Office of Dr. Travis Whitney

AgriLIFE RESEARCH
Texas A&M System

8-28-2015

This packet contains information related to the TX A&M AgriLife Research Wood to Feed Program. Information has been included to reveal that feeding ground woody plants to livestock is not a novel idea. Ground wood has successfully been used as a roughage source for at least 100 years.

Due to the positive results of the research that we have completed in the past 7 years, along with the long history of safely using ground woody products in feed, I submitted a proposal to the Association of American Feed Control Officials (AAFCO) to get ground juniper (redberry and blueberry) approved as a commercial feed ingredient. It is still under review by FDA for U.S. approval; however, I anticipate that it will be approved for use within Texas by the end of this year (2015). An additional AAFCO proposal is planned, in which I will request that other *Juniperus* spp. and various mesquite spp. be commercially approved. After juniper is approved, I will substantially increase efforts to bring together the right people to develop a Wood to Feed Industry so that ground juniper can be purchased like any other roughage ingredient (e.g., hay or cottonseed hulls).

Those involved in the Wood to Feed program are compassionate about synergistically helping ranchers reduce feed costs, helping landowners reduce brush infestation and enhance forage production, and helping communities (especially rural) remain economically viable. Thus, we are working diligently for the great state of Texas to make a Wood to Feed Program a reality, through research trials, field days, and various types of publications.

Please visit the Wood to Feed Website http://sanangelo.tamu.edu/people/faculty-2/dr-travis-r-whitney-associate-professor-livestock-nutrition for more information.

Sincerely,

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Progress Report 1972 *Cattle Series 141*

TEXAS AGRICULTURAL EXPERIMENT STATION

R. D. LEWIS, DIRECTOR, COLLEGE STATION, TEXAS, JUNE 28, 1957

Ground Mesquite Wood

As a Roughage in Rations for Yearling Steers

P. T. Marion, C. E. Fisher and E. D. Robison*

THE TEXAS AGRICULTURAL Experiment Station has conducted experiments at the Spur station and on cooperating ranches since 1938 in an effort to develop effective and economical methods of controlling mesquite, which infests about 70 million acres of grassland in the United States.

Exploratory feeding trials conducted at Spur during the past 3 years in an effort to find a new use for this pest have shown that ground mesquite wood (mesquite meal) is a possible source of bulk in rations for cattle when other roughages are scarce and relatively high in price.

A wood chipper was loaned to the Spur station in 1954 to prepare mesquite wood chips for use as a mulch in comparisons with cotton gin trash, manure and old silage in water conservation studies. Some of the chips were ground into a meal with a hammer mill to determine whether it could be used as part of the ration for wintering calves. A chemical analysis showed that the mesquite meal had a higher protein, fiber and calcium content than cottonseed hulls, and a slightly lower fat and carbohydrate content (Table 1). Carotene (vitamin A) also was found in the mesquite meal. This essential nutrient is not present or is very low in quantity in many dry roughages.

*Respectively, superintendent, formerly superintendent and assistant agronomist, Substation No. 7, Spur, Texas.

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SUMMARY

Yearling steers fed a ration containing 7.2 pounds of ground mesquite wood gained 2.20 pounds per head daily in a 140-day feeding trial in 1955-56 at the Spur station. Similar steers fed cottonseed hulls instead of mesquite meal gained 2.29 pounds per head daily. The steers fed the mesquite meal made a higher net return on the basis of $10 per ton for ground wood and $18 per ton for cottonseed hulls than those fed the cottonseed hull ration.

Yearling steers fed a ration containing 12.23 pounds of ground mesquite wood per head daily in a 112-day trial in 1956-57 made an average daily gain of 2.54 pounds, compared with 2.71 pounds for steers fed a silage ration. Both groups were fed a concentrate mixture with stilbestrol and aureomycin.

No ill effects resulted from feeding the ground wood. After 70 days of the 112-day trial, the steers weighed 1,050 pounds and consumed 16 pounds of mesquite meal per head daily in addition to 16 pounds of concentrate feed.

* * * * * * * * * *

A preliminary trial of 86 days was conducted during the winter of 1954-55 with two 450-pound calves fed a ration of 2 pounds each of cottonseed meal, grain, molasses and cottonseed hulls mixed with 6 pounds of mesquite meal. Two other calves were fed the same ration with cottonseed hulls substituted for the mesquite meal. The calves fed the mesquite meal ration gained an average of 1.35 pounds daily, while those fed the hull ration gained 1.54 pounds. Nightblindness, the first symptom of vitamin A deficiency, was observed in the calves fed the cottonseed hull ration, but those on the mesquite meal ration had normal night vision at the end of the trial.

Meanwhile, it was learned that C. E. Doolin had been feeding a ration containing mesquite

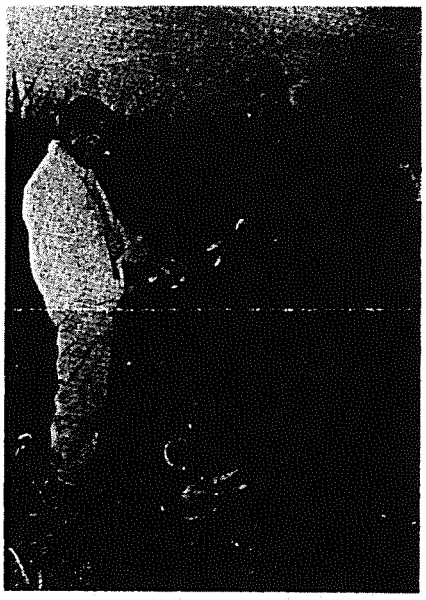

Figure 1. Green, second growth mesquite stems and branches 1 to 3 inches in diameter with slick bark are more desirable for the preparation of mesquite meal than larger, rough bark stems. These smaller branches have a higher percentage of sapwood than heartwood, and probably have a higher nutritive value than the larger stems.

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TABLE 1. CHEMICAL COMPOSITION OF GROUND MESQUITE WOOD, COTTONSEED HULLS, SUMAC FODDER AND SILAGE

Feed	Average composition, percent								
	Protein	Fat	N-free extract	Fiber	Water	Ash	Lime	Phosphorus	Carotene, ppm.
Mesquite meal	5.94	.78	35.39	48.66	5.60	3.63	1.32	.06	24.6
Cottonseed hulls	4.10	.90	35.30	47.60	9.40	2.70	.21	.03	None
Sumac fodder	4.80	2.00	43.70	19.10	24.50	5.90	.49	.14	None
Sumac silage	3.79	.76	12.72	6.03	74.46	2.24	.07	.04	60.0

meal to cattle on his Rio Vista ranch in Dimmit county. He fed a mixture of 1,000 pounds of mesquite meal, 500 pounds of molasses, 200 pounds of grain and 200 pounds of cottonseed meal as a maintenance ration for his cow herd. He also finished steers for the market on a ration consisting of 1,000 pounds of mesquite meal, 1,200 pounds of grain, 700 pounds of molasses and 200 pounds of cottonseed meal.

In the exploratory trials reported here, a ration with mesquite meal was compared with a cottonseed hull ration in a 140-day trial in 1955-56, and with a silage ration containing small amounts of cottonseed hulls and sorghum bundles in a 112-day trial in 1956-57.

PREPARATION OF MESQUITE MEAL

Chopping

The first step in preparing the wood was to cut green mesquite stems and branches 1 to 3 inches in diameter. Second growth stems from stumps killed above ground by frost, fire or other means made the best feed. These branches usually have slick bark and a higher percentage of sapwood than heartwood (Figure 1). The water content in mature, rough-bark branches is lower, and such compounds as oils, resins, gums and tannins accumulate in the heartwood. These substances and lignocellulose in the wood are thought to be largely indigestible.

After the wood was chopped, it was allowed to cure for 5 to 7 days. Freshly cut wood was high in moisture and molded when stored after chipping. The cured wood had a moisture content of about 28 percent and did not become moldy. It also was easier to grind.

The wood apparently may be harvested at any time of the year, but it usually has the highest nutritive value in the spring before leaf development begins.

The yield of stems and branches of second growth mesquite in a fairly dense thicket of brush was approximately 9 tons of oven-dry wood per acre. The area had been cutover in 1939 and had an average stand of 1,060 trees per acre. The moisture of the green wood cut during November was 44.3 percent.

Chipping

After the wood had cured, the limbs were fed into the mechanical chipper, as shown in Figure 2. The wood chipper used in these tests can chip 2 to 3 tons of mesquite per hour. The chips are shown on the left in Figure 3.

Grinding

A heavy-duty hammer mill with a 3/16-inch screen was used to grind the chips into a fine meal that was similar to sawdust. Freshly-ground wood is more palatable than dry wood, and a fresh supply was prepared each week. The wood shown in the center of Figure 3 was mixed with the concentrate feeds.

Mixing Rations

It is important to get a uniform mixture of the mesquite wood with the concentrates used

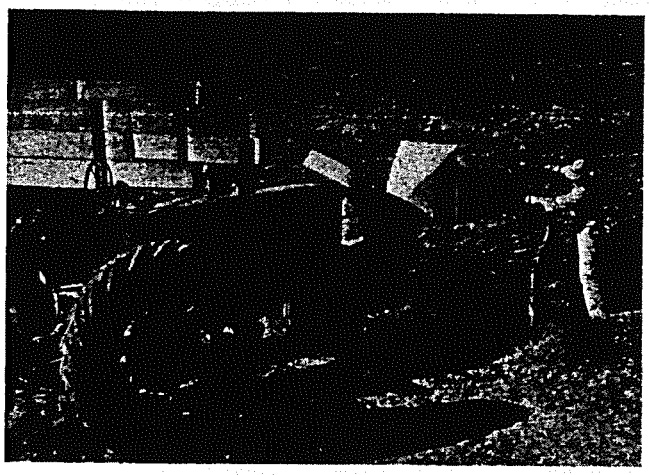


Figure 2. Left—After the wood was cured 5 to 7 days, the stems and branches were fed into a mechanical wood chipper. This machine can chip 2 to 3 tons of mesquite wood per hour.

Figure 3. Right—The chipped wood on the left is ground into a meal, shown in the center, by a hammer mill with a 3/16-inch screen. A mixture of ground mesquite wood and the concentrate feeds is shown on the right with a 2-day supply of stilbestrol plus aureomycin for 8 steers in the foreground.

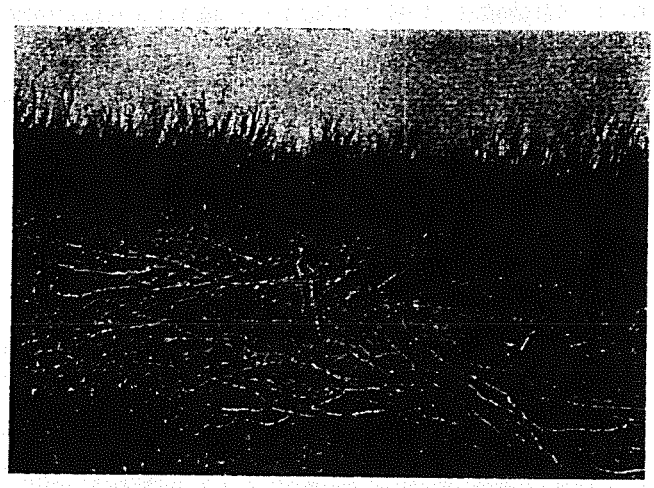


Figure 4. Left—Steers fed an average ration of 12.23 pounds of ground mesquite wood, 3.54 pounds of cottonseed hulls and 15.36 pounds of concentrates made an average daily gain of 2.54 pounds in a 112-day feeding period.

Figure 5. Right—This fairly dense thicket of second growth mesquite produced 8 to 10 tons of oven-dry wood per acre from an average stand of 1,060 trees per acre. Most of the stems were slick barked of 1 to 3 inches in diameter.

in the ration. The palatability of the ration was increased by blending the proper amount of molasses in the mixture. In addition to sweetening and giving the feed a more desirable odor, the molasses moistened and prevented the wood particles from becoming dry and hard.

The steers consumed a maximum of 10 pounds of mesquite meal per head daily without the addition of molasses in the 1955-56 trial. With molasses blended properly into the ration in the 1956-57 trial, the steers consumed up to 16 pounds of mesquite meal per head daily. The addition of stilbestrol and an antibiotic (aureomycin, terramycin or ilotycin) also improved the animals' appetites and increased the efficiency of feed utilization.

1955-56 TRIAL

Procedure

The 8 yearling steers used in this 140-day trial averaged 645 pounds. After a preliminary feeding period of 2 weeks, they were divided into two lots of 4 head each. An average daily ration of 2 pounds of cottonseed meal, 8.1 pounds of sorghum grain and 2 pounds of alfalfa hay was fed to both groups of steers. Those in the control group also consumed 13.15 pounds of cottonseed hulls per head daily, while those in the test lot also were fed 7.2 pounds of mesquite meal and 1.89 pounds of hulls. Stilbestrol was fed at a level of 10 milligrams per head daily to both groups (Table 3).

Alfalfa hay was included in the ration of the control group to prevent vitamin A deficiency. The mesquite meal contained enough carotene to supply an adequate amount of the vitamin to the test group.

After 56 days on feed, the mesquite meal for the test group was increased to 10 pounds per head daily and replaced all of the hulls. All of the wood used in the trial was chipped at one time and it became less palatable as the chips dried. During the last 28-day period, the steers would eat only 8 pounds of the wood meal per head daily. The palatability of this ration could have been improved by chipping and grinding a fresh supply of mesquite wood each week and blending it with molasses.

Table 2 shows the prices paid for the feeds. The cost of preparing the mesquite meal included labor, machinery and grinding and mixing charges.

Results and Discussion

The 4 steers fed the mesquite meal made an average daily gain of 2.20 pounds, compared with 2.29 pounds for those on the cottonseed hull ration (Table 3). Shrink enroute to market was

TABLE 2. AVERAGE DAILY RATION AND FEED COST USED IN THE 140 AND THE 112-DAY TRIALS

Feed	140-day trial			112-day trial		
	Mesquite	Control	Price per ton	Mesquite	Control	Price per ton
Cottonseed meal	2.00	2.00	$63.00	2.00	2.00	$56.50
Sorghum grain	8.10	8.10	33.00	9.34	8.99	41.80
Molasses				4.02		40.00
Alfalfa hay	2.00	2.00	34.00			
Mesquite meal[1]	7.20		10.00	12.23		10.00
Cottonseed hulls	1.89	13.15	18.00	3.54	4.17	25.00
Sorghum bundles or silage (dry basis)					10.37	30.00
Cost per day, cents	26.7	34.9		43.5	45.1	

[1]Cost of preparing mesquite wood meal included labor at $1.00 per hour, normal machinery operation and depreciation charges and $4.00 per ton charged by a local feed store for grinding the chips in a hammer mill. With cheaper labor and a larger operation, C. E. Doolin reports a cost of $5.00 per ton for preparing mesquite meal.

TABLE 3. FEEDLOT, MARKETING AND SLAUGHTER DATA ON STEERS FED MESQUITE MEAL FOR 140 AND 112 DAYS

Ration	Mesquite meal	Cottonseed hulls	Mesquite meal	Silage, hulls, bundles
Additives[1]	DES	DES	DES-AU	DES-AU
	140 days		112 days	
No. of steers	4	4	8	9
Av. initial weight	645	644	873	660
Av. final weight	953	964	1157	964
Av. daily gain, feedlot	2.20	2.29	2.54	2.71
Market weight	901	905	1105	917
Shrink enroute to mkt. %	5.5	6.1	4.5	4.9
Carcass weight, warm	547	560	652	557
Dressing percent	60.7	61.9	59.0	60.7
Carcass grade	8.2	8.0	8.0	7.3
Total cost, feed, mkt., etc.	$160.72	$169.76	$213.95	$184.07
Selling price	165.87	166.61	204.43	174.23
Net return or loss	5.15	-3.15	-9.52	-9.84

[1]DES: 10 mg. diethylstilbestrol per head daily; AU: 75 mg. aureomycin per head daily.

slightly lower for the mesquite-fed steers, and their dressing percentage was lower than for those fed cottonseed hulls. Carcass grades for the two groups were equal, and they sold for the same price.

With the feed prices shown in Table 2, the greatest difference between the two groups of steers was in the cost of the ration, 26.7 cents per head daily for the steers fed the mesquite meal and 39.9 cents for those fed cottonseed hulls. This difference gave an advantage in net return of $8.30 per head for the mesquite-fed steers.

1956-57 TRIAL

Procedure

After a preliminary feeding period of 1 week, 8 yearling steers averaging 873 pounds were started on a mesquite meal ration. These steers were compared with another group of 9 steers weighing 660 pounds which were fed a ration with a mixed roughage of cottonseed hulls, silage and sorghum bundles. Both groups were fed a level of 10 milligrams of stilbestrol and 70 milligrams of aureomycin. The average daily ration for the 112-day feeding period is shown in Table 2.

Several improvements over previous tests were made to increase the palatability of the mesquite meal ration used in this trial. Molasses was blended in the ration at the rate of 4 pounds per head daily. A fresh supply of green wood was chipped each week. A mechanical mixer was used to make a more uniform mixture of the feeds.

The difference in initial weights of the two groups of steers was greater than normally is desirable, but it is believed this factor did not seriously influence the data.

Results and Discussion

The starting ration for the mesquite-fed steers contained 8 pounds of ground wood per head daily. This amount was increased each week, and the amounts of hulls and bundles were decreased until the entire roughage consisted of mesquite meal. At the end of 70 days, the steers were eating 16 pounds of mesquite meal per head with 16 pounds of concentrates. Their average daily gain for the 112-day period was 2.54 pounds, compared with 2.71 pounds for the silage-fed steers.

There was very little difference in the slaughter and carcass data for the two groups of steers, as shown in Table 3. Both lots showed a net loss, but the mesquite-fed steers had an advantage of 32 cents per head over those fed silage.

Mesquite meal is a possible source of bulk in rations for cattle when other roughages are scarce and relatively high in price. The wood chipping machine, which costs $1,200 delivered in Texas, a heavy-duty hammer mill and a molasses mixer are needed to prepare and mix a mesquite meal ration properly. When other feeds are cheap and plentiful, there likely would be little or no demand for this type of roughage. However, mesquite may prove to be a dependable source of rough feed during a drouth.

ACKNOWLDEGMENTS

The Fitchburg Engineering Company of Fitchburg, Massachusetts, provided the wood chipping machine which made these studies possible, and the Dodge Jones Foundation, Abilene, Texas, provided funds to support certain phases of this work.

The assistance of Earl Burnett and Cecil H. Meadors, Jr. in the preparation of the mesquite meal is gratefully acknowledged.

Figure 1 was borrowed from the Lubbock Avalanche-Journal, Figure 2 from the Farm Journal and Figure 3 from Farm and Ranch.

Farmers Look

It ain't hay, but aspen holds promise as a new feed for livestock

Back in the drought-stricken, depression-ridden 1930s, some Minnesota farmers fed their cattle aspen bark and leaves. In those lean years, it was all they had.

Today, another drought has brought aspen bark—"popple"—into the limelight as a cattle feed, an economical supplement to scarce, high-priced hay. Some Minnesota farmers have already turned from the fields to the forests to help feed their herds.

Fine-ground aspen is like cash in hand, especially when drought conditions result in a scarcity of hay.

To The Forest

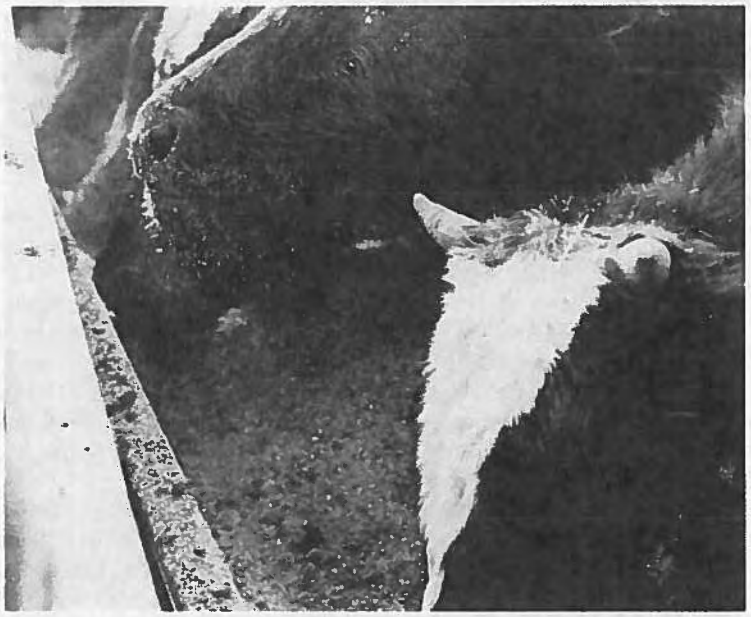
HARRY DAVEY

For years, Department of Natural Resources personnel and University of Minnesota researchers have studied bark as a suitable food for cattle. The results of their studies are now being marketed, pushed by the present hay shortage. Today's feed formulas are far more complicated than the crude, crash diets that farmers used in desperation many years ago.

Two pioneers in the development of aspen bark for cattle feed are William Dumke and Dr. Richard Goodrich. Dumke is a DNR forest products marketing specialist stationed in Brainerd, and Dr. Goodrich is a professor of ruminant nutrition in the UM animal science department.

Dumke estimates that three million tons of surplus aspen bark and wood exist in northern Minnesota. This potential cattle feed could probably be purchased and delivered up to 150 miles for as little as $20 per ton.

Minnesota's paper-making and sawmill industry would welcome this use



Cattle on the Jerome Krueger farm relish aspen feed. Krueger reaps $40 to $50 savings per ton of feed by using aspen rather than hay.

of what is otherwise a waste product. Why? Aspen bark is costly to get rid of. It must either be burned or buried. To reduce this expense, one Minnesota paper mill, Hennepin Paper Company in Little Falls, began furnishing central Minnesota farmers with aspen bark ground to feed size. Today, HPC prices its bark at about $6 per ton—which does not include hauling or fine-grinding.

Soon Aspen Fiber Corporation of Marcell, Minn., will break ground for a plant to produce dehydrated aspen pellets. Their product label has been approved by the Minnesota Department of Agriculture. The company hopes to begin production in late summer.

"Because of the burning ban last year, much of the bark produced in Minnesota was buried," Dumke said, "an expensive disposal problem. One part of Minnesota is throwing away something that could be very useful in another part of the state." The only exception to this waste, he added, is the small amount of bark that is processed for use in controlling weeds and to retain moisture around trees and bushes and as a fuel in some mills and pulp plants.

Old/New Idea. The idea of feeding bark to cattle is not new. Researchers at UM and at universities in South Dakota, Colorado, Chicago, Wisconsin, and in Canada have studied bark feed for many years.

Dr. Goodrich explains that aspen bark is low in protein and energy. For cattle feed, it must be ground fine and then mixed with protein and grain, such as oats, corn, or barley. The mixture could be 60 to 70 percent bark and 30 to 40 percent grain.

"Bark doesn't compare to normal rations, but if drought and hay shortage continue, we should at least look at it as a feed possibility," he said.

Since last year's drought, the Minnesota Extension Service has pushed its own research into high gear. Recently, MES reported on a bark feeding experiment on the Jerome Krueger farm seven miles east of Rice, Minnesota.

Krueger raises dairy cattle. Since October 1976, he has bought bark shavings for $5 per ton. He picks up the shavings from the Hennepin Paper Company in Little Falls, the same place where experimental stations and other farmers have been getting their supplies of bark.

Krueger re-grinds the bark on his farm and then feeds it to 20 head of young stock. At first, the animals hesitated. Even with nutrients added, it still looked and smelled like sawdust. And it was dry. "Eating it must be like eating flour," Krueger said.

But in time the cows got used to it and now gobble the stuff down. With soybean meal, molasses, salt, vitamins, and minerals added, the cost runs to $60 a ton, Krueger reported, still cheaper than $100 to $110 for a ton of hay.

An added benefit, Krueger said, is that "leftovers have a forest smell."

Commercial Possibilities. Extension service specialists say that the bark program is a short-term project that will end when hay supplies return to normal. They admit, however, that the feed has definite possibilities for future use.

"I think we're on the threshold of something pretty substantial here," said UM's Dr. Lewis Hendricks. Private companies are "waiting in the wings," marketing plans in hand.

Farmers who start now, he added, may be that much farther ahead financially if and when other farmers decide that the program has merit.

If the aspen feed program does prove successful, Bill Dumke surmises, it will make two important segments of our state economy happy. "The paper mill and sawmill operators will be happy to get rid of the bark and farmers will be happy to have an alternative to expensive hay." □

Harry Davey *and wife, Bern, live in Brainerd, Minn. He retired two years ago after publishing the* **International Falls Daily Journal** *for nearly two decades.*

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Scientists at Texas Tech University have developed a

Cattle Feed from Mesquite Wood

By Bob Bracher

A HIGH PROTEIN, inexpensive cattle feed from mesquite brush? It sounds impossible—but scientists at Texas Tech University have developed such a feed, and may be on the way to conquering one of the Texas livestock industry's largest problems, the infestation of mesquite brush.

Statistics have shown that 82 per cent of the Texas range lands are infested with some type of water-wasting brush. This constitutes some 88 million acres in the Lone Star State. Brush control methods of all magnitudes have been and are presently being researched in conquering this costly problem.

Dr. Joseph L. Schuster, chairman of the department of range and wildlife management at Texas Tech University at Lubbock, has noted that "water wasting plants invading the range lands of Texas each year consume more water than all towns, farms, industries and people in the state." Mesquite brush is the main invader in this part of the country, and no practical uses had been found for the plant until this new process of developing a single-cell protein feed was discovered.

The feed is estimated to cost only $27-$35 per ton which is much less than the current price of a milo and cottonseed meal ration of about $55 per ton. The converted feed will be a complete ration, not just a protein supplement, which will supply a high quality protein source and easy digestibility traits.

The conversion study for mesquite was initiated in June, 1970 in Lubbock, when Dr. Donald Thayer, assistant professor of biology at Texas Tech; Dr. S. P. Yang, professor and department chairman of food and nutrition at Texas Tech; and Dr. Schuster began researching the feed conversion from all segments of the problem.

The initial grants of money for research came from the Texas Brush Control and Range Improvement Association and the Dodge Jones Foundation in Abilene. Additional grants of money for brush control research from the state and the brush control association have carried the studies through to the current level.

Dr. Thayer has been working on the feed processing in his biology laboratories, while Dr. Schuster has approached the mesquite harvesting angle of the problem and Dr. Yang has researched the nutritional values of the feed for livestock.

The study has progressed in a mere

The mesquite wood held by Texas Tech University student William Chang, left, contains cellulose which can be converted into a high protein livestock feed by methods developed by Dr. Thayer and his associates.

"We have isolated 160 organisms which are capable of utilizing mesquite as a sole carbon source."

1½ years to the level that the scientists have produced a high quality feed that is rich in protein and carbohydrates. The new feed, converted solely from mesquite, consists of about 8 per cent protein, 59 per cent carbohydrates and 1 to 6 per cent fats. The process for converting a mesquite-wood base into single-cell protein feed is very similar to the way a rumen in a cow converts feed into digestible matter.

The conversion process begins when the pulverized or ground mesquite is put into a mineral salts solution with a nitrogen source. The solution is innoculated with microorganisms, which have been selected for their ability to convert the mesquite into a protein substance.

"Our aim is to produce a high quality feed that is rich in protein and is easily converted into energy by livestock," said Dr. Thayer. "To do this requires an aerobic organism which can convert cellulose into protein."

The organisms which are used in the conversion program are screened through enrichment cultures in which only those organisms capable of converting mesquite brush are chosen. The screening process begins when a handful of dirt is taken from a decaying mesquite tree and put into a mineral salts solution containing mesquite.

The organisms are allowed to grow and then one-tenth of the living bacteria is introduced into a similar solution and allowed to grow out. After the process is transferred about 10 times, there are only those organisms which can grow and live on mesquite brush left. It is these special organisms which are used in the feed conversion program.

"We have isolated 160 organisms this far which are capable of utilizing mesquite as a sole carbon source," Dr. Thayer said. "These organisms are selected on the basis of their ability to utilize mesquite which is based on the rate of hydrolysis, rate of growth of the organisms and the rate of protein growth."

The feed, in a purified form known as "98 A," has been tested on rats in the laboratory, with some very encouraging results when compared to soybean meal, casein and all the other standard protein supplements.

Tests show that the mesquite feed is equal in value to these other feeds with high protein and high digestibility rates.

Dr. Yang compared the amino acid composition of 98A protein to that of soybeans and the pattern established by the Food and Agriculture Organization (FAO) of the United Nations. Compared to the FAO pattern, 98A is superior in seven essential amino acids and has twice the quantity of methionine and more than double the amount of threonine.

A sufficient quantity of 98A has been produced to begin a cattle feeding study. Scientists in the department of animal

"We have estimated that we may be able to offer a rancher $1 per ton for his mesquite brush."

Once the microorganisms come in contact with the mesquite in the mineral salts solution, they attack the cellulose in the mesquite and attack some of the presugars and lignin. This breakdown of the cellulose and lignin results in various components such as the carbohydrates for the growth of single cell bacteria which are high in protein.

"With a 50 per cent hydrolysis of the mesquite, we end up with about a 20 per cent protein substance and when added to the residue, which is unused plant material, the total feed ration is complete," Dr. Thayer commented.

science have fistulated the rumen of a steer and inserted a plastic cannula. Using this technique, nylon bags will be filled with the microbial protein and inserted into the rumen for differing periods of time. When the nylon bags are removed, weight loss of the dry matter will indicate the digestibility of the material.

Dr. Robert Albin of the animal science department, who is associated with Dr. Yang in the experiment, explained that the use of a rumen fistula in an animal makes it possible to perform extensive testing with very little diet material.

Dr. Thayer, left, and Dr. Schuster test the high-protein single-cell feed in one of the pieces of some $160,000 worth of equipment that is being used in the feed production research.

Dr. Schuster is conducting studies on the most practical way to harvest mesquite, like this mechanical harvester that shreds the brush and leaves the mesquite wood in wind rows.

"The problem in a cow converting from one material to another, is caused by the rumen which has a symbiotic system with the bacteria digesting cellulose which the animal in turn uses," Dr. Thayer said. "Cattle are not very efficient converters of cellulose, with only about an average of 15 per cent digestibility rates for digesting cellulose."

The feed processing study is now at the point of requiring more funds to increase the size of animals that are being tested on feed. The scientists are interested in acquiring funds to construct a research pilot plant, which would allow them to control all factors necessary to evaluate different types of processing. From that research plant, a larger commercial plant could be designed to handle a number of cattle and feed them this single-cell protein substance that comes from mesquite.

Another interesting aspect of the study is in the use of manure for a nitrogen source in growing the bacteria. Thayer said that a number of problems must be overcome before this could be effectively included in the feed processing procedure including the isolation of pathogens, the accumulation of antibiotics and the carry-over of diethylstilbestrol.

The researchers have found that an initial sample of 1,000 pounds of mesquite will yield 700 pounds of feed with 8.2 per cent crude protein, 59 per cent carbohydrates and 1 to 6 per cent fats.

Dr. Schuster is conducting a study to develop a process of harvesting the mesquite with a mechanical harvester. He is also working with scientists to use stacked brush that has been cleared, where they could grind it in the field and transport the pulverized mesquite to the laboratory.

The size of the mesquite that is used for feed varies from a powder to three-inch sticks.

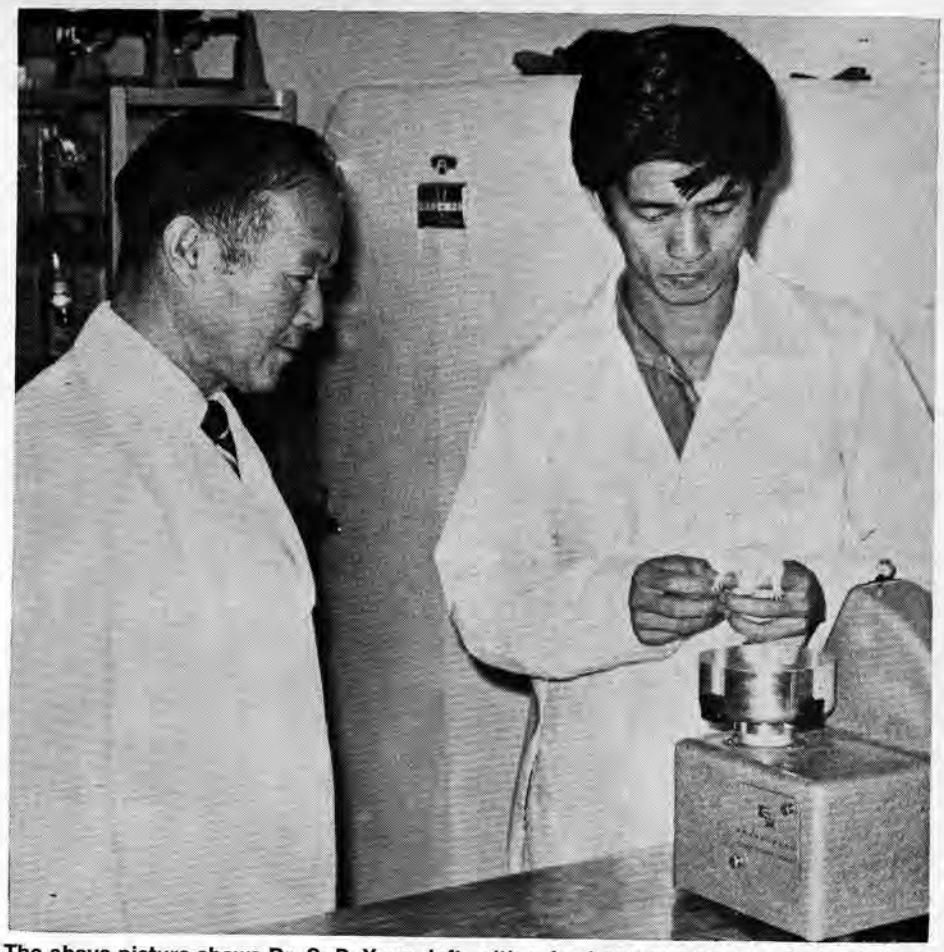
"We have estimated that if the process of converting brush into feed continues to progress as it has, we may be able to offer a rancher $1 per ton for his mesquite brush," Dr. Schuster said. "This would more than pay for clearing of land in most areas of the state, with as much as 30 tons per acre on some range lands."

The development of this process into a full-scale commercial operation that would be capable of feeding 50,000 head of cattle each day may be just around the corner, as soon as adequate funds are available to continue research.

Dr. Thayer commented that the important phase of this study is in "converting what is now an ecological problem into an asset and doing it at no cost to the environment."

"It is not going to stop with mesquite and it is going to lead to the elimination of a lot of solid waste pollution from our environment in the near future," said Dr. Schuster.

The new feed is not an impossible dream, but a feasible answer to one of Texas' most pressing and dangerous problems, the water-wasting and grass-killing infestations of mesquite brush. ■



The above picture shows Dr. S. P. Yang, left, with a food and nutrition graduate student, Huei-Hsiung Yang, measuring the growth of young rats on the microbial protein, "98A." After testing the rats and receiving favorable results, the Tech scientists began testing the high-protein feed on a fistulated steer. The researchers, below, are using a rumen cannula inserted surgically in this steer. Left to right are animal science professor Dr. Robert C. Albin, Dr. Yang, and Huei-Hsiung Yang.

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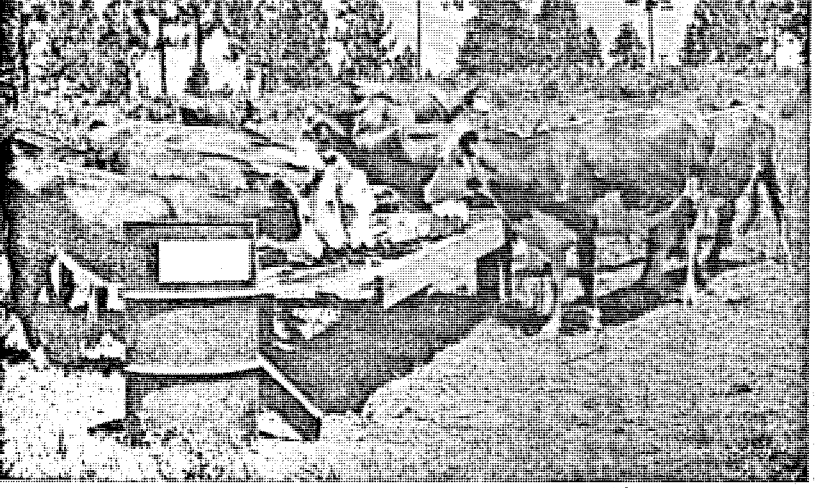

WOOD RESIDUE MATERIALS offer potential as roughage for cattle. Such roughage is essential to normal digestion. Someday soon perhaps a scene such as this will be common on farms near sources of sawdust or wood residues.

The trend toward feeding beef and dairy cattle in large, centralized operations has raised the possibility that wood residues may find an outlet as the roughage component of prepared feeds. Feeding trials on this aspect of wood-waste utilization are underway at several locations. If successful, a sizable tonnage of our unused residues will find a market.

Wood could be more than a roughage material to the ruminant. Containing some 70 to 75 percent carbohydrate constituents, it could well be a source of energy to the animal, provided of course, that these carbohydrates could be made available for digestion. Complete delignification is effective, but too costly. The search for equally effective but less expensive pretreatments is underway at a number of laboratories. Success in this search could be most important to nutritional demands of a hungry world.

Wood Wastes For Animal Feeding

R. W. Scott, M. A. Millett, and G. J. Hajny

FROM A TOTAL TIMBER CUT in the United States of more than 150 million tons in 1962, about 38 million tons of unused wood residues were generated (6). Bark residues added another 20 million tons. In addition, millions of undesirable trees in our forests and large amounts of other residues such as bagasse and seed hulls constitute an enormous waste of unused cellulose. The disposition of much of this is of increasing concern.

In seeking likely solutions, a number of applications have been examined that show promise for using residue materials rather than disposing of them. Agricultural outlets are especially intriguing because of their potential for large-scale consumption. The concept of utilizing woody materials as a feedstuff for domestic animals is very old, but the practice has been resorted to only in times of great need. Because of ominous forecasts of increasing food shortages in some parts of the world, it would seem highly appropriate to re-examine the use of wood materials as a feedstuff.

Woody materials might serve two distinct functions in animal feeding: (1) As roughage with little or no nutritive value and (2) as energy feed. The first function is the simpler and more likely to find application in the near future. Attaining the second will be much more difficult, but it has greater potential to contribute significantly to man's food supply.

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The authors are Chemists, Forest Products Laboratory, U.S. Forest Service, USDA, Madison, Wisconsin. Acknowledgment is made to the Tennessee Valley Authority, Division of Forestry Development, Norris, Tenn., for cooperation and support in this work.

Wood as Roughage

Through the years wood has evoked little interest as roughage in the diet of ruminants. Most beef and dairy cattle as well as sheep are maintained on pasture or range land or are fed harvested roughage. However, the rapidly developing trend in this country toward large, centralized feeding operations may soon change this practice. Feedlot animals are fed high-energy grain rations that are increasingly being supplied by manufacturers of complete, mixed feeds. This requires manufacturers to search for roughage substitutes that have physical properties compatible with auto-

mated mixing and feeding equipment. Corn cobs, cottonseed hulls, sand, oyster shells, rice hulls, and flax chives have been used for this purpose. Success with these substitutes, however, is limited because of one or more objectionable features: High cost, seasonal unavailability, mechanical properties causing difficult mixing in feeds, or incompatibility with digestive systems of the animals. Because of these features, animal-feeding trials have been initiated at a number of universities in the United States and Canada to determine the acceptability of wood wastes as feed roughage. Preliminary results have been favorable (1, 3, 4, 5).

If trials conclusively demonstrate that wood or bark waste can be used for animal feeding or cheaply converted to a form acceptable for consumption, questions of availability, location, and price will be important. Of the large amounts of wood residues, those most available come from residues of processing plants. In 1962 it was estimated (6, Table 45) that there were 4.9 million tons of hardwood and 14.2 million tons of softwood residues from these sources. It is interesting that if these residues were used at a level of 10 percent in feeds, the 19.1 million tons of wood residues would supply more than enough roughage for all concentrates fed to all livestock in the United States (2, Tables 1 and 2, p. 3).

According to a recent estimate (16), 2,008 feedlots in 32 states in 1967 each had capacities for more than 1,000 head of cattle and from them about 9.8 million head were marketed. This was 46 percent of the total marketings of cattle in these states. Although these feedlots are scattered across the United States, a few states account for a large percentage of the total cattle in feedlots. In 1967, about 45 percent of the total cattle in feedlots were marketed from Nebraska, Iowa, Kansas, and Illinois, which with other Central States included 62 percent of the total marketed. Further large percentages of feedlot cattle were marketed in California (9.4 percent), Texas (7.6 percent), and Colorado (6.1 percent).

The area where feedlots and large amounts of wood processing plant residues are nearest each other occurs in the western mountain states where there are large quantities of softwood residues. The South Atlantic States, where there are both softwood and hardwood plant residues, have small numbers of feedlots for beef cattle.

Increasing numbers of dairy cattle, however, are being fed concentrates. In New York and Pennsylvania about 3.7 million tons of concentrates were fed to milk cows and other dairy cattle in 1959 (2, Tables 5 and 6). In these states, prices for conventional roughage materials range from $20 to $40 per ton, and are increasing. These roughages include hay, corncobs, cottonseed hulls, and like products, which provide modest energy values with some protein but which also have certain disadvantages that have been mentioned. An acceptable nonnutritive roughage derived from wood residues might find a market in a price range of $15 to $20 per ton. Cattle population, feed surpluses or deficits, and wood-residue availabilities in various regions of the United States are listed in Table 1.

Ruminant Digestion of Cellulose

In addition to wood used as roughage, there is the uncertain but most interesting possible use as energy feed. Although the horse digests cellulose very well and hogs appear to have some capabilities for this, it is the ruminant animals such as cattle and sheep that have the advantage of being peculiarly adapted to digest cellulose. In the ruminants, nature provides an outstanding example of a symbiosis of particular benefit to man. The symbiotic arrangement consists of the animal's rumen, a chamber preceding its true stomach, and the ability of the rumen to culture cellulolytic micro-organisms. In many ways the animal's physiology and anatomy provide ideal fermentation conditions for the micro-organisms, which in turn provide the animal with nutrients by enzymatically breaking down cellulose and hemicelluloses. Pure cellulose is fully digestible; thus it provides as much energy as the best feed grains. The energy-yielding products which the animal absorbs into its bloodstream from this anaerobic fermentation are primarily acetic and propionic acids. In addition to the digestion of cellulose, another advantage results from the ruminant's ability to digest the proteins of bacteria and protozoa that pass on into its digestive tract. The lignin of forages remains largely unused and is excreted. In the overall process, man gains because material not suitable as food for humans is converted into milk, meat, wool, and leather.

Of some importance now, and of considerable importance in the future, is the fact that the animals that are able to use cellulose as a feed are less competitive with man than the animals that require grain. Because of the large loss in mass and energy in converting grain starch to meat, man's most economical use of starch is using it directly and obtaining protein from vegetables and fish. The proteins of milk and meat are, however, an important part of man's diet especially where there is a high standard of living, and they are apt to remain as important foods in the foreseeable future. For obtaining protein, the ruminants have an advantage over other domestic animals because rumen micro-organisms are able to convert simple nitrogen compounds, such as urea, into protein. Demonstrations such as in the work by Virtanen (26) in Finland have shown good milk production by cows fed only urea, cellulose, and starch as the bulk of their diets. Therefore, cows produce high-quality milk and meat from sources of energy (cellulose) and nitrogen (urea) that cannot be used directly by man.

Methods for Making Wood Carbohydrates Available as an Energy Food

Although most woods contain from 70 to 75 percent carbohydrates, a relatively small percentage is digested by ruminant animals. The low digestibility has generally been attributed to a protective action by the lignin, the degree of protection varying at least partially with the degree of lignification. Thus, hardwoods with their lower lignin levels are more digestible as a class than are the softwoods. Even among hardwoods, there is a considerable range of digestibility. In a recent paper, Mellenberger and others (10) have reported a 30 percent *in vitro*

(rumen fluid) digestion of aspen wood with 20.5 percent lignin content. In contrast, oak wood with a lignin content of about 24 percent was digested only to the extent of 5 percent. Spruce wood with about 30 percent lignin had zero digestibility. It is evident that before wood residues can receive any consideration as an energy feed-stuff for ruminants, some form of pretreatment to effect a release of wood carbohydrates from their association with lignin will be necessary. To be commercially acceptable, this pretreatment must be accomplished at low cost.

One general method of releasing wood cellulose and hemicellulose is solubilization by chemical breakdown to sugars, usually by acid hydrolysis (7). These sugars are a satisfactory source of food energy, but hydrolytic methods and other degradative procedures such as ionizing radiation (9, 14) have not produced sugars at competitive prices. A corollary method is the solubilization of the more accessible hemicelluloses by mild hydrolysis. Masonex (24), a byproduct from the manufacture of hardboard, is an example of such a recovery and of the use of wood hemicelluloses in animal feeds. Its application demonstrates that the economic difficulty can be overcome if costs can be shared with another product or products.

Another general method of releasing carbohydrates from wood is pulping. During World War II more than 1.5 million tons of sulfate and sulfite pulps from spruce, pine, and fir were fed to cows and horses in the Scandinavian countries (8, 11). This demonstrated dramatically the capability of wood to supply food energy. In the postwar economy, however, the usual feeds became available at much lower prices and use of the high-quality wood pulps declined rapidly. More recently, interest has been aroused in the application of pulping procedures that exert a marked effect on digestibility but that do not remove appreciable amounts of lignin. Saarinen, *et al.* (15) showed that rams were able to digest 85 to 90 percent of the carbohydrates of certain sulfate and sulfite pulps that still retained about 17 percent lignin.

Hydrolysis and pulping are ultimate cellulose-releasing methods; hydrolysis degrades the cellulose and releases the soluble glucose and pulping makes the cellulose available by removal of the lignin. It is useful to consider pulping as a method that exposes cellulose, for on this basis other techniques may be compared. An example is vibratory ball milling, a procedure that exposes more and more cellulose as particle size decreases. The important difference is that this is accomplished without removal of lignin. In a series of studies, Virtanen and coworkers (27-30) showed a direct relationship between the degree of subdivision of wood and its degradation by bacteria. Pew (12) and Pew and Weyna (13) found a similar relationship between particle size and the degradation of wood by the enzymatic action of isolated cellulases. Whether finely ground wood can function effectively as an energy source in the diet for ruminants is a subject now under investigation at the Forest Products Laboratory and the University of Wisconsin. The commercial practicality of this type of process will also receive attention.

Yet another method, used on straw, is alkaline steeping. This was used in Europe during both world wars to supplement meager feed sources, and has had recent use in Norway. As a result of treatment with a 1.5 percent sodium hydroxide solution, the digestibility of the residual straw is about 30 percent more than that of the original straw. The digestibility of the treated straw is comparable to that of a good hay. This method has been suggested for upgrading bagasse (17).

Alkaline steeping solubilizes about 20 percent of the straw. The was

Table 1. — ANNUAL PRODUCTION OF CATTLE, OF WOOD RESIDUES FROM MANUFACTURING, AND OF HAY BY REGIONS IN THE UNITED STATES.

Region	Cattle[1]		Wood Residues[2]		Hay[3]
	Beef	Dairy	Softwoods	Hardwoods	Excess or Deficit
	(Million head)		(Million tons)		(Million tons)
New England	0.1	1.0	0.3	0.1	+ 1.3
Mid-Atlantic (N.J., N.Y., Pa.)	.6	3.7	.1	.5	+ 3.9
South Atlantic	2.6	4.4	3.4	2.3	− 2.1
East South Central (Ala., Ky., Miss., Tenn.)	4.9	2.8	0.4	0.7	− 2.6
West South Central (Ark., La., Okla., Tex.)	13.3	2.3	.5	.5	−13.4
Lake States (Mich., Minn., Wis.)	2.8	7.2	.2	.3	+ 8.1
Corn Belt (Ill., Ind., Iowa, Mo., Ohio)	13.3	5.6	.0	.4	+ 1.9
Northern Plains (Kans., Nebr., N.D., S.D.)	11.1	2.1	.0	.0	+ 1.0
Mountain	9.4	1.2	2.9	.0	− 1.1
Pacific (Calif., Oreg., Wash.)	4.5	2.2	6.3	.1	+ 1.7
All Regions	62.6	32.5	14.1	4.9	− 1.4

[1]Based on 1960 data in "Feed consumed by various classes of livestock by states, 1949-1950 and 1959-1960 with 1964-1965 national estimate and comparisons," USDA Econ. Res. Serv., Statist. Bull. 379, Oct. 1966.

[2]Calculated from data for 1962, Table 45, Appendix, using 30 pounds per cubic foot for conversion of cubic feet to tons, in "Timber trends in the United States," USDA Forest Serv., Forest Res. Rep. 17, 1965.

[3]From average of 1959-1963 data corrected for 10 percent moisture, Table 1, in "Hay in the United States," USDA Statist. Bull. 349, 1964.

liquors contain appreciable quantities of hemicelluloses that are an economic loss and also pose a disposal problem. The method, however, is of interest because of its potential practical value and also because of the principle involved. A possible interpretation of the increased digestibility of alkali-treated straw is that additional cellulose is exposed to the action of bacterial enzymes because of the strong swelling action of the alkali (22). On this basis the action could be compared with that of ball milling.

Several years ago, Stranks, in a series of papers (18-21), reported on the microbiological degradation of wood and its possible implications for waste-wood utilization. He confirmed the beneficial effect of very fine grinding and also showed the beneficial effect of alkaline cooking of hardwoods. More comparable to the cold alkaline treatment of straw was a test by Saarinen *et al.* (15) who found that rams could digest 43 percent of the residue from steeping birch wood in 2.5 percent sodium hydroxide solution at 25° C. The steeping extracted 12 percent of the wood; it is possible that without this loss, about 50 percent of the wood might have been digested. This digestibility would be about the same as the *in vitro* digestibility of silver poplar wood that was treated with 9 to 15 percent sodium hydroxide (based on wood weight) by Wilson and Pigden (31). They found that the digestibility was raised from 5 percent to 40 to 50 percent. The same treatment of straw raised its digestibility to 70 to 80 percent, which is more than that of a good hay (55 to 60 percent). Wilson and Pigden avoided the extracting of alkali-soluble material from the wood and straw by using low levels of alkali that were left *in situ*. In preliminary feeding trials with sheep they found that treated straw was acceptable at a 40 percent level in the feed. Favorable results from several cattle-feeding experiments led Ustinov (25) to conclude that alkali-treated aspen and birch sawdust could be recommended at levels as high as 25 to 30 percent of the nutritive value of the ration.

Further evidence for the increased accessibility of cell wall carbohydrates after alkaline swelling is the increased digestion by cellulases shown by Pew and Weyna (13). By alternate alkaline and enzyme treatments they reached about 80 percent digestibility of the carbohydrates of otherwise very resistant spruce wood. Direct measurements of the irreversible total swelling of the cell wall of hardwoods following treatment with dilute alkali were made by Tarkow and Feist (23) who also related the increased digestibility to the increased swelling (22). These workers postulated that the increased swelling was caused by the breakage of intermolecular crosslinks, most likely, polyuronic acid ester bonds.

FROM A FISTULATED HOLSTEIN, University of Wisconsin graduate student Roger Mellenberger removes stomach contents for use in FPL experiments to determine digestibility of various normal and modified woods.

Summary

It is easy to be intrigued by potentialities for utilizing substantial quantities of wood residues in the animal feedstuffs market. Of the two alternatives discussed here — roughage or energy source—roughage offers more immediate promise. Feeding studies now under way are designed to provide factual data on optimum particle size and dietary level as well as on effect on carcass yield and quality. Well documented results with adequate dissemination of information could mean ready acceptance of wood residues as a roughage component of feedlot rations and of the complete feeds now in demand by dairymen operating near large population centers. If feeding tests are successful, initial penetration of this market area may occur within the next few years.

It is too early to announce any promising leads for using wood as an energy food. Experience has shown that some form of pretreatment of the wood is necessary because the carbohydrates of most native woods are almost untouched in the ruminant digestive tract. As noted, some improvement in digestibility can be obtained without complete separation of cellulose and lignin. An essential factor is that cellulose be accessible to the action of rumen micro-organisms. This accessibility can be improved by several procedures: Vibratory ball milling, ionizing radiation, or strong swelling agents such as alkali. All are able to increase the digestibility of wood residues; hardwoods in general are more responsive than softwoods. Although conventional pulping is too expensive to be considered for this purpose, it should be considered that most of the criteria that have been used to guide pulping techniques—such as fiber length and low lignin content—are not important for feeding purposes. Consequently, there is some hope that inexpensive techniques to improve the digestibility of wood will be introduced.

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Grinding towards success

Hank Lohmeyer **Published on Wednesday, 27 February 2013 14:08** Hits: 416

Kirt and Keith Mautz are brothers and graduates of Olathe High School who have harnessed the American free enterprise spirit to build their Olathe feedlot operation into a busy hub of local resource use and innovation.

Photos by Hank Lohmeyer A conveyor piles up mountains of ground aspen bark used and marketed as quality cattle feed by brothers Kirt and Keith Mautz of Olathe.

The brothers, who are in partnership in the Banner Road operation with their mom, Penney, have branched out from the feedlot into composting, custom grinding and feed mixing, and another experimental enterprise – biochar.

Brothers Kirt and Keith Mautz have harnesed a free enterprise spirit with local resources to create a growing operation on Banner Road. They are shown in the yard with some of the 75 tons of ground aspen bark they process, use and sell weekly.

Almost everything in the Mautz operation revolves around feeding the 800 head of cattle currently in the feedlot, and using the by-product. That includes their biochar experiment.

Biochar is a form of charcoal made from the vast local supply of ground-up wood chips from beetle kill pine. The finished biochar product would look familiar to anyone who regularly cleans out a wood burner.

Biochar's physical structure, with millions of microscopic internal channels and cavities, helps make it useful as a soil amendment. It provides desired soil health benefits by retaining water and nutrients in the soil. And, Kirt says, it provides habitat for beneficial microorganisms that promote soil health.

A fistful of ground aspen bark feed supplement looks like everyday garden mulch.

"Biochar would work like any type of carbon filter to hold nutrients, requiring use of less water and fertilizer," Kirt said.

Making biochar involves burning off volatile chemicals in the pine chips which leaves a featherweight chip of charcoal-like biochar. The process, called "gasification," runs at 200,000 btu continuously and produces waste heat that Kirt says is capable of helping heat his 5,000-sq.-ft. shop and his house. The gasification process is self-sustaining and needs an added fuel boost only to get the process started.

Kirt came across some research that's been done on biochar, got interested, and then bought a gasifier unit from a fellow in Illinois who built it in his own shop.

The same physical structure that makes biochar beneficial as a soil amendment also

A by-product of beetle kill pine – biochar – that can help keep animals and soil healthy.

benefits their cattle, which get a 1 percent portion of it in their feed ration. Feeding biochar confers health benefits to the animals, Kirt says.

It's not known exactly how biochar's health benefits work. One theory is that beneficial bacteria that aid the ruminant process live in the biochar's microscopic pores, increasing feed nutrient use. The result is like adding protein supplement, Kirt says. He cites a study showing increased weight gain of up to 25 percent feeding 1 percent biochar, compared with a control.

Kirt processes beetle kill wood chips to make biochar in a device called a “gasifier.”

Biochar, Kirt explains, is also said to have beneficial results in hog and poultry ration. The biochar itself confers no nutrient value.

When the material eventually passes out of the animal, it is composted along with the manure, adding additional benefit to the final compost product.

The Mautz operation makes another innovative product that has made Kirt and Keith believers. It, too, is derived from a plentiful by-product of the local timber industry – aspen bark.

When feed prices started heading for the stratosphere, Kirt said he hit on the idea of trying ground-up aspen bark in the cattle feed. After all, elk eat lots of it.

A tub grinder at work processing aspen bark feed, part of the 75 tons per week being fed in the valley by three operators now.

The ground aspen bark enterprise has grown. In addition to the Mautz feedlot, there are two other operators in the valley, with all of them using 75 tons of the product every week and feeding as many as 5,000 head here, Kirt said.

They use 30 percent of the ground aspen bark in their feed ration. The brothers sell the ground aspen bark for $100 a ton, Kirt said, a price that any operator can compare for himself with current local prices of grass hay.

Kirt says that the aspen bark ration "cuts sickness in the cattle by 90 percent." He said that aspen bark's "relative feed value tested out better than grass hay. The relative feed value (has measured) up to 130." He backs up that statement with a laboratory analysis of his aspen bark showing a relative feed value of 128.

A research paper from South Dakota State University on measuring relative feed value gives "full bloom alfalfa a relative feed value of 100" on the scale.

The Mautz brothers also produce and sell compost as part of their operation. The compost they market, though not itself certified organic, is "certified for use in producing organic food products."

The Mautz brothers operate an armada of heavy equipment in their operation including tub grinders, a massive compost sifter, conveyors, loaders and more, including the biochar gasifier.

They call their operation 3XM Grinding and Composting. They say, "We began grinding as a way to process feed for our cattle. Over the past 15 years we have improved our fleet of grinders to include tub grinders that can process up to 1,000 yards, or 300 tons of material per hour. We are the premier custom grinding operation in our area.

"We have the raw materials to create the blend of soil amendment that is just right for your needs. We have a variety of ingredients available that ensures we can make the best product for your specific needs. We can also get a compost analysis of any blend we make. We process our compost in late fall, and then allow it to cook throughout the winter. The high temperature the compost reaches (160 degrees Fahrenheit) ensures that all weeds and pathogens are killed. We specialize in doing custom regrind."

WERA-39-WSASAS Sheep Symposium

Integrating Advanced Concepts into Traditional Practices

June 19, 2013

Museum of the Rockies

Montana State University

Bozeman, Montana

PROCEEDINGS

2013 WERA-39-WSASAS SHEEP SYMPOSIUM:

INTEGRATING ADVANCED CONCEPTS INTO TRATIONAL PRACTICES

JUNE 19TH, 2013

MUSEUM OF THE ROCKIES

MONTANA STATE UNIVERSITY, BOZEMAN, MT

PATRICK HATFIELD, SYMPOSIUM CHAIR

CHRISTOPHER SCHAUER AND J. BRET TAYLOR, EDITORS

VOLUME 67

PROCEEDINGS

WESTERN SECTION

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2013 Sheep Symposium
Integrating Advanced Concepts into Traditional Practices
Museum of the Rockies, Montana State University
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ALTERNATIVE FEEDS: A SOLUTION FOR A TEMPORARY CRISIS OR A PERMANENT PROBLEM?

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ABSTRACT: Feed costs represent a significant portion of the total cost of livestock production. Historically, when traditional feed costs are inflated, alternative feed ingredients are more thoroughly researched, discussed, and eventually used in livestock diets. As the price of feed ingredients return to normal, use of alternative feeds quickly subsides. However, recent factors including drought, rising fuel costs, and competition for biofuel feed resources have caused an unprecedented rise in feed costs. These factors, along with current issues such as economic stagnation, greater emphasis on enhancing natural resources, and increased environmental and livestock production regulations, suggest that a temporary crisis may be developing into a permanent problem. Numerous alternative human food and crop residues, (e.g. bread, candy, cotton gin trash) have been researched and used to help stabilize inflated feed costs, but they are not always available, have variable nutritional characteristics, and can be difficult to handle. In contrast, an alternative feed does exist, which is abundantly available throughout North America, requires no inputs such as fertilizer, irrigation, pesticides, or herbicides, and is highly resilient to drought and market volatility: woody plants. Therefore, the process of converting woody plants to feed should be revived by making it more efficient, enhancing the nutritional value of the final products, and documenting benefits to the animal, natural resources, and rural economies. Currently, no other program is available that can economically, or even theoretically, reduce brush encroachment while concurrently producing a livestock feed ingredient that is cost competitive to traditional roughages.
Keywords: alternative feeds, feed cost, livestock production, juniper, roughage

Temporary Crisis or Permanent Problem?

The change in feed costs over the past decade is alarming and has proven to be unsustainable for many livestock production sectors. Rising feed costs (Figure 1) can be attributed to many factors, such as rising fuel costs and federal mandates of feed resources being diverted to biofuels production (EIA, 2012; Wise, 2012). These costs are exacerbated by matters such as inflation and drought-induced feed shortages. One notable example is the current price of cottonseed hulls (CSH), which provide little nutritive value and function mainly as a roughage ingredient to maintain rumen function (Table 1). As of February 15, 2013, Texas markets priced CSH at $145/dry ton, not including average freight of $3/loaded mile (Hansen-Mueller Inc., McKinney, TX). During the 2011 drought, CSH sold for approximately $350/ton in some markets until they were no longer available in Lubbock (Feedstuffs Magazine, October 5, 2011).

Currently, roughage ingredients of similar nutritional quality to CSH (Table 1) are difficult to economically justify in livestock diets when priced above $130/ton. The question is, how many times within the next 5 yr will CSH be priced below $130? Between June, 2010 and February, 2013, CSH were priced less than $130/dry ton only 85 out of 177 reports; only 3 times between January, 2012 and February 2013 (Texas markets; Hansen-Mueller Inc., McKinney). Higher quality roughage ingredients such as alfalfa hay have an even more discouraging price history for the livestock feeder.

During times of feed shortages and elevated feed costs, livestock producers are more predisposed to utilize alternative feeds, even if those feeds have not been thoroughly researched or analyzed for nutrients. As the cost of traditional feed ingredients returns to normal, use of alternative feeds subsides. For instance, high feed prices during 1918 to 1919 and during the 1930's, resulted in greater research and use of sawdust and ground aspen trees in livestock diets (Davey, 1977; NRC, 1983); however, use during both periods halted as the price of traditional ingredients returned to normal. Even though woody residues have not been generally recognized as competitive feed alternatives under normal economic conditions (Scott et al., 1969), it is notable that *Populus* trees were approved as an Association of American Feed Control Officials feed ingredient in 1980 (AAFCO, 2011).

We predict that livestock producers will need to increase use of precision diet formulation to maximize gain-to-feed efficiency and increase feed storage capacity to help stabilize feed price fluctuations. In addition, greater transportation and feed costs will encourage onsite confined feeding operations and grazing systems that utilize local feed resources to reduce time spent in the feedyard. These predictions are partially based on the fact that the regulatory burden on large concentrated animal feeding operations is rapidly increasing. In some areas, this will lead to a greater demand for brush control to enhance forage production. We also predict that membership in livestock cooperatives will become more important, to share financial burdens, equipment, labor, and expertise. These predictions justify the establishment of a national *Wood-to-Feed Program* that will remain economically and environmentally sustainable even if traditional feed ingredients become "reasonable" once again.

Alternative Feed Examples and Considerations

The number of alternative feed ingredients that have been used in livestock diets is extensive and cannot be thoroughly discussed in this paper; however, the following references provide abbreviated summaries: (NRC, 1983; Lardy and Anderson, 2003; Blache et al., 2008). Before potential feed ingredients can be commercially fed to livestock, feeds must first be approved through FDA or AAFCO procedures to ensure the feeds are safe for the animal and do not result in residual compounds in milk or meat that affect human health. Furthermore, certain issues need to be considered before using any feed, especially alternative feeds that have not been extensively researched. For example, depending on concentration certain secondary plant compounds, i.e. condensed tannins (CT) and terpenoids, can either reduce animal performance (Barry and Forss, 1983; Pritz et al., 1997; Blache et al., 2008) or increase animal performance (Waghorn et al., 1987; Min et al., 2001; Ramirez-Restrepo and Barry, 2005).

Diets containing greater than 5% mesquite leaves can reduce intake and BW gain in sheep (Baptista and Launchbaugh, 2001), due to compounds such as flavonoids, phenolics, and alkaloids (Cates and Rhoades, 1977; Solbrig et al., 1977; Lyon et al., 1988). Other compounds to consider are phytoestrogens and certain minerals such as Se, as previously reviewed (NRC, 1983; Blache et al., 2008). Thus, analyzing each ingredient for chemical composition and purity is especially important in alternative feeds. Two other important considerations include the need for specialized facilities and equipment to store, move, and process low-density feeds and the use of pre-treatment technologies (e.g. air- and oven-drying, ensiling, and pelleting) that can reduce concentrations and bioactivity of secondary plant compounds. Each individual buyer will need to use research, experience, or both, to determine if the ingredient is worth purchasing.

Development of the Texas AgriLife *Wood-to-Feed Program*

Goats will consume juniper leaves while grazing (Malachek and Leinweber, 1972); thus, our first experiment centered on feeding lambs mixed diets that contained redberry juniper leaves. Because blueberry juniper was more readily browsed than redberry juniper (Riddle et al., 1996) and goats consumed more juniper than sheep (Straka, 1993), we hypothesized that our results would be even more relevant to goats and blueberry juniper. In this experiment, replacing 50% of the CSH with redberry juniper leaves increased animal performance in lambs, compared to diets containing CSH or juniper leaves as the sole roughage source (Whitney and Muir, 2010). These results led to a study in which mixed diets containing ground juniper leaves and small stems were fed to lambs. The juniper successfully replaced all of the oat hay in diets containing 40% DDGS (T. R. Whitney, unpublished data). Additional studies showed that redberry juniper-based diets can reduce *Haemonchus contortus* infection (Whitney et al., 2011; T. R. Whitney, unpublished data) and that other *Juniperus* spp. have similar nutritional characteristics as compared to redberry juniper (Table 1).

A further review of the literature revealed a wealth of information related to successfully incorporating woody material into livestock diets (e.g. Sherrard and Blanco, 1921; Archibald, 1926; Hvidsten, 1940; Nehring and Schutte, 1950; Marion et al., 1957; Parker, 1982; NRC, 1983). These reports, along with numerous others, demonstrate a potential to reduce woody plant encroachment, while synergistically developing a low-cost livestock feed ingredient. For example, Marion (1957) reported that steers fed mixed diets containing 50% ground mesquite wood performed similar to steers fed 50% CSH and that the mesquite meal cost 44% less than CSH. So, why did this process not develop into a permanent production practice? Many suggest that the low cost of traditional roughage sources did not justify the additional labor and equipment costs needed to convert standing trees into feed. However, machinery and techniques available today are much more capable and efficient in converting large quantities of standing trees into quality hammer-

milled feed products. Also, brush encroachment has become the center of attention for natural resource, livestock, and wildlife management and soil and water conservation, and the current price of roughage feed ingredients justifies an integrated program that converts woody plants into feed.

The Texas AgriLife *Wood-to-Feed Program* has been developed from almost a century of documented research efforts, advanced technology, entrepreneurship, and foresight of our predecessors. The primary goal is to increase the value of encroaching woody plant species to reduce harvesting costs, while synergistically increasing grass production and ecosystem health, and reducing livestock feed costs. Multiple scientists and industry partners with complementary backgrounds and specialties are collaborating to rapidly increase adoption rate of this proven practice.

Implications

Rising livestock feed costs will necessitate changes within all livestock industries. Production practices will shift as producers address feed ingredient shortages. Energy, economic, and regulatory challenges will accelerate adoption of feeding alternative ingredients in livestock diets. The feasibility of any alternative feed depends on cost and availability. While the cattle industry is an excellent outlet for woody feed ingredients, small ruminants stand to benefit from utilizing ground woody plants perhaps even more than cattle, in part due to their suitability to landscapes where woody plants dominate. In certain circumstances, woody plants are an on-site feed resource on many sheep ranches throughout the U.S. Numerous benefits to rangelands, the livestock industry, and local economies will be recognized when large amounts of brush are harvested for livestock feed. Producers should be ready if the current price of feed transitions into a permanent problem.

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Table 1. Chemical composition (%, DM basis) and 48-h IVDMD of traditional and alternative feed ingredients[1]

	Nutrient[2]					
Item	CP	NDF	ADF	Ash	CT	IVDMD
Alfalfa, mid-bloom hay	17	47	36	9	-	71
Coastal bermudagrass hay	10	73	36	6	-	56
Sorghum-sudangrass hay	8	67	43	10	0.9	50
Cottonseed hulls	6.6	79	69	2.7	5.6	21
Redberry juniper, leaves	7.1	37.7	31.2	5.3	5.5	67
Redberry juniper, whole tree	3.6	66	56	4.2	4.7	29
One-seed juniper, whole tree	3.6	64	53	4.4	2.7	32
Eastern red cedar, whole tree	3.7	68	58	3.5	5.6	29

[1]NRC, 1983; NRC, 2007;Whitney, T. R., and J. P. Muir. 2010; W. C. Stewart and T. R. Whitney, unpublished data.

[2]CP = crude protein; NDF = neutral detergent fiber; ADF = acid detergent fiber; CT = condensed tannins; IVDMD = invitro dry matter digestibility.

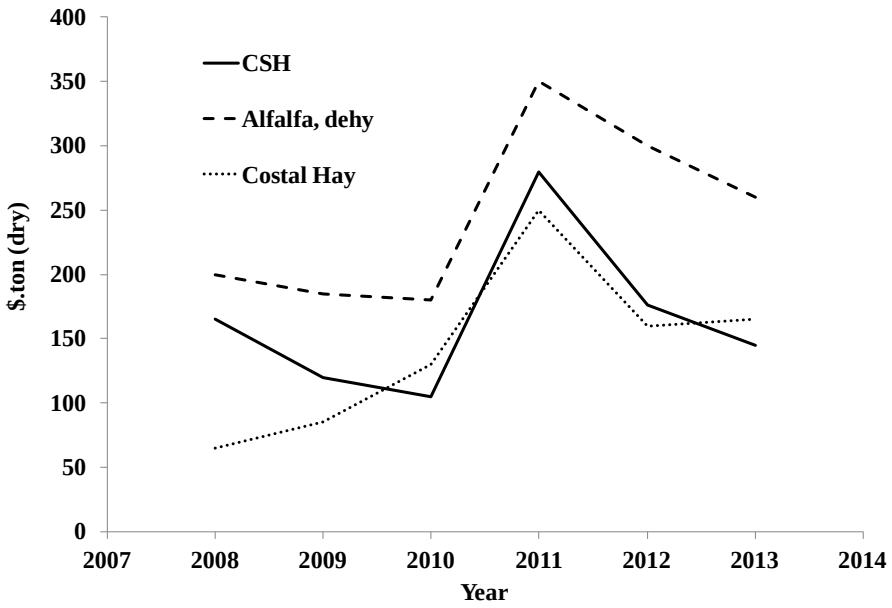
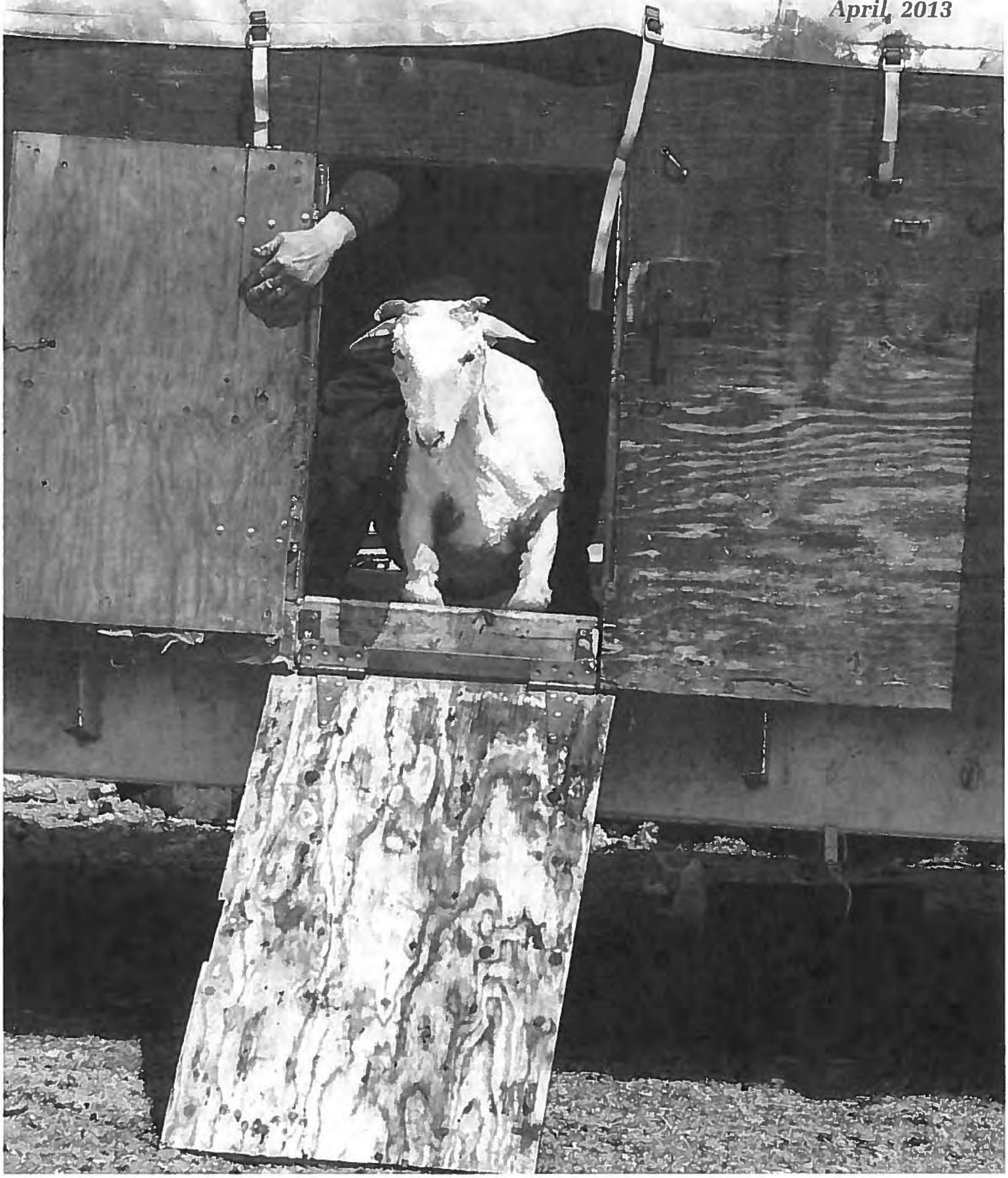


Figure 1. Market prices (at source and not delivered) for traditional roughage ingredients: cottonseed hulls (CSH; Hansen-Mueller Trading, McKinney, TX); dehydrated alfalfa (Alfalfa, dehy), and round bales of coastal bermudagrass hay (Costal Hay; USDA-AMS, 2008-2013).

A GUIDE FOR SHEEP AND FARM LIFE

THE SHEPHERD

April, 2013



Perhaps some of you have heard the saying, "Insanity is doing the same thing, over and over again, but expecting different results." I don't consider myself insane but have fallen victim to repeating mistakes, which I later realize I had learned at an earlier juncture in my life. Whether this is due to habit, fatigue, or frustration, avoidable mistakes are always being made. This may ring true with the hectic pace on your farm or ranch. Oftentimes we are too busy running between chores, meetings, and a day job to make time to strategically plan for oncoming challenges, whatever they may be.

Given last year's historic drought and subsequent high cost of feed, many of us may be looking ahead and planning accordingly for an equally dry summer. The following may help generate some options just in case feed and fuel remain expensive.

Option One: Feeding Pine Bark

Researchers from Tuskegee University and Mississippi State University conducted a study feeding Loblolly pine bark to 60 lb Kiko crossbred kids to measure the effects on growth, performance, rumen fermentation, blood parameters, fecal egg counts, and carcass characteristics. The pine bark was donated from a local timber processing company and hammer milled to 3mm. It was then fed as a grain mixture containing 0, 15, and 30% pine bark.

So why pine bark? Not only are pine trees abundant throughout the southeast U.S., the bark contains an optimal condensed tannin concentration (2-4%). What's great about this is final body weight, average daily gain, overall intake, and gain to feed ratio increased as pine bark increased in the kid's diet. Does this sound too good to be true? Maybe not. Researchers observed that the increasing levels of pine bark favorably modified rumen fermentation (VFA's and ammonia production) and efficiency. For some, the cherry on top of this study was finding parasitic loads significantly reduced in goats consuming the pine bark compared to the control group.

The multifaceted benefits of feeding pine bark observed in this study are amazing! Some of these benefits may be attributed to the condensed tannins (CT). Some forages containing condensed tannins can be a mixed bag in terms of the CT percentages in the plant and how bio-active the CT are. It appears with pine bark that an optimal 2-4% CT may be a major selling point in feeding pine bark.

Option Two: Utilization of Woody Biomass.

Utilization of woody-biomass as a feed resource is not entirely novel nor is it limited to certain regions of the U.S. High feed prices during 1918 to 1919 and during the 1930's, resulted in greater research and use of sawdust and ground aspen trees in livestock diets (NRC, 1983). However, use of woody-biomass during both periods halted as the price of traditional ingredients returned to normal. An example specific to the southwestern U.S. from Marion (1957) reported that steers fed mixed diets containing 50% ground mesquite wood performed similar to steers fed 50% CSH and that the mesquite meal cost 44% less than CSH.

Texas, New Mexico, and Oklahoma, represent 27.5% of the sheep and goats as well as 20% of the cattle in the U.S. Within these states, livestock production occurs on rangelands that are adversely affected by juniper encroachment (NASS, 2012). Woody invasive species such as juniper (Juniperus spp.; i.e., "brush") occur on millions of acres throughout the U.S. and continue to increase at rapid rates. Eastern Red Cedar alone is currently estimated to have spread to 12.6 million acres (28% of the Oklahoma landscape; NRCS, 2008). The increasing abundance of these woody species has led to ecological degradation, soil erosion, and decreased economic viability of rangeland areas. Juniper encroachment becomes exacerbated during hot, dry conditions when forage availability is critical because infestations decrease forage production, plant diversity, and water infiltration rates.

The realities of woody-plant encroachment and ongoing drought in the southwestern U.S. has resulted in inflated feed costs, even with low quality feed ingredients. Take for example cottonseed hulls, a common roughage ingredient in the southern plains and southwest U.S. Note: I am not talking about cotton seed meal which is considered a high quality (40% crude protein) feed ingredient. In contrast cotton seed hulls are approx. 30% digested, 5% crude protein and function primarily to facilitate proper rumen fermentation. The devastating drought of 2011 resulted in cottonseed hulls trading for $320/ton as opposed to the previous decades selling for $80/ton. This of course contributes to the cost of a complete mixed feed (14% CP) selling for upwards of $450/ton.

One solution to the inflated cost of feed has been to harvest and grind abundant, woody plants for use in sheep and goat diets. A renewed effort by researchers at the Texas A&M Research and Extension San Angelo, Texas has found woody plants can be competitive nutritionally and economically. Most sheep feeding trials have been limited to the red berry juniper species. However research has recently expanded to one-seed juniper of New Mexico and eastern red cedar in Oklahoma. The first lamb crop from ewes consuming up to a pound of ground juniper a day are being evaluated to determine if feeding ground juniper has any effect on lambing rate and pre-weaning lamb performance. Results of this study will be forthcoming.

To date researchers have found feeding ground juniper can: Reduce Haemonchus contortus fecal egg production; Reduced H. contortus larval viability in the laboratory; Has greater digestibility, similar crude protein, and less indigestible fiber than cottonseed hulls. Increases "healthy" fatty acids in lamb meat.

Less than 1 ½ inches of precipitation since the first of the year here in San Angelo, TX, is drying up my optimism for good grazing and moderate feed costs for 2013. I realize there is still hope for rain, nevertheless planning in the spring for a dry summer may keep one ahead of the frantic search for feed in July. Unfortunately, utilization of alternative/novel feed ingredients only gets real attention in the heat of the drought. There's nothing like $300/ton hay and $5.00/gallon diesel to help spur some creative thinking when it comes to feeding the flock. Independence from the feed mill and more reliance on the pasture and range is the benchmark for many profitable sheep operations. Yet both confinement and grazing based operations can agree that drought constricts feed supplies and profit margins.

For more information on feeding pine bark go to: Min, B. R., Solaiman, S., Gurung, N., Behrends, J., Eun, J. S., Taha, E., & Rose, J. (2012). Effects of pine bark supplementation on performance, rumen fermentation, and carcass characteristics of Kiko crossbred male goats. Journal of Animal Science.

For more information on feeding juniper refer to:

Whitney, T. R., A. E. Lee, D. R. Klein, C. B. Scott, and T. M. Craig. 2010. A modified in vitro larvae migration inhibition assay using rumen fluid to evaluate Haemonchus contortus viability. Vet. Parisitol. 176:217–225.

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Dispatch from Mormon Trail Farm....

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Just how much is "free" feed worth these days? Like most things, I guess it all depends.

I think in nearly 40 years of farming, this winter has perhaps been our toughest struggle in the livestock business. We have relied heavily on stockpiled fall and winter grazing for our sheep and cattle most of those 40 years. This year, there was none.

We have faced stiff challenges to extending the grazing season before. My first year of farming, 1974, was tough. It was not particularly noteworthy for any specific weather event. It was just one of those Murphy's Law years when everything that could go wrong, did.

Planting was delayed due to wet conditions during April and May. June, July and August were terribly hot and dry. Then, the growing season came to an abrupt end with a hard freeze the third week in September. First and second cutting hay yields were good that year, however, and there was decent pasture regrowth in the fall due to early cool temperatures. We and our animals survived our first big test in good shape.

1977 remains our poorest corn crop ever. Yields for the entire farm averaged in the upper teens. But, the drought that year was isolated. It was intense in a fairly narrow band extending from southeast Nebraska and northeast Kansas into central Iowa. It was our year to win the lottery – we were smack dab in the middle of it!

Farmers not far away had hay to sell but, ironically, we didn't need it. Good rains came in late August, saving a fairly decent soybean crop and rejuvenating our cool season grass pastures with some excellent fall growth. With very poor corn pollination that year, most of the sugars and starches that would normally accumulate in the grain remained in the plant. Since corn varieties resistant to herbicides and insects hadn't been invented yet, the leaves, husks and stalks were not only nutritious, but palatable. Cows and ewes ate them with relish down to stubs and stayed in excellent condition in the process.

1983 and 1988 were more noteworthy droughts over a larger area, but their impact on us, locally, was less severe. 1993 saw extreme hay shortages in Iowa due to prolonged wet weather. Many hay fields were cut, but never harvested due to constant rain and mud. Throughout the growing season, hay was left in the fields to rot, damaging future stands in the process. But, there was certainly adequate moisture for fall pasture regrowth, and stockpiled forage yields were good.

Stockpiled grazing, of course, is never an exact science and weather during the growing season isn't always the only limiting factor. 2000-2001 was terrible for winter grazing. Plenty of grass was available and both ewes and cows can dig through a surprising amount of snow to find it – but not if it's covered by a frozen, icy crust. Such a barrier existed from early December through most of March that year necessitating the feeding of huge amounts of hay. But, when warmer temperatures finally did arrive, the fescue underneath was still green and lush for the taking.

This year, hay was scarce over a huge area. We bought some in late November from a neighbor who sold most of his cows. He was the smart one. Those big round bales of mixed grasses and legumes cost just over $200 per ton – more than double the highest price I had ever paid previously for hay.

Earlier, I mentioned the non-GMO corn used back in the 1970's. Today's hybrids genetically engineered to withstand weed and insect pressure are (in my opinion) far superior to those available just a couple of decades ago. By all accounts, the drought of 2012 surpassed anything seen in Iowa since the mid-1930's. It was more than media hype – it was real! Incredibly, however, some corn this year produced yields considered good even in a "normal" year. The flip side of GM corn, however, is that wet or dry, hot or cold, livestock generally find the residue less palatable for grazing. And, as grain yields have improved, there probably isn't as much nutrition left in the plant anyway.

Our fall-calving cows have grudgingly gnawed away at harvested stalk fields all fall and winter. But, they definitely told us they didn't like it – and their falling body condition scores second that notion. The closest we could come to "free" feed this year was the purchased corn stalk bales that cost us $50/ton by the time we got them home. To those outside of corn country, that may not sound like much compared to current hay prices. The problem is there's not much nutrition there either. The old saying is that in an emergency, a bale of modern Bt corn stalks will beat a snow bank for livestock feed – but not by much!

A couple of local cattle producer friends attempted to enhance the value of their stalk bales by tub grinding, treating them with hydrated lime and then ensiling the chopped material in a bunker silo. It was somewhat unnerving to watch as local co-op staff applied chemicals at one of the sites while wearing Haz-Mat suits. The reason for the gaudy outfits was the caustic nature of the liquid reagent being used. It's a potently basic formula which helps break down lignin in the plant, boosting digestibility in the rumen of cattle and sheep. Scientists at Iowa State University and the University of Nebraska say if properly mixed, fermented and aged, the lime treated residue can replace up to 20 percent of the corn in a feedlot ration.

That sounds pretty good, but one neighbor who tried it said you might want to be fairly certain of those numbers before starting. He had to construct a silage pit, purchase a large material bucket for his tractor loader, a new mixer wagon for feed delivery and portable bunks to place the feed in. Plus, there were the direct costs of operating two tractors, $5/ton for custom grinding, $20/ton for chemicals and $12/ton to haul water to the site. "Pretty soon," he said, "you're not talking free feed any more!"

Another farmer from southeast Iowa has been widely publicized recently regarding a process he developed to feed sawdust to wintering beef cows. Actually, there is research on that subject dating back to the 1960's and he says he began using the process in the late 1970's. News accounts say he originally cooked a sawdust mash solution with nitric acid to break down chemical bonds and make the inherent cellulose more digestible. Now a new, undisclosed process has been developed in cooperation with a local feed company.

The farmer's cattle reportedly consume about 30 pounds per day of a mixture that is 70 percent sawdust. A story appearing in the Cedar Rapids *Gazette* indicates the cattle "eat it like candy ... licking their lips" in the process. "They're a happy bunch ...," says his veterinarian.

Hopefully so. But I'm curious to hear more about the "undisclosed" process. Somehow, I'm guessing once we find out, the feed won't be "free" any more. ■

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Wood and wood-based residues in animal feeds

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Wood and Wood-based Residues in Animal Feeds

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Cellulose is the most abundant, naturally renewable material on earth. It, and hemicellulose, make up about 70% of the dry weight of shrubs and trees. The cellulose of woody plants, however, is largely unavailable to ruminants because of the highly crystalline nature of the cellulose molecule and the existence of a lignin-carbohydrate complex. If convenient ways can be found to enhance the availability of wood cellulose to enzymatic or microbiological systems, wood residues could provide an additional renewable energy feed supply for a world that can maintain no contingency reserve of feedstuffs. It would permit utilization of the large quantities of cellulosic residues that occur during harvest and manufacture of wood and cellulose products and provide a method of disposal of the used products.

This article presents a summary of research conducted on the use of wood and wood-based materials in animal feeds at the Forest Products Laboratory and the University of Wisconsin, and research in cooperation with the Tennessee Valley Authority, the U.S.D.A. Agricultural Research Service, Animal Nutrition Laboratory, Pennsylvania State University, and Auburn University.

Animal Feeding Studies

Early Research. Efforts by the Forest Products Laboratory to utilize wood in animal feeds began in 1920 when eastern white pine and Douglas-fir sawdust were hydrolyzed and fed to animals at the University of Wisconsin and the U.S. Department of Agriculture, Beltsville, Md. The work was started as a result of high feed grain prices during 1918-19. Wood was hydrolyzed and the washings and hydrolyzate were neutralized, concentrated, mixed with the unhydrolyzed residue and dried (1).

[1] Forest Service, U.S. Department of Agriculture. Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

This type of material was used in several feeding experiments with sheep and dairy cows (2-4). Results indicated that certain animals could eat rations containing up to one-third hydrolyzed sawdust mixture. Animals requiring considerable energy intake such as dairy cows could eat up to 15% of the hydrolyzed mixture without noticeable milk production effects. It was determined that the eastern white pine mixture was 46% digestible and that the Douglas-fir mixture was 33% digestible. It was concluded that feeding hydrolyzed wood was practical only when natural feed grains were in short supply.

Research on wood hydrolysis was conducted in the 1940's to produce concentrated sugar solutions suitable for stock and poultry feed. Over 200 tons of molasses were produced in pilot plants and sent to universities, agricultural experiment stations, and other agencies for feeding tests with milk cows, beef cattle, calves, lambs, pigs, and poultry (5,6). In general, the tests indicated that wood-sugar molasses is a highly digestible carbohydrate feed comparable to blackstrap molasses. In addition, the protein value of torula yeast, grown on neutralized dilute wood hydrolyzate, was found to be equivalent to casein when supplemented with methionine (7). Torula yeast has also been produced in three North American plants on the residual sugars in spent sulfite pulping liquors. Two plants are now operating.

Results from feeding tests with wood molasses led to production during the early 1960's of a concentrated hemicellulose extract called Masonex, a byproduct from hardboard production by the Masonite Corporation (8).

Current Studies. Recent research on the use of wood and wood residue in animal feeds was started as one approach to utilize the vast quantities of residue from logging, lumber and plywood manufacturing, and pulp and papermaking. Wood residue may serve as a source of digestible energy or as a roughage in ruminant rations. Fattening feedlot cattle, as well as lactating dairy cattle, need a minimum of fibrous feed in their ration and it is conceivable that indigestible fibrous wood residues could play a non-nutritive role in ruminant nutrition. It has been estimated that all of the wood and bark residues would supply more than enough roughage for all concentrates fed in the United States (9). In addition, more than 1.7 million tons of partially digestible pulp and papermaking fiber residues are produced annually that could supplement feed grains as sources of energy.

Animal feeding studies were conducted to determine acceptability, palatability, and digestibility of wood and bark residues to determine their value as roughage substitutes. Various physical and chemical methods to increase cellulose availability to rumen micro-organisms were evaluated with *in vitro* rumen methods. Digestibility trials were then conducted to determine

the *in vivo* digestibility of products from selected treatments. Pulp and papermill fiber residues were also evaluated by chemical analysis, *in vitro* and *in vivo* methods. Rations containing as much as 80% fiber residues were fed to animals through a complete reproductive cycle to determine long-term effects on general health and reproductive capacity.

In Vitro Assay Methods. The dry matter digestibility of various wood species and of the effects of chemical and physical pretreatments on digestibility was determined by the *in vitro* rumen method of Mellenberger, et al. (11). Results are reported as percent weight loss after 5 days of incubation at 39° C. An enzyme method was developed to provide an alternative assay procedure that did not depend upon the availability of a rumen fistulated cow (12). This method utilizes "Onazuka" SS enzyme obtained from *Trichoderma veride* in an acetate buffer and usually a 10-day incubation period. Digestibility is determined by analyzing the solution before and after incubation to determine the increase in reducing substances. The results of this test do not directly indicate rumen digestibility but they do indicate changes in digestibility.

The *in vitro* rumen test indicated that the digestibility of all wood species is low (13,11). All softwoods or coniferous species are essentially nondigestible. Hardwoods, or deciduous species, are somewhat digestible. Digestibility of the wood and bark of several tree species is shown in Table I. Note that the digestibility of soft maple wood is about 20%, aspen wood is about 33%, and aspen bark is about 50%.

Figure 1 shows results of feeding trials with red oak wood (14) and aspen wood and bark (15) and a method for estimating the *in vivo* digestibility by extrapolation of the data to 100% wood or bark. The red oak trial was with sheep, and the aspen wood and bark trial was with goats. Thus for red oak, the estimated *in vivo* digestibility is 0%; for aspen wood it is estimated to be about 40%, and for aspen bark it is about 50%. This indicates that aspen wood and bark could supply considerable digestible energy as well as roughage for ruminants.

Wood Residues as an Alternate Source of Roughage. Even though most untreated woods can contribute little to the dietary energy needs of ruminants, wood can still serve a useful function as a roughage substitute. Roughage is required in the ration to provide tactile stimulation of the rumen walls and to promote cud-chewing, which in turn increases salivation and supply of buffer for maintenance of rumen pH. Roughage materials currently used include hay, corn cobs, cottonseed hulls, oat hulls, rice hulls, and polyethylene pellets. A roughage substitute should be: readily obtained at low cost, effective at low levels, uniform in chemical and physical characteristics, capable of easy and uniform

Table I

in vitro Dry-Matter Digestibility of Various Woods and Their Barks

Substrate	Digestibility[a] Wood	Digestibility[a] Bark	Substrate	Digestibility[a] Wood	Digestibility[a] Bark
	%	%		%	%
HARDWOODS			HARDWOODS--continued		
Red alder	2	--	Soft maple small twigs	37	--
Trembling aspen	33	50	Sugar maple	7	14
Trembling aspen (groundwood fiber)	37	--	Red oak	3	--
Bigtooth aspen	31	--	White oak	4	--
Black ash	17	45	SOFTWOODS		
American basswood	5	25			
Yellow birch	6	16	Douglas-fir	5	--
White birch	8	--	Western hemlock	0	--
Eastern cottonwood	4	--	Western larch	3	7
American elm	8	27	Lodgepole pine	0	--
Sweetgum	2	--	Ponderosa pine	4	--
Shagbark hickory	5	--	Slash pine	0	--
Soft maple	20	--	Redwood	3	--
Soft maple buds	36	--	Sitka spruce	1	--
			White spruce	0	--

[a]For comparison: Digestibility of cotton linters was 90%; of alfalfa, 61%.

mixing, maintain normal rumen functions and feed intake, and able to prevent rumen parakeratosis and liver abscesses (16). If it is used in dairy rations, it should maintain normal milk fat test.

The roughage qualities of red oak sawdust have been determined by feeding beef cattle and sheep (17-19). In addition to the usual criteria of weight gain and efficiency of feed conversion, such measurements of carcass quality as grade, rib-eye area, and fat marbling were also noted. Attention was focused on livers and stomachs at slaughter, because abnormalities in these organs are characteristic of animals on roughage-deficient diets. It was concluded that oak sawdust was an effective roughage substitute when used as 5 to 15% of the total ration.

Roughage is necessary in dairy cow rations to prevent abnormally low milk fat tests (20). For economic reasons it is desirable to produce milk of high fat content. Hay supplies are, at times, limited and costly in some areas. In these areas it would be desirable to have an alternate roughage that would meet the "roughage requirement" for lactating dairy cows, that is not seasonal and would be compatible with automated feeding systems. Aspen sawdust, which is about 35% digestible, was fed at various concentrations to lactating dairy cows to determine if part or all of the hay could be replaced when feeding high-grain rations.

One feeding experiment (21) with lactating cows shows that aspen sawdust was effective as a partial roughage substitute in a high-grain dairy ration. The aspen sawdust was air-dried and hammermilled to pass through a screen plate with 1/8-inch-diameter holes. Cows maintained a normal milk fat level on 2.3 kg. of hay and about 17 kg. of pelleted grain, one-third of which was aspen sawdust. Cows receiving a similar ration without sawdust had a milk fat content half as great. The ratio of ruminal acetate to propionate was much higher in the cows fed aspen. Inclusion of aspen in a high-concentrate ration nearly doubled ruminating time. If less dietary aspen would be equally as effective in complete pelleted dairy rations, aspen sawdust could become an attractive roughage substitute in areas where hay is expensive and difficult to obtain.

In a second experiment (22), combining various levels of aspen sawdust with 5% bentonite and 2% sodium bicarbonate (based on the total ration), it was found that aspen sawdust could be a roughage extender or a partial roughage substitute in high-concentrate dairy rations. Sawdust maintained fat test and diminished off-feed problems when constituting about 30% of the ration dry matter in high or all-concentrate dairy rations. Since the dry matter digestibility of aspen sawdust was less than for other ration components, cows eating sawdust-containing rations compensated for the lower digestibility by eating more of the ration; thus, cows maintained total digestible energy

intake. Whether high-producing cows already at maximum feed intake could do this is questionable.

Aspen sawdust has useful roughage characteristics, but using it as the only roughage in high-concentrate dairy rations cannot be recommended. Approximately 30% of the ration dry matter would have to be sawdust; that is too high to be practical because the cows would have trouble consuming that large a volume of feed. Sodium bentonite and sodium bicarbonate apparently have an additive effect toward maintaining fat test when combined with aspen sawdust. In combination with bentonite and bicarbonate, smaller quantities of sawdust would probably be sufficient to maintain a given fat content of milk.

As little as 2.3 kg. of hay/cow per day is effective in stabilizing feed intake. To supplement the hay, adding 10-15% of the high-concentrate diet as aspen sawdust, 5% as sodium bentonite, and 2% as sodium bicarbonate might extend limited forage supplies. Since aspen sawdust does not serve well as the sole source of roughage in a complete all-concentrate ration, its potential appeal as a forage substitute for lactating dairy cows is reduced.

Pretreatments to Increase Digestibility

Several physical and chemical pretreatments were tested for their ability to increase digestibility of wood cellulose. The treatments were electron irradiation, vibratory ball milling, gaseous and liquid ammonia, gaseous sulfur dioxide, dilute sodium hydroxide, and white-rot fungi (23-25). Each of the treatments is capable of producing a product at high yield without a waste stream or byproduct.

The digestibility response to the various treatment conditions was followed by *in vitro* rumen and cellulase digestion assay procedures. Larger quantities of products of selected treatments were prepared for animal digestion trials with goats to determine *in vivo* digestibility and to observe palatability and acceptability. Goats were selected because they are small ruminants and require less space and feed.

High-Energy Electron Irradiation. The effect of exposure to increasing levels of electron irradiation on the *in vitro* digestibility of aspen and spruce is shown in Table II. Aspen carbohydrate digestion is essentially complete if it is assumed that only carbohydrate has been solubilized at an electron dosage of 10^8 rep. (roentgen equivalent physical). However, the lignin content of this aspen was 19.5%, and it might be expected that some lignin degradation products would be formed at this dosage level. If water soluble, these would contribute to the figure for dry matter digestibility. In any event, electron irradiation is an effective means for enhancing the digestibility

Table II

Effect of Electron Irradiation on *in vitro* Rumen Digestibility of Aspen and Spruce

Radiation dosage	Digestibility	
	Aspen[a]	Spruce
rep.[b]	%	%
0	55	3
10^6	52	3
10^7	59	5
5×10^7	70	8
10^8	78	14

[a]*Populus tremuloides*. This sample was from a board containing a high proportion of tension wood fibers. Tension wood is characterized by an exceptionally high carbohydrate-to-lignin ratio; thus, the high digestibility of this untreated aspen sample in comparison with that shown in Table I.

[b]Roentgen equivalent physical.

of aspen. It does very little to improve digestibility of spruce, however; the maximum digestibility was only 14% at the highest dosage level. Although higher dosage levels would probably improve digestibility further, they would also increase the level of carbohydrate destruction. From earlier work on the use of electron irradiation to enhance wood saccharification (26) it was shown that carbohydrate destruction was about 15% at 10^8 rep. and increased to about 45% at 5×10^8 rep. The product of the latter dosage was almost completely water soluble and was strongly acidic.

Vibratory Ball Milling. The effect of vibratory ball milling on the *in vitro* rumen digestibility of aspen and red oak is shown graphically in Figure 2. *In vitro* digestibilities of both woods increased rapidly with milling time to about 30 min. and then increased more slowly with further milling. Digestibility was highly dependent on time of *in vitro* rumen incubation; at least 5 days of incubation were required for digestibilities to attain 90% or more of their plateau values.

In vitro rumen digestibility of aspen and red oak which had been milled for 240 min. was 80% and 67%, respectively. Results of an enzymatic hydrolysis of the milled products using a cellulase demonstrated that this was not merely a solubilization effect. The 240-min. milled aspen and oak produced 63% and 57%, respectively, of their weight as glucose after enzyme digestion. Sugar production from the unmilled aspen and oak was 10.0% and 0.0%, respectively. Of the total carbohydrates in aspen and red oak, 70-80% was made accessible to cellulase digestion by vibratory ball milling.

In Figure 3 *in vitro* rumen digestibility is plotted as a function of milling time for five hardwood species. The digestibility values are those obtained with 5-day incubation. The first 20-30 min. of milling appear to have the major influence on digestibility. A digestibility plateau is apparently attained beyond which additional milling is of little value.

It is difficult to ascribe definite reasons for the wide variation in response between the woods. Certainly particle size alone is not the governing factor. All wood samples received the same degree of milling, and settling tests in water indicated similar particle size distribution. The controlling factor must be the quantity, chemical nature, and distribution of lignin.

The very selective response of the various species to vibratory ball milling makes this technique of limited value as a general means for upgrading the digestibility of wood residues. Moreover, there is a question whether finely ground wood will function as effectively in the ruminant as it does in *in vitro* assay. With forages, fine grinding has increased the *in vitro* digestibility of cellulose, but it has not produced similar

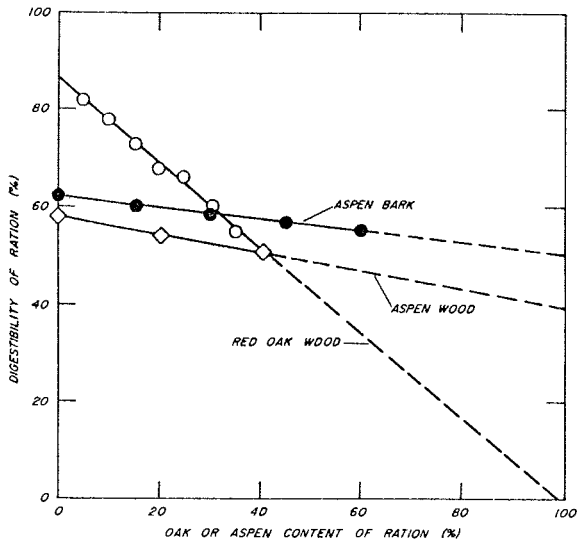

Figure 1. In vivo *digestibility of red oak and aspen wood and aspen bark*

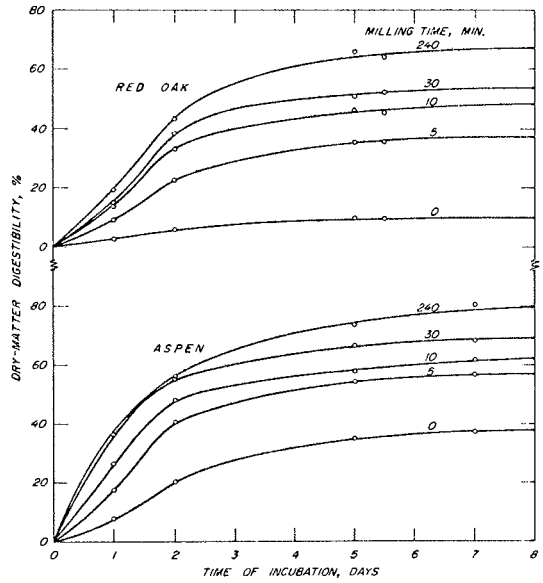

Figure 2. Relation of in vitro *rumen digestibility of red oak and aspen to time of* in vitro *rumen incubation and extent of vibratory ball milling*

responses when fed to ruminants, when digestibility in fact has been decreased. Insufficient residence time in the rumen has been postulated as the cause of the lowered digestibility of finely ground feeds.

Treatment with Anhydrous Liquid Ammonia. As shown in Table III, treatment of aspen sawdust with anhydrous liquid or gaseous ammonia provided a substantial increase in *in vitro* digestibility, raising it to approximately that of hay. There is no significant difference in the digestibilities between the two types of treatment. The effect is rapid; a 1/2-hour treatment with gaseous ammonia at 30° C. yielded the same digestibility value as a 73-hour treatment.

On the basis of X-ray diffraction measurements, total crystalline content was probably not altered sppreciably, but it has been shown that treatment with liquid ammonia causes a phase change from cellulose I to cellulose III (27). Since digestibility of aspen wood was increased to more than 50% with liquid ammonia treatment, support is given the idea that the pertinent action of the treatment is the ammonolysis of cross links of glucuronic acid esters (28).

Hardwoods which have been treated with liquid ammonia and air dried have a markedly increased swelling capacity in water (29). This swelling action provides greater access to the structural carbohydrates by rumen bacteria and their associated enzymes. An additional nutritive benefit is the increased nitrogen content of the ammoniated product through formation of amides and ammonium salts by reaction with the acetyl and uronic acid ester groups of the wood. Kjeldahl analysis of ammoniated aspen showed 9% crude protein compared to 0.5% for untreated wood. Aspen appears to be unique in its digestibility response to ammoniation. The digestibilities of ammonia-treated spruce and red oak were 2% and 7-10%, respectively.

Air-dried aspen sawdust, hammermilled to pass through a screen plate with 1/16-inch-diameter holes, was treated with gaseous anhydrous ammonia and fed to goats in rations containing increasing amounts up to 50% treated aspen. The treatment was done in batches in a 13-cubic-foot rotating digester. The digester, containing the wood, was evacuated to 20 in. Hg for 20 min. and then pressurized to 70 lb. in.$^{-2}$ with anhydrous ammonia for 2 hours. During pressurization, temperature of the wood increased rapidly from 30° C. to a maximum observed temperature of 74° C. and then decreased to 55° C. The decrease was due to heat loss to the metal digester and to the air. It was calculated that the observed temperature rise could have been caused by the heat of reaction of ammonia dissolving in moisture present in the wood. No neutralization of free or adsorbed ammonia on the product was attempted. Ammonia smell from the product was not noticeable after airing the product on the floor for 1 week.

Table III

in vitro Rumen Digestibility of Aspen Sawdust Exposed to Anhydrous Liquid and Gaseous Ammonia

Treatment[a]		
Chemical	Time	Digestibility
	hr	%
Control	--	33
Liquid NH_3	1	51
Gaseous NH_3	1/2	48
	2-1/2	47
	16	46
	73	46

[a]At 30° C.

Table IV

Effect of Alkali Treatment on the *in vitro* Rumen Digestibility of Various Hardwoods

Species	Yield	Control	Treated[a]
	%	%	%
Trembling aspen	87	33	55
Bigtooth aspen	90	31	49
Black ash	91	17	36
American basswood	89	5	55
White birch	92	8	38
Yellow birch	94	6	19
Eastern cottonwood	93	4	11
American elm	93	8	14
Soft maple	92	20	41
Red oak	94	3	14
White oak	90	4	20

[a]5-g wood treated for 1 hr with 100 ml of 1% NaOH, washed to neutrality, and dried.

A digestion trial with goats, as was done with aspen bark, indicated an extrapolated *in vivo* dry-matter digestibility of 50%.

Treatment with Aqueous Sodium Hydroxide. The results of *in vitro* rumen digestion show a range of response to the alkali treatment for the various species investigated (Table IV). Aspen and basswood, attaining a digestibility of 55%, are outstanding in their response to alkali pretreatment. The tenfold increase for basswood is especially intriguing. Bigtooth aspen is only slightly less digestible than trembling aspen. Black ash, white birch, and soft maple show an intermediate response with digestibilities ranging between 35% and 40%. The other species have digestibilities of less than 20%. Douglas-fir and Sitka spruce, which are softwoods with a maximum *in vitro* digestibility of 1% and 2%, respectively, did not respond to the alkali treatment. The difference in response appears to be related to the lignin content of the treated hardwoods (Figure 4).

To better define conditions for optimum processing, aspen was treated at room temperature with 0.5% and 1.0% solutions of sodium hydroxide at various liquid-to-solid ratios. Then it was washed to neutrality, dried and assayed. The results in Table V show that from 5-6 g. of NaOH per 100 g. of wood are necessary for a maximum effect on *in vitro* digestibility. This was attained with a 12:1 liquor-to-wood ratio at the 0.5% alkali level or a 6:1 ratio with 1% alkali. It is interesting that the minimum quantity of sodium hydroxide needed for attaining maximum digestibility is roughly equivalent stoichiometrically to the combined acetyl and carboxyl content of the aspen. The main consequence of alkali treatment thus appears to be the breaking (by saponification) of intermolecular ester bonds (28,30). Rupture of these cross links promotes the swelling of wood in water beyond normal water-swollen dimensions; thus it favors increased enzymatic and microbiological penetration into the fine structure of wood. At optimum conditions (6 g. NaOH to 100 g. wood) the yield is about 95%. The 5% loss in weight is caused by saponification and removal of acetyl groups during the water wash.

Treatment with Sulfur Dioxide. It was found that gaseous sulfur dioxide can disrupt the lignin-carbohydrate association *in situ* and yield a product of high digestibility without physical removal of the lignin. Wood in the form of sawdust was reacted for 2 hours (hardwoods) or 3 hours (softwoods) at 120° C. with an initial SO_2 pressure at room temperature of 30 lb. in.$^{-2}$ and a water-to-wood ratio of 3:1 (no free liquid). After blowdown and a brief evacuation to remove adsorbed SO_2, the treated woods were neutralized to about pH 7 with sodium hydroxide and then air dried. Table VI presents analytical data and values for 48-hour cellulase digestion for both the original woods and

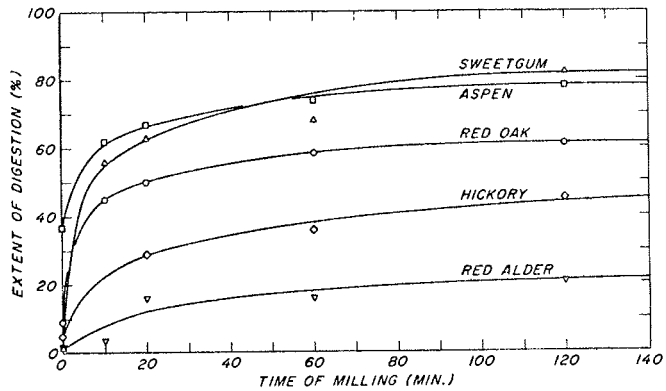

Figure 3. Relationship between in vitro *rumen digestibility and time of vibratory ball milling*

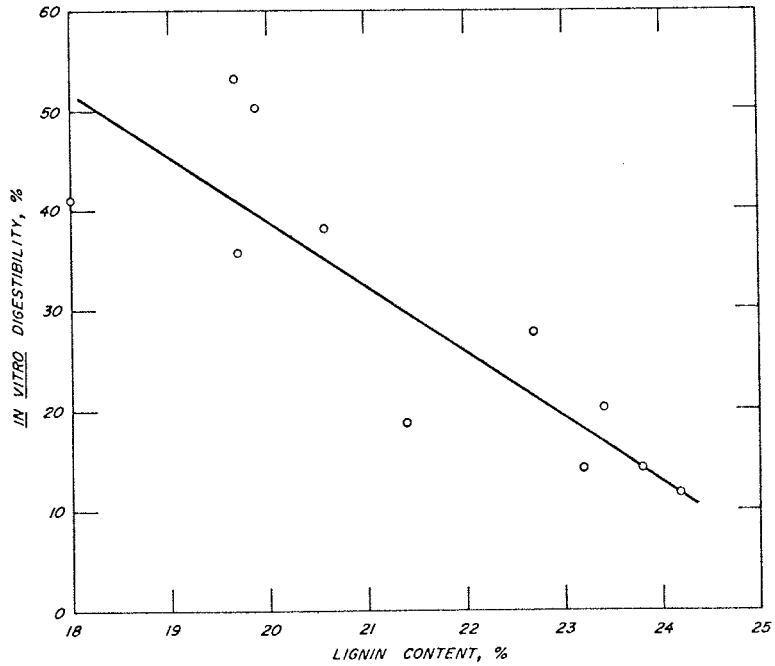

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Figure 4. Relationship between lignin content and in vitro *digestibility for NaOH treated hardwoods* (30)

Table V

Effect of Alkali Treatment Variables on the *in vitro* Dry-Matter Digestibility of Aspen

NaOH concen-tration	Ratio of solution to wood	NaOH per 100 g wood	Treating time	Yield	Digestibility
%		gm	hr	%	%
0	0	0	0	100	37
0.5	4:1	2	2	98	47
	8:1	4	2	98	50
	12:1	6	2	95	55
	16:1	8	2	93	53
1.0	2:1	2	1	98	41
	4:1	4	1	96	48
	6:1	6	1	95	51
	8:1	8	1	94	50
	10:1	10	1	93	54
	20:1	20	1	87	50

Table VI

Composition and Cellulase Digestion of Various Woods

Before and After SO_2 Treatment

Species	Lignin		Carbohydrate		Digestibility	
	Before	After	Before	After	Before	After
	%					
Quaking aspen	20	7	70	71	9	63
Yellow birch	23	9	66	67	4	65
Sweetgum	20	5	66	64	2	67
Red oak	26	8	62	60	1	60
Douglas-fir	30	24	65	63	0	46
Ponderosa pine	31	19	59	58	0	50
Alfalfa	17	--	51	--	25	--

the treated products. Data for alfalfa is included for comparison.

Cellulase digestion of the original woods was minimal, from a high of 9% for aspen to essentially 0% for the two softwoods. Even with alfalfa, only half of the available carbohydrate was converted to sugars. Yields of the SO_2-treated products were 106-112% based on starting material, a result of the sulfonation and neutralization reactions. Although all of the lignin was retained in the products, Klason lignin analysis of the five treated hardwoods showed lignin values of only 5-9%. This suggested that the original lignin had been extensively depolymerized during SO_2 treatment and converted to soluble products, a fact subsequently confirmed by extraction with boiling water. Depolymerization was less extensive with the two softwoods, and the higher Klason values are reflected by a decreased digestibility. Enzymatic conversion of the hardwood carbohydrates was essentially quantitative, indicative of a complete disruption of the strong lignin-carbohydrate association in the original woods. The 60-65% digestibility of the treated hardwoods is comparable to the digestibility of a high quality hay. The two softwood products would be equivalent to a low quality hay, but might be upgraded through a better choice of processing conditions.

A 140-kg. batch of SO_2-treated material was prepared from red oak sawdust and fed to goats at levels of 0, 20, 35, and 50% of a pelleted forage ration over an 8-week period to obtain information on palatability, possible toxic side effects, and *in vivo* nutritional value. Average *in vivo* digestibilities for dry matter and carbohydrate as a function of wood content of the rations are plotted in Figure 5. Extrapolation of the curves to 100% SO_2-treated wood yielded values of about 52% for dry matter digestion and 60% for carbohydrate digestion. From the shallow slope of the curves, it appears that a vapor phase treatment with sulfur dioxide effectively converts red oak sawdust into a ruminant feedstuff having the digestible energy equivalence of a medium quality hay. Neutralization of the treated product with ammonia rather than sodium hydroxide would augment its protein equivalence.

Treatment with White-Rot Fungi. White-rot fungi decompose lignin as well as cellulose and hemicellulose in wood. Some remove lignin faster than they do the carbohydrates relative to the original percentage of each. The resulting decayed wood has a lower lignin content than that of the original wood.

Nine white-rot fungi were examined for their ability to remove lignin faster than polysaccharides from aspen and birch wood. During decay most of the fungi decreased the lignin content of the wood; that is, they removed a larger percentage of the lignin than of polysaccharides. Lignin removal was always accompanied by removal of polysaccharides. The decayed woods

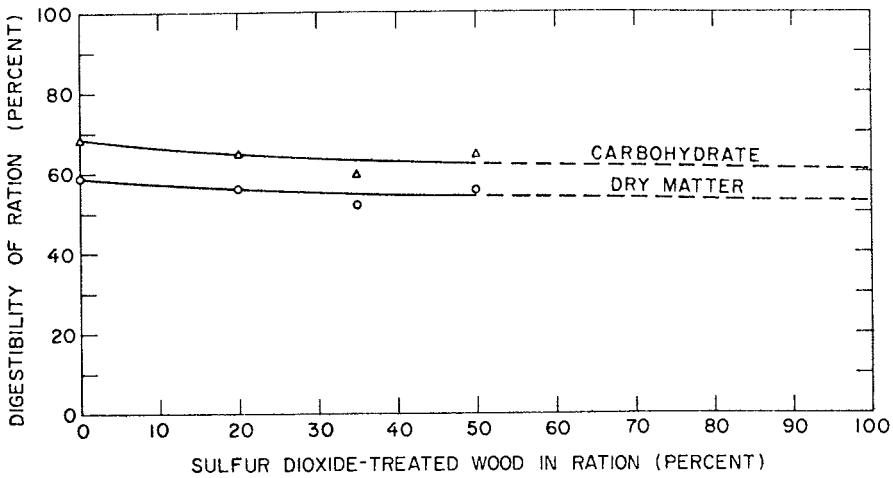

Figure 5. In vivo *dry-matter digestion of rations containing sulfur dioxide-treated red oak*

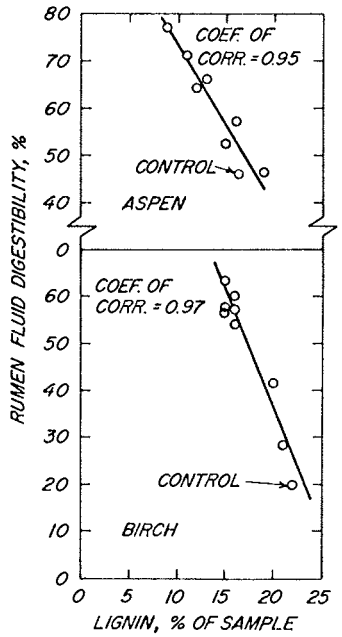

Figure 6. Relationship of in vitro *rumen digestibility to lignin content of white-rotted wood*

have higher *in vitro* rumen digestibility than the untreated wood and digestibility is inversely related to the lignin content as shown in Figure 6.

Pulp and Papermill Residues and Wood Pulp

Effect of Delignification on Digestibility. Lignin appears to be a major obstacle to microbiological attack of wood. Delignification would then seem to be a straightforward approach to making cellulose available to microbes. To obtain information on the effect of method and degree of lignin removal necessary to make various species digestible, a series of kraft pulps having a range of yields and lignin contents were prepared for *in vitro* rumen digestibility determination (31).

Four wood species were included: two hardwoods, paper birch and red oak; and two softwoods, red pine and Douglas-fir. Pulping variables were selected to produce pulps with yields from 40-80% and lignin content from 1-32%. Since hemicellulose is removed more rapidly than lignin during the early stages of pulping, some of the high-yield pulps have a higher percentage of lignin than the original wood.

Data showing the relationship between *in vitro* digestibility and extent of delignification for kraft pulps made from the four species are shown in Figure 7. Extent of delignification is the percent of the lignin removed from the original wood. It is calculated from pulp yield and lignin content of the original wood and the pulp.

Figure 7 shows that an appreciable difference exists in the delignification-digestibility response between hardwoods and softwoods. With the two hardwoods, digestibility increases rapidly with delignification and then approaches a digestibility plateau of about 90% as delignification approaches completion. With the two softwoods, there is a distinct lag phase, especially pronounced with Douglas-fir, during which extensive delignification is accompanied by only minor increases in digestibility. Following this lag phase, digestibility rises rapidly and almost linearly with delignification up to the digestibility maximum.

As interpolated from these four curves, the extent of delignification necessary to obtain a product having an *in vitro* digestibility of 60%, that of a good quality hay, is shown in Table VII along with data on the lignin content of the original woods and lignin content of the pulp. In common with alkali treatment (Figure 4), digestibility response strongly correlates with lignin content, response being measured in terms of the degree of pulping action needed to achieve a specified level of product utilization. Additional support for this lignin dependency was obtained by Saarinen et al. in an investigation of the *in vivo* digestibility of a series of birch and spruce pulps prepared by 10 different pulping techniques (32). Recalculation of

Table VII

Degree of Delignification Required to Attain

60% *in vitro* Digestibility

Wood	Required delignification[a]	Lignin in original wood	Lignin in pulp
	%		
Paper birch	25	20	21
Red oak	35	23	20
Red pine	65	27	14
Douglas-fir	73	32	13

[a]Based on original wood.

their data provided the results shown in Figure 8, which also includes curves for red pine and paper birch from Figure 7 for comparison. In spite of the wide variation in delignification techniques employed by the two investigations, the results are quite comparable. This leads to the further conclusion that it is primarily the degree of delignification that governs pulp digestibility, not the method of pulping.

A similar relationship was encountered with respect to the growth of the fungus Aspergillus fumigatus on a variety of commercial pulps prepared under different conditions (33). As determined by the protein content of the fungal mass, reasonable growth on hardwood could be obtained at lignin contents of 14% or less, whereas fungal growth on softwoods was restricted to pulps having less than 3% residual lignin.

Pulp and Papermill Residues. It is estimated that 80 lb. of fiber residues are generated for each ton of wood pulp that is produced and processed into finished products. Thus, more than 1.7 million tons per year of pulp and papermaking fiber residues are produced annually. Most of these residues have undergone at least partial delignification, which increases the accessibility of the wood carbohydrates to the rumen microorganisms and associated enzyme systems. In search for productive outlets for the fibrous residues, *in vitro* and *in vivo* estimates of digestibility and chemical analysis for lignin, total carbohydrate, and ash constituents were made on representative samples of commercial residues. On selected residues, feeding trials were conducted to observe ewe and beef steer performance (10).

Data for composition and *in vitro* dry matter digestibility of various types of commercially obtained pulpmill residues are given in Table VIII. As expected, groundwood fines yielded digestibility values comparable to those observed for sawdust of the same species--0% for the pine and spruce and about 35% for aspen. All of the listed screen rejects and chemical pulp fines had digestibilities of more than 40%, and digestibility of two of the pulp fines was more than 70%. Thus, based on *in vitro* dry matter digestibility, any of the screen rejects and chemical pulp fines could serve as a useful source of dietary energy for ruminants. The mixed hardwood, kraft bleached chemical pulp fines are essentially pure cellulose.

It can be noted in Table VIII that the Klason lignin and the total carbohydrate contents of the aspen groundwood, aspen sulfite screen rejects, and aspen sulfite parenchyma cell fines are almost identical, whereas the *in vitro* dry matter digestibility ranges from 37-73%. The digestibility of fines of aspen parenchyma cells, for example, is higher than would be predicted on the basis of lignin content because the parenchyma cells contain substances that analyze as lignin. Microscopic examination

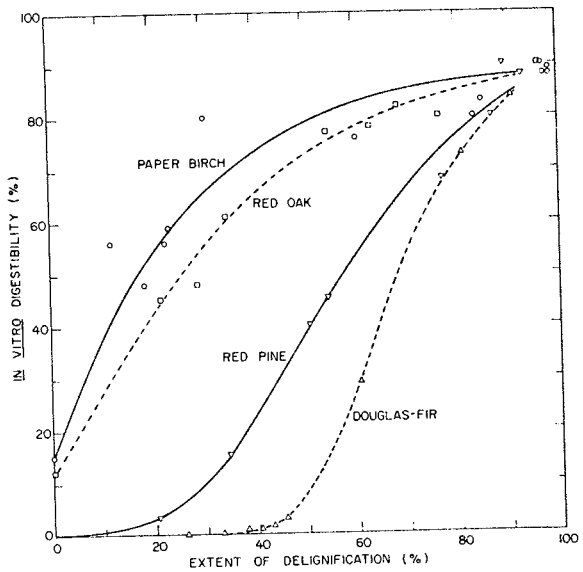

Figure 7. Relationship between in vitro *digestibility and extent of delignification for kraft pulps made from four wood species*

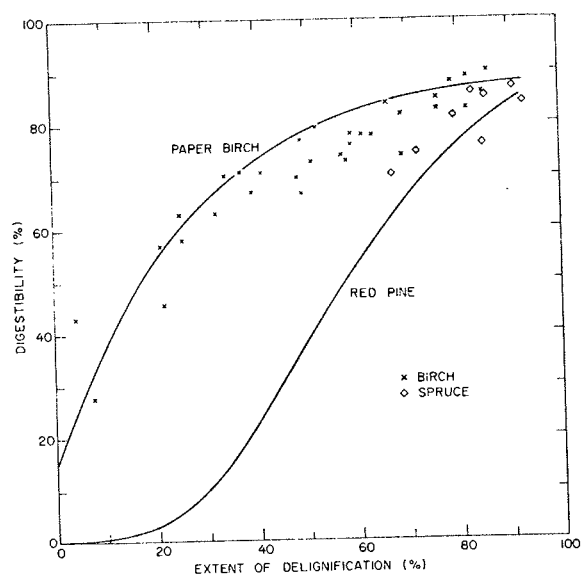

Figure 8. Relationship between digestibility and extent of delignification for wood pulps. (Data points from Saarinen, et al. *(32). Curves from Figure 7.)*

Table VIII

Composition and *in vitro* Rumen Digestibility of Pulpmill Residues

Type of residue	Lignin	Carbo-hydrate	Ash	Digesti-bility
	- - - - - - - - -	%	- - - - - - - - -	
Groundwood fines				
Aspen	21	73	1	37
Southern pine	31	59	1	0
Spruce	31	60	1	0
Screen rejects				
Aspen sulfite	19	77	2	66
Mixed hardwood, sulfite	24	65	14	54
Mixed hardwood, kraft	25	74	9	44
Chemical pulp fines				
Mixed hardwood, kraft (bleached)	<1	109	1	95
Aspen sulfite (parenchyma cells)	20	73	2	73
Southern pine, kraft (unbleached)	28	68	4	46

Table IX

Composition and *in vitro* Rumen Digestibility of Combined Pulp and Paper Mill Sludges

Type of residue	Lignin	Carbo-hydrate	Ash	Digesti-bility
	%			
Groundwood mill				
Mixed species + mixed chemical pulps	50	41	38	24
Southern pine + mixed hardwood kraft	24	60	15	19
Semichemical pulpmill				
Aspen	20	71	2	57
Aspen + mixed hardwoods	55	29	13	6
Chemical pulpmill				
Deinked waste paper, tissue	23	71	22	72
Milk carton stock	28	67	25	65
Mixed chemical pulps, tissue	17	76	13	60
Aspen and spruce sulfite	45	46	45	35

of these fines showed the presence of large quantities of dark resin-like globules. Successive extraction of these fines with ethanol and ethanol-benzene (1/2; v/v) removed more than 15% of the sample. Klason lignin content after extraction was 8.4%.

The digestibilities of the southern pine unbleached kraft pulp fines are also higher than would be predicted on the basis of lignin content. Southern pine wood and the unbleached pulp also contain substances that could analyze as lignin.

Table IX shows the composition and the *in vitro* dry matter digestibility of various combined pulpmill and papermill primary clarifier or lagoon sludges. Because the groundwood mill sludges are mostly groundwood fiber, the digestibility is expected to be low although the total carbohydrate content is high. The digestibility of this type of sludge will increase as the amount of chemical pulp fiber increases in the sludge. One of the semichemical pulpmill sludges was high in digestibility and total carbohydrate and low in ash, but the other was low in digestibility and total carbohydrate. This indicates the amount of variation that can be expected between mills that use the same pulping process. The digestibility of the other residues ranged from 35-72% with ash contents ranging from 13-45%.

The Klason lignin results also include acid-insoluble paper additives (ash) as lignin. Errors in the lignin analysis are evident in the data listed in Table IX for the combined pulpmill and papermill residues that have high ash content.

Composition of the ash from five pulp residues are shown in Table X, with data for aspen wood and alfalfa hay included for comparison. Except for sulfur, the residues generally exhibit lower levels of the elements P, K, Ca, Mg, and Na than does alfalfa. The Ca level in one residue is higher than that of alfalfa; the Na level is higher in two residues. Certain residues have appreciable amounts of Al and Fe. In some cases, water treatment sludges may enter the clarifiers along with the fiber residue. This would increase the levels of Al and Fe. Residue 7 is high in Zn and Mn, and residues 3, 5, and 7 are high in Cu.

A number of sludges have digestibility values comparable to hay. Their suitability for animal feed, however, will depend on the amount of ash and the chemical nature of the individual ash constituents. For example, moderate levels of clay-type filler could be tolerated, but the presence of more than trace amounts of certain heavy metals would rule out use as a feedstuff. Thus each pulp and papermaking residue should be chemically characterized before it can be recommended as a feedstuff.

Four typical residues--screen rejects from the sulfite pulping of aspen, unbleached parenchyma cell fines from an aspen sulfite tissue mill, unbleached fines from a southern pine kraft mill, and bleached fines from a mixed hardwood southern kraft mill--were blended with other ration ingredients, pelleted and fed to goats, sheep, and steers (10). Results from the

Table X

Composition of Ash From Selected Residues, Aspen Wood, and Alfalfa

Ash constituent	Type of residue[a]						
	1	2	3	4	5	6	7
	% [b]						
P	0.003	0.23	0.04	<0.01	0.02	<0.01	0.23
K	.06	2.1	.30	.05	.10	<.02	.10
Ca	.18	1.3	2.6	.70	.60	.21	.28
Mg	.03	.30	.04	.04	.08	<.01	.08
Na	.003	.15	.03	.10	.02	.43	.20
S	--	.30	1.5	1.1	.37	.28	.62
	ppm [b]						
Al	16	--	520	66	670	97	540
Ba	19	--	91	13	32	21	16
Fe	35	200	2,300	63	340	95	350
Sr	10	--	44	13	11	6	16
B	3	--	16	2	4	4	14
Cu	6	13	74	6	40	8	99

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Table X

Composition of Ash From Selected Residues, Aspen Wood, and Alfalfa--continued

Ash constituent	Type of residue[a]						
	1	2	3	4	5	6	7
	ppm[b]						
Zn	19	20	14	6	37	4	330
Mn	10	32	44	2	7	9	330
Cr	.3	--	7	1	5	5	13
	%						
Total ash[b]	0.60	8.0	17.4	2.1	2.1	1.8	3.4

[a]1, aspen wood; 2, alfalfa hay; 3, mixed hardwood sulfite screen rejects; 4, aspen sulfite screen rejects; 5, aspen sulfite parenchyma cell fines; 6, mixed hardwood sulfite pulp fines; and 7, southern pine unbleached kraft pulp fines.

[b]Based on moisture-free sample.

(Page 2 of 2)

digestibility trials indicate that the *in vivo* dry matter digestibilities are 58, 52, 47, and 78%, respectively. This indicates substantial utilization of the carbohydrate constituents.

The rumen contents of steers fed unbleached southern pine kraft mill fines and steers fed a control ration containing no pulp fines were analyzed for pH, ammonia, volatile fatty acids, and microbial population. No significant differences could be observed between the rumen contents of steers on the control ration and those on the experimental rations.

Steers averaging 226 kg., fed a ration containing 50% unbleached southern pine kraft mill fines, gained 0.5 kg. per day during a 58-day growth trial. During another growth trial, steers averaging 221 kg. were fed a ration containing 75% parenchyma cell fines. These steers gained an average of 0.45 kg. per day during 101 days. These weight gains are not high but they are acceptable wintering growth rates. Feed efficiencies for the two experiments were 11.7 and 16.9 kg. feed per kg. gain.

Rations containing 60% and 75% parenchyma cell fines have been fed to ewes and beef cows with good results. Ewes fed pelleted rations containing 75% fines for one year, and supplemented with additional grain during the last month of pregnancy and during lactation, produced as much wool and weaned as many lambs as did a hay fed control group. Ewes fed a similar ration containing aspen bark in place of pulp fines performed equally as well. Total feed consumption was higher for the groups fed pulp fines and aspen bark reflecting a slightly lower digestibility of these materials compared to hay.

Beef cows fed 2-3 kg. of hay plus a mixture of parenchyma cell fines and grain (83% fines and 17% of grain and mineral supplement) for a period of about 7 months appeared normal in every respect. Palatability of the pulp fines mixture was good.

Summary

The roughage qualities of wood in ruminant rations have been evaluated and compared to other roughages. Wood has been shown to be effective as a roughage replacement. Depending upon the other ration ingredients, concentrations of 5-15% screened sawdust in rations for beef cattle appears practical. For lactating dairy cows, aspen sawdust could be used as a roughage extender or as a partial roughage substitute in high grain rations. Some long hay appears to be necessary in the ration to stabilize feed intake.

The potential of wood and bark, chemically and physically treated wood, and pulp and papermaking residues as energy sources in ruminant rations has been examined by chemical analysis and *in vitro* and *in vivo* methods. *In vitro* rumen and enzyme methods were developed to assay wood-based materials for digestibility.

Of the woods tested, all of the coniferous species are essentially undigested by rumen micro-organisms. Deciduous species, with a few exceptions, are only slightly digested. Aspen is the most highly digestible species tested, giving both an *in vitro* and *in vivo* digestibility of about 35%. Aspen bark is about 50% digestible. The resistance to micro-organisms appears to be related to the lignin-carbohydrate complex and the crystallinity of the cellulose.

The coniferous species and most deciduous species were quite resistant to vibratory ball milling, electron irradiation, dilute alkali, and liquid ammonia treatments to increase digestibility. Treatment with gaseous sulfur dioxide appears especially interesting as a way to increase the digestibility of wood. Since no water is added and the product is not washed, yields of over 100% are obtained. The product was accepted by animals during digestion trials.

Delignification of wood by normal wood pulping methods produces materials with high rumen digestibility. It was shown that the digestibility of deciduous species increases rapidly compared to coniferous species as lignin is removed. It was also shown that digestibility depends upon the extent of lignin removal and not upon the method of lignin removal.

Pulp and papermaking residues were analyzed for lignin, carbohydrate, rumen digestibility, ash, and ash constituents. *In vitro* rumen digestibility of many of the residues ranged from 45-60%; some attained levels as high as 90%. *In vivo* digestibilities of four typical pulpmill residues ranged between 47 and 78%, and were in reasonable agreement with the *in vitro* values. Certain residues appear suitable as feed ingredients while others are not suitable because they contain high amounts of ash or contain ash with high concentrations of heavy metal contaminants.

Pulp fines, constituting 50-75% of the ration for steers, ewes, and beef cows were readily consumed. Steer growth rates of approximately 0.5 kg. per day were obtained. Ewes and cows were maintained at an adequate level of nutrition so normal reproduction occurred and growth of nursing offspring was normal. Total feed consumption tended to be higher with the groups fed wood residues, reflecting the slightly lower digestibility of these materials compared to hay.

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