 g for growth chamber experiment were sieved into five size fractions. The weight of soil that remained on mesh sizes 2, 1, 0.5, 0.25, 0.15, and 0.53mm was recorded and reported as a fraction of the total sample weight (Kemper and Rosenau, 1986). Soil water stable aggregation was determined with a method of W. D. Kemper and R. C. Rosenau (1986) modified by A. C. Kennedy and P. Frohne (personal communication) using the size fractions obtained from the mechanical

flat sieve shaker (5 grams of soil that remained on mesh sizes of 2, 1, 0.5 and 0.25 mm was weighed into separate aggregate holders, PVC pipes (approximately 6.3 cm in diameter and 3.8 cm in height) with cloth attached at one end. The aggregate holders were exposed to 1 cm tension of water (negative potential), allowed to equilibrate for at least 3 hours, transferred to 250 ml beakers using approximately 50 ml water, and placed on an orbital shaker set at 60 rpm for 10 minutes. The contents of the beakers were poured through a 250  $\mu$ m mesh size sieve and then through a 53  $\mu$ m sieve. A large plastic weigh boat was placed under the sieves to catch the soil and water material passing through the 53  $\mu$ m sieve, called the fines fraction. Soil remaining on 250  $\mu$ m and 53  $\mu$ m sieves were removed with water, transferred to a large plastic weigh boat, dried at 85 °C, weighed, and reported as a fraction of the sample weight (approximately 5 g) for each aggregate size evaluated. Macroaggregate stability was defined as the percent of water-treated aggregates that remains on a 250  $\mu$ m sieve after 1 cm of tension water treatment and the microaggregate stability as the percent remaining on a 53  $\mu$ m sieve (Kemper and Rosenau, 1986).

*Statistical analyses.* Analyses of variance were performed by the GLM procedure of SAS (SAS institute, 1994-1996). Means separation are designated for the 0.05 significant levels using Bonferroni-Dunn test statistics.

## **Results and Discussion**

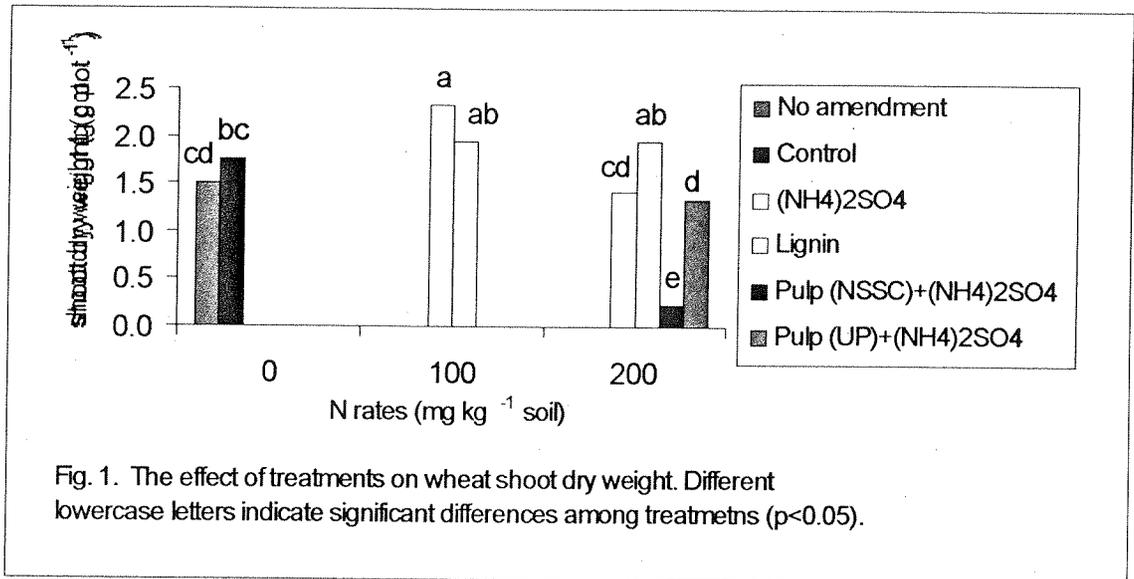
*Wheat growth, development and N uptake.* Comparable wheat growth and development was observed for the no amendment control and the 0 N control, indicating that P and K were not limiting in this soil. The N fertilizer and pulping amendments had a significant effect on wheat growth (Table 2). The N rate of 100 mg/kg soil from

(NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> resulted in the highest leaves, tillers, and shoot dry matter among treatments, while 200 mg N/kg soil decreased tiller production and shoot dry matter while increasing shoot N, suggesting NH<sub>4</sub> toxicity or adverse effects of the resulting lower pH with the high rate of inorganic fertilizer. The addition of lignin at equivalent total N rates of 100 mg kg<sup>-1</sup> soil resulted in similar shoot dry weights to that obtained with the inorganic N, and at the high rate of lignin increased shoot dry weight by 38.6% relative to the inorganic N equivalent (200 mg kg<sup>-1</sup>) (Fig. 1), suggesting that the addition of lignin-bound N reduced the high N toxicity effect noted with (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>.

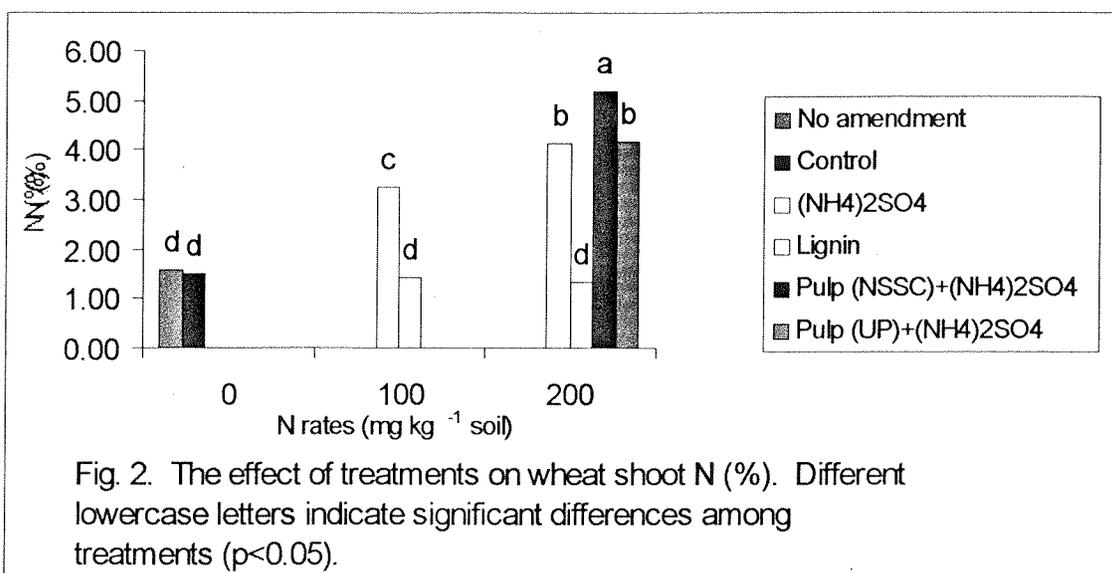
Table 2. Wheat growth and development as affected by N fertilizer and pulping byproducts.

N source	N rate (mg/kg)	Leaves (per plant)	Tillers (per plant)	Shoot dry matter (g/pot)	Shoot N (%)	Shoot N (mg/pot)
No amendment	0	4.00 c	0.54 c	1.50 cd	1.58 d	23.7 cd
0 N control	0	4.00 c	0.79 bc	1.74 bc	1.50 d	26.2 c
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	100	4.46 ab	1.92 a	2.32 a	3.25 c	75.3 a
	200	4.16 bc	0.83 bc	1.40 cd	4.14 b	58.2 b
Lignin	100	4.63 a	1.15 bc	1.94 ab	1.40 d	27.1 c
	200	4.67 a	1.20 b	1.94 ab	1.32 d	25.6 c
Pulp liquor (NSSC)+(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	200	3.00 d	0.0 d	0.22 e	5.20 a	11.7 d
Pulp Liquor (UP)+(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	200	3.91 c	1.25 b	1.33 d	4.16 b	55.2 b
L.S.D <sub>0.05</sub>		0.45	0.44	0.42	0.33	12.6

Means with the lowercase letter are significantly different (p<0.05).



The neutral sulfite semi-chemical pulp liquor (NSSC) in combination with 200 mg N kg<sup>-1</sup> (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> had the lowest leaves, tillers, and shoot dry matter, and the shoot dry weight accounted for 14.7% of that of control and 12.6% of that of 0.0 mg N/kg soil, respectively; emergence of wheat seedlings was inhibited in this treatment (Table 2). The combination of pulp liquor (UP) and (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> resulted in much smaller shoot biomass decreases, -11.3% and -23.6% compared to the no amendment and 0 N controls, but the negative effects were comparable to the shoot biomass decline for the high rate of (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>, so UP did not provide additional negative effects on wheat growth above and beyond that elicited by the (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>.



Although the rice straw lignin provided comparable amounts of total N to that supplied with the other treatments, the shoot N concentrations were not different from the 0 N control, suggesting the amount of plant available N may have been limiting for the rice straw-lignin treated plants. Previous incubation studies indicated that most of the N in this lignin is organically bound and exhibits slow N mineralization rates. The combination of NSSC pulp liquor and  $(\text{NH}_4)_2\text{SO}_4$  resulted in the highest shoot N concentration (Fig. 2) but lowest N content per plant, due to low biomass production.

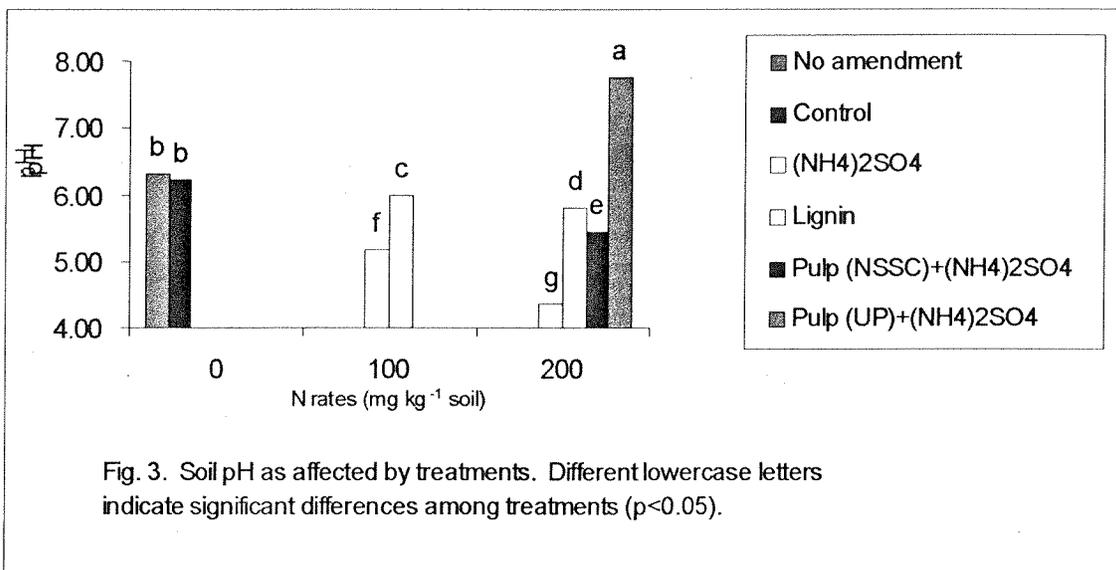
**Soil chemical properties.** The pulping byproducts differed in their effects on soil pH, EC,  $\text{NH}_4^+$  - N and  $\text{NO}_3^-$  - N (Table 3). Soil pH decreased from 6.22 to 4.37 by increasing N rate as  $(\text{NH}_4)_2\text{SO}_4$  from 0 to 200 mg N /kg soil had the lowest soil pH of 4.3, which may have been one contributing factor for the significant reduction of wheat shoot dry weight (Fig. 1).

Table 3. Soil properties as affected by different treatments \*

N source	N rate (mg/kg)	pH	EC (ds/m)	NH <sub>4</sub> <sup>+</sup> - N (ppm)	NO <sub>3</sub> <sup>-</sup> - N (ppm)
No amendment	0	6.31 b	0.33 e	2.40 c	0.70 e
Control	0	6.22 b	0.38 e	2.38 c	1.00 e
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	100	5.17 f	1.74 d	2.68 c	15.7 d
	200	4.37 g	2.69 c	15.0 b	78.6 b
Lignin	100	6.00 d	0.53 e	2.52 c	0.93 e
	200	5.80 d	0.56 e	2.05 c	0.87 e
Pulp liquor (NSSC)+(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	200	5.43 e	12.90 a	41.6 a	125.0 a
Pulp Liquor (UP)+(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	200	7.77 a	3.06 b	3.45 c	25.2 c
L.S.D <sub>0.05</sub>		0.15	0.33	6.14	5.84

Means with the lowercase letter are significantly different (p<0.05).

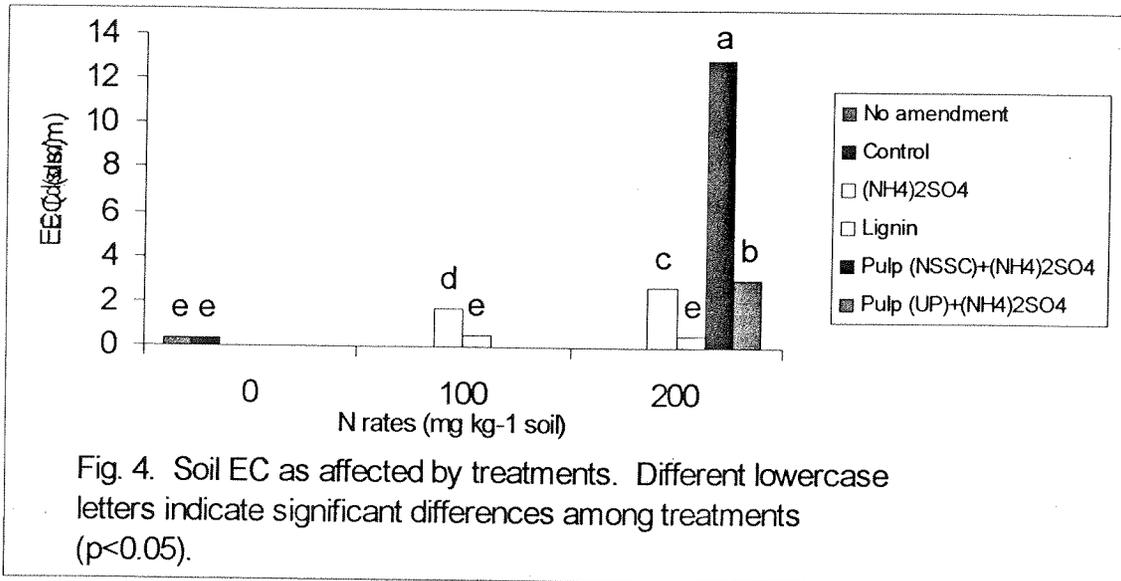
The research by Mahler and McDole (1987) indicated that wheat yield in N. Idaho decreased when soil pH was below 5.3. Soil acidification occurs as a result of the nitrification of ammonium fertilizer (Hetrick and Schwab, 1990; Rode and Runge, 1991; Darusman Stone et al., 1991). Rice-straw lignin significantly decreased soil pH in comparison with no amendment and control, but there was no significant differences in pH for two rates of lignin and the effects were not as severe as for the (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub>. In incubation experiment with the same rates of lignin application, pH significantly decreased with increasing lignin rate during the duration of incubation (Fig. 3) with the lowest pH of 5.47. Compared to the



same N rates of  $(\text{NH}_4)_2\text{SO}_4$  dosed at 100 and 200 mg N/kg soil, soil pH was higher for lignin treatments, indicating the nitrification of  $\text{NH}_4^+$  - N was lower for the addition of lignin than for the addition of  $(\text{NH}_4)_2\text{SO}_4$ , because main N forms of lignin are in organic N. This results can be explained by the soil  $\text{NO}_3^-$  - N and  $\text{NH}_4^+$  - N content for lignin and  $(\text{NH}_4)_2\text{SO}_4$  treatment (Table 3).

The UP and NSSC pulp liquors in combination with  $(\text{NH}_4)_2\text{SO}_4$  had significant effects on soil pH. The UP increased soil pH to 7.77 among treatments while the NSSC decreased soil pH to 5.43. The UP black liquor had an initial pH of 11.62, coupled with the presence of alum as a pulping catalyst, likely served as a pH buffering compound.

Soil EC significantly increased with increasing N rate for  $(\text{NH}_4)_2\text{SO}_4$  (Fig. 4). Compared to the no amendment and 0 N controls, lignin dosed at 100 and 200 mg N/kg soil (equivalent to 3.06 and 6.12 g lignin/kg soil) significantly increased soil EC, but there was no significant difference for EC between two rates of lignin application. Soil EC



was the highest among all treatments at  $12.90 \text{ dS m}^{-1}$  for NSSC in combination with  $(\text{NH}_4)_2\text{SO}_4$ , which may have been a reason why the growth of wheat was inhibited for this treatment, since high dissolved salt concentrations cause water to move from plant cell into the soil solution. The NSSC liquor contained the highest concentration of Na of the 3 pulping byproducts.

**Soil aggregate size distribution and aggregate stability.** There were significant differences in the aggregate size distributions among treatments (Table 4). Lignin addition of  $200 \text{ mg N/kg soil}$  (equivalent to  $6.12 \text{ g lignin kg}^{-1} \text{ soil}$ ) increased by 75.5% and 50% the weight of  $>2 \text{ mm}$  diameter aggregates above the 0 N and no amendment controls, respectively. Lignin applied at a rate of 100 and 200 mg N/kg soil also had more  $>2 \text{ mm}$  aggregates than  $(\text{NH}_4)_2\text{SO}_4$  at the same corresponding N rates, suggesting lignin specifically promoted soil aggregation. The  $(\text{NH}_4)_2\text{SO}_4$  dosed at 100 and 200 mg N/kg soil did not result in significant differences in  $>2 \text{ mm}$  aggregates when compared to 0 N and no amendment controls. The  $(\text{NH}_4)_2\text{SO}_4$  dosed at 200 mg N/kg soil had significantly

higher >2 mm aggregates than (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> dosed at 100 mg N/kg soil. Aggregates >2 mm in diameter from lignin were much greater at the end of the growth chamber experiment than for lignin-amended soil with no plants grown (data not shown), suggesting wheat root may have played a major role in the formation of aggregates (Roldan and Albaladejo, 1996).

Table 4. Soil aggregate size distribution (%) as affected by different treatments

N source	N rate (mg/kg)	> 2 mm	2-1 mm	1-0.5 mm	0.5-0.25 mm	0.25-0.15 mm	0.15- 0.053 mm	<0.053 mm
No amendment	0	26.8 c	5.1 ab	4.8 a	8.6 bc	19.9 abc	30.7 a	3.4 cd
Control	0	22.9 d	4.4 b	4.0 ab	8.0 cde	21.6 a	33.6 a	4.1 ab
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	100	23.3 d	4.9 ab	4.4 abc	8.5 bcd	21.2 ab	33.0 a	4.2 a
	200	27.5 c	4.7 b	3.9 cd	8.4 bcd	20.2 ab	31.3 a	3.8 abc
Lignin	100	34.6 b	5.1 ab	3.6 de	7.4 de	17.8 cd	27.3 b	3.4 bcd
	200	40.2 a	4.7 b	3.2 e	6.9 e	16.0 d	25.3 bc	3.0 de
Pulp liquor (NSSC)+(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	200	39.2 a	4.1 b	3.2 e	10.2 a	18.1 cd	22.4 c	2.1 f
Pulp Liquor (UP)+(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	200	32.6 b	5.8 a	4.2 bc	9.5 ab	19.2 bc	25.6 b	2.4 ef
L.S.D <sub>0.05</sub>		3.30	1.08	0.51	1.21	2.20	2.92	0.71

\* Means with the lowercase letter are significantly different (p<0.05).

Although NSSC pulp liquor in combination with (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> had the lowest wheat growth among treatment, it resulted in a percentage of >2 mm aggregates comparable to lignin dosed at the rate of 200 mg N kg<sup>-1</sup> soil. The combination of UP pulp liquor and (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> significantly increased > 2 mm aggregates compared to 0 N and no amendment controls, and also was greater than the (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> without pulp liquor. . The NSSC pulp liquor in combination with (NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> resulted in the highest aggregates 0.5 – 0.25 mm in diameter.

Macroaggregates >2 mm consist of 20 – 250 mm microaggregates held together mainly by transient binding agents only in soils which contain low organic C (<1%), and

the stability of macroaggregates >2 mm is related to the growth of roots and hyphae (Tisdall and Oades, 1982). Obviously, wheat root increased the formation of >2 mm aggregates, and the addition of lignin may have significantly increased the fungi hyphae, another contributing factor for higher >2 mm aggregate formation for lignin-amended treatments than for  $(\text{NH}_4)_2\text{SO}_4$ -amended treatments, no amendment or control.

Significant differences were seen for aggregates 2 - 1, 1 - 0.5, 0.5 - 0.25, 0.25 - 0.15, 0.15 - 0.053 and <0.053 mm in diameter among treatments. It is noted that the addition of lignin significantly increased >2 mm aggregates at the expense of smaller aggregates.

There were significant differences in wet macro- and micro-aggregate stability of aggregates of >2 mm, 1-2 mm, 1-0.5 mm and 0.5-0.25 mm in diameter among treatments (Table 5). Compared to no amendment, the application of lignin at both rates significantly increased the wet macro-aggregate stability of >2 mm, 2-1 mm and 1-0.5 mm aggregates, and significantly decreased wet micro-aggregate stability of those aggregates, but significantly decreased (or there were no significant differences) wet macro-aggregate stability of 0.5-0.25 mm aggregates; Compared to control, lignin dosed at both rates resulted in significantly higher wet macro-aggregate stability and significantly lower micro-aggregate stability of >2 mm aggregates. Compared to the corresponding N rate of  $(\text{NH}_4)_2\text{SO}_4$ , lignin significantly increased wet macro-aggregate stability and decreased wet micro-aggregate stability of > 2 mm aggregates, and significantly decreased wet macro-aggregate stability and increased wet micro-aggregate stability of 2-1 mm, 1-0.5 mm and 0.5-0.25 mm aggregates.

Table 5. Wet aggregate stability (%) as affected by different treatments

N source	N rate (mg/kg)	>2 mm		2-1 mm		1-0.5 mm		0.5-0.25 mm	
		macro	micro	macro	micro	macro	micro	macro	micro
No amendment	0	41.1 e	52.7 a	50.2 c	41.8 a	57.0 cd	33.6 ab	67.4 ab	24.6 bc
Control	0	42.8 de	50.7 ab	59.8 ab	30.6 bc	61.3 abc	31.2 bc	68.8 ab	23.2 bc
(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	100	50.3 bc	42.4 cd	59.4 ab	32.2 bc	61.2 abc	28.1 bc	66.5 ab	25.4 bc
	200	52.7 abc	42.0 cd	64.3 a	28.6 c	65.6 a	26.7 c	72.0 a	21.4 c
Lignin	100	54.9 ab	39.6 cd	60.7 ab	30.0 c	59.8 bcd	32.7 ab	64.9 b	27.5 b
	200	56.9 a	37.0 d	56.9 b	35.9 b	63.0 ab	30.0 bc	69.7 ab	24.4 bc
Pulp liquor (NSSC)+(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	200	41.1 e	53.0 a	49.4 c	41.9 a	55.3 d	37.2 a	58.4 c	34.9 a
Pulp Liquor (UP)+(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	200	48.4 cd	44.6 bc	56.4 b	35.8 b	59.3 bcd	33.7 ab	67.5 ab	26.4 bc
L.S.D <sub>0.05</sub>		6.20	6.76	5.52	5.65	5.55	5.88	6.41	5.79

\* Means with the lowercase letter are significantly different (p<0.05).

(NH<sub>4</sub>)<sub>2</sub>SO<sub>4</sub> at both rates also resulted in significant higher wet macro-aggregate stability of >2 mm aggregates at the expense of wet micro-aggregate stability, and significantly increased (or there were no significant differences) macro-aggregate stability and decreased micro-aggregate of 2-1 mm 1-0.5 mm and 0.5-0.25 mm aggregates when compared to no amendment or control.

The NSSC and UP pulp liquors exhibited similar >2 mm aggregate stability to the no amendment and 0 N controls.

## Conclusions

1. Rice straw lignin significantly decreased soil pH and increased EC, increased N availability, but slow N mineralization reduced N uptake by wheat compared to equivalent rates of  $(\text{NH}_4)_2\text{SO}_4$ .
2. Lignin significantly increased the formation of  $>2$  mm aggregates and macro-aggregate stability of  $> 2\text{mm}$  aggregates compared to no amendment and 0 N controls, or compared to the corresponding N rates of  $(\text{NH}_4)_2\text{SO}_4$ , indicating lignin in the presence of wheat roots can increase the formation of large aggregates, thus increasing soil resistance to wind and water erosion.
3. Pulp liquors (NSSC and UP) in combination with  $(\text{NH}_4)_2\text{SO}_4$  at a rate of  $200 \text{ mg N kg}^{-1}$  significantly increased the formation of 2 mm and 0.5-0.25 mm aggregates, and the combination of pulp liquor (UP) and  $(\text{NH}_4)_2\text{SO}_4$  significantly increased the formation of 2-1 mm aggregates when compared to no amendment or 0 N controls.
4. The NSSC pulp liquor in combination with  $(\text{NH}_4)_2\text{SO}_4$  at a rate of  $200 \text{ mg N kg}^{-1}$  soil wheat shoot weight to 14.7% and 12.6% of that of no amendment and 0 N controls, respectively; High soil EC may have been a contributing factor to the negative effect on wheat growth.
5. The UP pulp liquor (UP) in combination with  $(\text{NH}_4)_2\text{SO}_4$  at a rate of  $200 \text{ mg N kg}^{-1}$  soil resulted in comparable shoot growth, tillering and N uptake to the  $(\text{NH}_4)_2\text{SO}_4$  at a rate of  $200 \text{ mg N kg}^{-1}$  treatment alone. This amendment increased soil pH while other amendments reduced soil pH. Long term effects of adding alum additions to soil from UP black liquor need to be investigated.

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