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PULP AND PAPERMAKING RESIDUES AS FEEDSTUFFS FOR RUMINANTS

M. A. Millett,[1] *A. J, Baker,*[1] *L. D. Satter,*[2] *J. N. McGovern* [3] *and D. A. Dinius* [4,5]
U.S. Department of Agriculture and University of Wisconsin, Madison 53705

Summary

IN a search for a more productive outlet for the fibrous residues generated during commercial pulp and paper operations, representative residues were screened for their potential as feedstuffs for ruminants, In vitro rumen digestibilities of many of the residues ranged from 45 to 60% ; some attained levels as high as 90%. Analytical data for Klason lignin, total carbohydrate, and ash constituents were also obtained.

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 obtained in sufficient quantity for feeding trials with goats, sheep, and steers. The residues were blended with other ration ingredients, and pelleted. *In vivo* digestibilities for the four residues are estimated to be 58, 52, 47 and 78%, respectively, indicative of substantial utilization of the available carbohydrate constituents. A ration containing 77.4% parenchyma cell fines adequately maintained ewes for 2.5 months, and had good acceptability.

Steers were fed rations containing 0 and 50% unbleached southern pine kraft pulp fines ad libitum for 58 days. Average daily gain was 0.77 and 0.54 kg, daily feed intake as a percent of body weight was 2.84 and 2.48, and feed/gain ratio was 9.44 and 11.69 for the 0 and 50% pulp rations, respectively. Rumen pH, ammonia, and volatile fatty acid ranged from 6.4 (0 pulp ration) to 6.6 (65% pulp ration), 17 (65% pulp ration) to 24 mg/100 ml (0 and 20% pulp ration), and 44 (0 and 35% pulp ration) to 83 mm/1 (50% pulp), respectively. Neither these parameters nor microbe populations were different ($P < .05$) from simultaneously sampled control steers.

Introduction

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. Improved technology is expected to decrease that rate of residue from new pulp processing, but the increased use of recycled pulp will increase the rate of residue production. Where using these residues as a boiler fuel is not feasible, disposal by burning or as landfill is common practice. Although these are expedient disposal methods, they are not ecologically satisfactory solutions. The residues are a potentially valuable source of carbohydrate.

Most pulp and papermaking residues have undergone at least partial delignification, which increases the accessibility of the wood carbohydrates to rumen micro-organisms and their associated enzyme systems. Bleached chemical pulp fines should be highly digestible by ruminants. The purpose of this investigation, therefore, was to estimate the nutritive value of representative samples of commercial pulpmill and papermill residues in ruminant rations. Therefore, *in vitro* and *in vivo* estimates of digestibility were 'made, and investigation of ewe and beef steer performance were conducted.

Experimental Procedure

In Vitro Digestibility. Assays of dry matter digestibility of all residues were conducted by the in vitro rumen method of Mellenberger *et al.* (1970). Results are reported by weight loss after 5 days of incubation at 39C.

[1] Forest Products Laboratory. Forest Service. The Laboratory is maintained at Madison (N. Walnut Street. 53705) io cooperation with the University of Wisconsin, Madison.
[2] Department of Dairy Science, Madison.
[3] Department of Forestry. Madison.
[4] Nutrition Institute, Ruminant Nutrition Laboratory, Agricultural Research Service, Beltsville, Md. 20705.
[5] Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the U.S. Department of Agriculture. The authors thank Robert Lana and Bill Van Loo, University of Wisconsin Dairy Science Department: Marilyn Effland, Jean Wipperman, and Lester Zank, Forest Products Laboratory: and Donna Kern and Ed Williams, Ruminant Nutrition: for their technical assistance.

Goat Digestion Trials. Each of three selected pulpmill residues was dried and blended with other ration ingredients to form three sets of rations each containing 0, 20, 35 or 50% pulp residue (table 1). The pulp residues selected for feeding studies were: (1) Aspen sulfite screen rejects from mill 2; (2) chemical pulp fines—parenchyma cells, aspen sulfite (unbleached); and (3) chemical pulp fines—mixed hardwood, kraft (bleached). As shown in table 2, these materials had *in vitro* digestibilities of 66, 73 and 95%, respectively. Residues 1 and 3 were obtained wet (about 65% water) and were air-dried prior to blending with the ration ingredients. In addition, residue 3 was hammermilled, without a screen, after drying to break up large fiber clumps. Residue 2 had been dried to 28% moisture content at the mill in a Rietz dryer preparatory to disposal by burning. This material was granular, and required no hammermilling. All the rations were fed in the form of 5-mm-diameter pellets.

The rations were fed to four Saanen goats weighing 40 to 50 kg each at the rate of 2% of body weight. The 0% pulp residue ration was fed first; then, in succession, the higher pulp-containing rations. Each ration was fed for 2 weeks, with the first week being an adjustment period and the second a period of collecting feces. A 10% aliquot of feces was obtained daily, and composited. The composite sample was used for analyzing dry matter and carbohydrate content.

Steer Digestion Trial. A steer digestion trial was conducted with chemical pulp fines—southern pine, kraft (unbleached, mill 5), air-dried and blended with ration ingredients at levels of 0, 20, 35, 50 and 65% as shown in table 1, then pelleted into 17-mm-diameter pellets. All of the rations contained 14.2% crude protein. Each of the rations was fed to four steers (200-kg yearling Herefords) at 2.5% of body weight in the same sequence as used in the goat studies. Following a 13-day period for adjusting to each ration, feces were collected daily for the next 7-day period. Feces from each animal were mixed, and a 5% aliquot held for analysis. At the end of the period, the aliquots were combined to give a composite sample for each steer. Fecal dry matter was determined as the average of duplicate 5-g samples from the blended composite.

Four additional Hereford steers were maintained on the control ration (table 1, 0% pulp) for the duration of the experiment, and were housed in individual pens adjacent to the steers that were used for determining digestibility. Samples of rumen contents were taken via stomach tube from all eight steers on each of the last 2 days of each collection period. Thus, statistical comparisons of rumen data could be made between sets of animals being fed the control and the experimental diet during this 2-day period as well as those steers being fed the treatment diets throughout the experiment. Rumen contents were analyzed for pH, ammonia, volatile fatty acids and microbial populations. The populations were determined by direct count of protozoal types and of total bacteria and by morphological and gram-stain differentiation of bacteria (Slyter, Nelson and Wolin, 1964).

Steer Growth Trial. Ten Hereford steers averaging 226 kg were randomly assigned

TABLE 1. COMPOSITION OF RATIONS USED IN GOAT AND STEER DIGESTION TRIALS

	Goat rations[a]				Steer rations[b]				
	Pulp content[c]				Pulp content[d]				
Ingredient	0	20	35	50	0	20	35	50	65
	%								
Pulp residue	0	20	35	50	0	20	35	50	65
Alfalfa meal	87	65.7	41.8	21.1	..	..	..	..	..
Timothy hay	..	..	..	..	72	52	37	22	7
Cracked, shelled corn	5	5	5.7	5.3	15	10.5	7	3.5	0
Soybean oil meal	1	2	10	16	5	9.5	13	16.5	20
Molasses	5	5	5	5	5	5	5	5	5
Urea	0	0.3	0.5	0.6	1	1	1	1	1
Trace mineralized salt	1	1	1	1	1	1	1	1	1
Dicalcium phosphate	1	1	1	1	1	1	1	1	1

[a] Each ration was supplemented with 2,200 IU each of vitamins A & D, and 0.2 IU of vitamin E per kilogram of feed.
[b] Each ration was supplemented with 1,000 IU of vitamin A and 250 IU of vitamin D per kilogram of feed.
[c] Three types of pulp residues were used at each of these levels: (1) screen rejects of aspen sulfite pulp from mill 2, (2) chemical pulp fines of unbleached aspen sulfite pulp consisting principally of parenchyma cells, and (3) chemical pulp fines of bleached mired hardwood kraft pulp.
[d] Chemical pulp fines, southern pine. kraft (unbleached, mill 5).

TABLE 2. COMPOSITION AND *IN VITRO* DRY MATTER DIGESTIBILITY OF PULPMILL RESIDUES

Type of residue	Klason lignin[a]	Total carbohydrate	Ash	*In vitro* dry matter digestibility
	%			
Groundwood fines				
Aspen	21	73	1	37
Southern pine	31	59	1	0
Spruce	31	60	1	0
Screen rejects				
Aspen, sulfite (mill 2)	19	77	2	66
Aspen, sulfite (mill 4)	20	72	1	64
Aspen, sulfite (knotter rejects, mill 2)	24	69	2	58
Mixed hardwood, sulfite (mill 1)	24	65	14	54
Aspen and spruce, sulfite (mill 3)	19	76	1	47
Mixed southern hardwoods, kraft (mill 5)	25	74	9	44
Chemical pulp fines				
Mixed hardwood, kraft (bleached)	<1	109	1	95
Mixed hardwood, sulfite (unbleached)	6	89	2	90
Hemlock, sulfite, parenchyma cells, (unbleached)	9	92	2	75
Aspen, sulfite, parenchyma cells, (unbleached)	20	73	2	73
Southern pine, kraft (unbleached, mill 5)	22	75	5	53
Southern pine, kraft (unbleached, mill 6)	28	68	4	46

[a] Includes ash not soluble in H_2SO_4.

either to the 0% pulp or the 50% pulp rations (table 1), and individually fed *ad libitum* for 58 days. The diets were fed in meal form, and fresh feed was offered once daily. The refused feed was removed weekly. The steers were weighed on 2 consecutive days at the start and the end of the feeding trial to measure gain in weight.

Ewe Acceptance Trial. A study was conducted to determine how the animals accepted a ration with a high level of aspen sulfite parenchyma cells (unbleached chemical pulp fines). Thirty nonpregnant ewes whose lambs were weaned about 1 month before the start of the experiment were fed for 77 days a ration of 77.470 pulp fines, 9% soybean meal, 9% cracked-shelled corn, 2% urea, 1% each of dicalcium phosphate and trace mineral salt and 0.5% Na_2SO_4. Each ration was supplemented with 2,200 IU each of vitamins A and D and 0.2 IU of vitamin E/kg/feed. The moisture content of the pulp fines was high; thus the dry matter content of the complete ration averaged between 72 to 80%. Dry matter intake increased from 1.5 kg/ewe/day at the start of the experiment to l.8/kg/ewe/day toward the end. The amount of feed offered was adjusted so feed would be consumed by the next feeding. The feed consumed, therefore, approached but was not quite equal to *ad libitum* intake. Body weights were determined at the beginning and at the end of the experiment.

Chemical Analyses. Klason lignin values were determined by a modification of TAPPI Standard Method T 22 M-54 (Technical Association of the Pulp and Paper Industry, 1971), in which 0.3 g of sample was macerated with 3 ml of 72% sulfuric acid for 1 hr. at 30C, diluted with 84 ml of water, autoclaved at 120C for 1 hr., filtered on a tared Gooch crucible with an asbestos pad, washed with 250 ml hot water, air-dried overnight, vacuum-dried 4 hr. at 65 C, and weighed. The insoluble material remaining in the crucible, expressed as a percentage of the initial oven-dry sample, is reported as Klason lignin.

The filtrate from lignin analysis, which contains all of the pulp carbohydrates as simple sugars, was diluted to 2 liters, neutralized with calcium carbonate, and filtered. Triplicate 0.75-ml aliquots of this solution were analyzed for total reducing sugars by Nelson's modification of the Somogyi method (Nelson, 1944). Results were calculated as weight percent glucose based on the original sample and reported as total carbohydrate.

Total ash was determined by TAPPI Standard Method T 2 11 M-58 (Technical Association of the Pulp and Paper Industry, 1971). For a limited number of samples, the total ash was analyzed for 14 elements by atomic absorption techniques (Christensen, Beckman and Birdsall, 1968). Sulfur was analyzed by an X-ray fluorescence method (Phifer, 1969); rumen volatile fatty acids, by a gas chroma-

tography method (Baumgardt, 1964); ammonia, by the Conway method (Conway, 1950); and energy, with a bomb calorimeter (Parr Instrument Co., 1948).

Results and Discussion

Composition and In Vitro Digestibility of Pulp Residues. Data for composition and in vitro dry matter digestibility of various types of commercially obtained pulpmill wastes are given in table 2. As expected, the fully lignified groundwood fines yielded digestibility values comparable to those observed for sawdust of the same species—60 for the pine and spruce and about 35% for aspen.

Disruption of the lignin-cellulose matrix of wood by chemical pulping leads to an impressive enhancement of dry matter digestion. All of the listed screen rejects and chemical pulp fines show digestibilities of more than 40%. The digestibility of four of the pulp fines is 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 2 that the Klason lignin and the total carbohydrate contents of the aspen groundwood, aspen sulfite screen rejects, and aspen sulfite parenchyma cell fines we almost identical, whereas the in vitro dry matter digestibility ranges from 37 to 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 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%.

Table 3 shows the composition and the *in vitro* dry matter digestibility for 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 pulp mill 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. For the chemical pulp mill sludges, the 5% digestibility of the secondary waste treatment sludge and the low total carbohydrate content show that the secondary treatment process consumed most of the available carbohydrate. The digestibility of the others ranged from 35 to 72% with ash contents ranging from 2 to 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 3 for the combined

TABLE 3. COMPOSITION AND *IN VITRO* DRY MATTER DIGESTIBILITY OF COMBINED PULPMILL AND PAPERMILL SLUDGES

Type of residue	Klason lignin [a]	Total carbohydrate	Ash	*In vitro* dry matter digestibility
	%			
Groundwood mill				
Mixed species plus some mixed chemical pulps	50	41	38	24
Southern pine plus some hardwood kraft	24	60	15	19
Semichemical pulp mill				
Aspen	20	71	2	57
Aspen plus mixed hardwoods	55	29	13	6
Chemical pulp mill				
Deinked wastepaper, tissue	23	71	22	72
Softwood sulfite, glassine	13	74	14	66
Reprocessed milk carton stock	28	67	25	65
Mixed chemical pulps, tissue	17	76	13	60
Mixed hardwood bleached kraft, printing	17	75	11	59
Aspen sulfite, tissue	19	77	2	50
Aspen and spruce sulfite, tissue	45	46	45	35
Secondary waste treatment sludge	38	5	45	5

[a] Includes ash not soluble in H_2SO_4.

pulpmill and papermill residues that have high ash content. Corrections can be made by determining the ash content of the lignin residue. The nutritive value of various papers and selected wastepaper has been estimated by Mertens and Van Soest (1971) and Mertens *et al.* (1971). They reported ash content from 0% to 29%, permanganate lignin content from 3% to 30% and in vitro dry matter digestibility of 27% to 98%. The digestibility was negatively related to lignin content.

Composition of the ash from five pulp residues are shown in table 4, with data for aspen wood and alfalfa hay (National Research Council, 1971) 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 AI 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 equal to medium- to high-quality hay. Their suitability for animal feed use, however, will depend on the amount of ash and the chemical nature of the individual ash constituents. For example, although moderate levels of clay-type filler could be tolerated, 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.

The analysis of ash for elements in 38 paper samples showed that the concentration of some elements varied by several orders of magnitude; it was indicated that the unusual concentrations of elements could be a problem if paper is fed to ruminants (Mertens and Van Soest, 1971).

Goat Digestion Trials. Data for dry matter and carbohydrate digestibility are listed in table 5 for each dietary level of pulp in each of the three selected residues. The data for dry matter digestion are plotted in figure 1.

For the screen rejects rations, the dry matter and the carbohydrate digestibility increases slightly with increasing concentration of screen rejects. Extrapolation of the data as shown in figure 1 to 100% pulp residue in the ration yields a value of 66% for dry matter digestibility. The in vitro digestibility shown in table 2 is also 66%. Similar extrapolation of the carbohydrate data yields a value of about 80% for digestibility of carbohydrate.

The screen rejects have a dry matter digestibility about equal to that of good-quality hay, and the available carbohydrate appar-

TABLE 4 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	0.06	2.1	0.30	0.05	0.10	<.02	0.10
Ca	0.18	1.3	2.6	0.70	0.60	0.21	0.28
Mg	0.03	0.30	0.04	0.04	0.08	<.01	0.08
Na	0.003	0.15	0.03	0.10	0.02	0.43	0.20
S	....	0.30	1.5	1.1	0.37	0.28	0.62
	Parts per million [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
Zn	19	20	14	6	37	4	330
Mn	10	32	44	2	7	9	330
Cr	0.3	..	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 (mill 1); 4, aspen sulfite screen rejects (mill 2); 5, aspen sulfite parenchyma cell fines (unbleached); 6, mixed hardwood sulfite pulp fines (unbleached); and 7, southern pine unbleached kraft pulp fines (mill 5).

[b] Based on moisture-free sample.

TABLE 5. DIGESTIBILITY BY GOATS OF RATIONS CONTAINING PULPMILL RESIDUES

% pulp in ration	Aspen sulfite screen rejects		Aspen sulfite parenchyma fines		Hardwood kraft bleached pulp fines	
	Dry matter	Carbo-hydrate	Dry matter	Carbo-hydrate	Dry matter	Carbo-hydrate
	%					
0	59.9	66.8	53	58.5	58.7	64.2
20	57.7	69.1	55.7	64.4	71.9	81.6
35	62.7	77.9	54.4	61.2	77.8	87.2
50	64.2	77.7	50.0	54.5	78.0	86.3

ently is readily digestible. Since the rejects are screened out because they are not completely pulped and defibrated, they are somewhat coarse and may also function ai roughage.

For the rations containing parenchyma fines, data for the dry matter and carbohydrate digestibilities show considerable scatter, but have a downward trend with increasing concentration of fines. Extrapolating the curve in figure 1 yields a value of about 50% for dry matter digestibility at 100% lines in the ration compared to an *in vitro* value of 73%. Extrapolating the carbohydrate digestibility data yields a value of 58% for carbohydrate digestion.

This low *in vivo* dry matter digestibility may be due to particle size. The small particles of dried fines are conglomerates of the very short fibers (0.01 mm) that separate into the fine fibers when wet. Perhaps the fine fibers do not remain in the rumen long enough for complete utilization. It is apparent, however, that these fines do provide the energy equivalent of a low- to medium-quality hay.

For the rations of mixed hardwood kraft fines, the dry matter and the carbohydrate digestibility increases rapidly with increasing

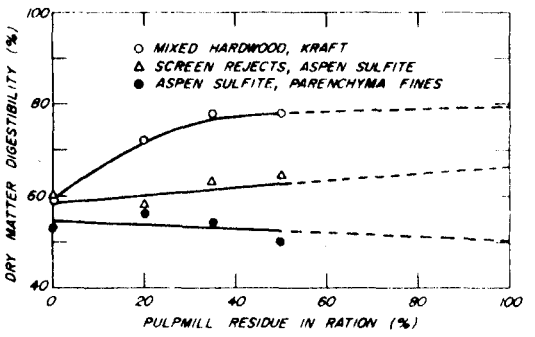

Figure 1. Relationship of digestibility of dry matter by goats to percent of papermill residue in ration.

amounts of fines in the ration. Extrapolation of the data as shown in figure 1, yields a value of 80% dry matter digestibility at 100% lines. An *in vitro* analysis showed 95% digestibility. The data for carbohydrate digestibility extrapolates to 88% at 100% fines These fines are almost pure cellulose.

Saarinen, Jensen and Alhogärri (1959), using rams, determined *in vivo* digestibility of 40 wood pulps produced by various pulping methods. The digestibility ranged from 27% to 90%; it was related to the lignin to cellulose ratio.

Steer Digestion Trial. Digestibilities of the rations used to evaluate southern pine fines of kraft unbleached pulp are given in table 6. Since all rations fed the steers contained 28% concentrate, an alternative method of estimating digestibility can be used. In this method, dry matter digestibility of the pulp fines is determined by linear extrapolation to a point at which pulp fines make up 72% of the ration. This gives an extrapolated digestibility value of 54% for the ration. The digestibility of the concentrate portion (28% of total ration), taken from Morrison (1956) is 82%. Thus, by computation, the amount of digestible dry matter of the pulp fines was 43%. Similar calculations for energy, acid-detergent fiber, and carbohydrate digestibilities gave values of 42, 33 and 58%, respectively. This method is perhaps the method of choice if concentrate makes up a constant proportion of the total ration. The *in vitro* dry matter digestibility of the pulp fines is 53%. Again, as postulated earlier for the aspen parenchyma fines, the lower *in vivo* digestibility of these kraft pulp fines may be due to passage of a portion of the fines through the rumen without bacterial degradation Consumption of the fines did not, however, cause a diarrhetic condition.

Rumen pH (table 6) did not change significantly among the varying percentages of pulp fines or throughout the study did it

TABLE 6 DIGESTIBILITY OF RATIONS CONTAINING FINES[a] AND RUMEN ANALYSIS OF STEER DIGESTION TRIAL

Item	% pulp fines in ration				
	0	20	35	50	65
Digestibility, %					
Dry matter	68.0	66.1	61.9	60.0	53.9
Energy	68.1	64.1	61.0	57.9	54.4
Acid detergent fiber	54.1	56.9	48.2	43.1	40.1
Carbohydrate	71.7	72.8	69.5	64.1	58.6
Rumen analysis					
pH	6.4	6.6	6.5	6.6	6.6
Ammonia, mg/100 ml	23.9	24.4	16.7	19.5	16.6
Total VFA, μmole/ml	43.6[b]	63.1[c]	45.1[b]	83.2[d]	73.3[cd]
Acetate, molar %	66.2	66.7	61.8	64.6	65.8
Propionate, molar %	17.0	20.8	24.7	23.5	25.5
Isobutyrate, molar %	0.8	0.9	0.8	0.6	0.7
Butyrate, molar %	14.6[b]	9.2[cd]	11.1[c]	9.4[cd]	6.7[d]
Isovalerate, molar %	0.5	1.1	0.9	0.8	0.6
Valerate, molar %	0.8	1.3	0.7	1.1	0.6
Acetate/propionate ratio	3.9[b]	3.2[bc]	2.9[c]	2.8[c]	2.6[c]
Acetate/butyrate ratio	4.6[b]	7.4[c]	6.7[c]	7.1[c]	10.0[d]

[a] From southern pine kraft unbleached pulp.
[b, c, d] Means bearing different superscripts differ significantly ($P<.05$).

differ ($P>.05$) from the pH of the steers maintained on the control rations. Ammonia concentrations in the rumen tended to decline, and total volatile fatty acid (VFA) concentrations tended to increase with increasing levels of pulp fines. Total VFA concentration in the rumen of steers maintained on the control ration (data not shown) also tended to increase as the experiment progressed. Thus, since neither total VFA nor ammonia concentrations were significantly different from those of control steers sampled at simultaneous times, it is questionable whether dietary effects should be attributed to the differences among percentage of fines in the rations.

Molar percentages of acetate and propionate in the rumen did not change significantly with increasing levels of pulp fines although there was a tendency for propionate to increase (table 6). The apparent decrease in acetate/propionate ratio with increasing fines is a reflection of the apparent increase in propionate. The molar percentages of butyrate decreased ($P<.05$) with increasing levels of fines and, conversely, the acetate butyrate ratio increased. Actual concentrations of butyrate were not significantly different among rations with pulp fines, a reflection of increased total VFA concentration with decreased molar percentage of butyrate. Rumen butyrate concentration and molar percentage in steers fed 65% fines were significantly lower ($P<.05$) than those of control steers sampled at the same time.

The data for protozoa and bacteria in tables 7 and 8 primarily reflect the variability found in microbe populations of the rumen. The particularly low number of rumen bacteria for steers fed the 20% pulp fines ration corresponds with an almost equally low number (17.1×10^8) of bacteria found in the control steers when sampled at that time. Actually, differences in microbe population were larger between the fines-fed and the control-fed sets of steers when both received the control ration rather than when fed any one of the pulp fines rations. The population of rumen protozoa on all rations remained typical of forage-fed animals, and no detrimental effects on protozoa or bacteria were apparent.

For steers fed 50% and 70% Douglas-fir wood pulp for 70 days, rumen protozoal population was reported as 2.75×10^6 and 5.63×10^6 per milliliter of rumen content, respectively, while for the control steers fed 82% barley, the population was 2.14×10^7/ml (Clarke, Shah and Dyer, 1971). They reported slightly higher bacterial numbers for the control steers but no difference in morphology.

Steer Growth Trial. The five control steers gained significantly more ($P<.05$) than the pulp-fed steers during the 58-day feeding period (table 9). The control animals also tended to consume more feed and to have a lower feed/gain ratio, although the differences between the two groups for these measurements were not significant ($P>.05$). Steers fed the pulp ration tended to sort the ingredients and reject the pulp fines, indicating that the fines may have been unpalatable.

TABLE 7. PROTOZOA POPULATION OF RUMINAL INGESTA FROM STEERS FED VARYING LEVELS OF PULP FINES

Protozoa	% pulp fines in ration				
	0	20	35	50	65
Total protozoa/ml (x 10^{-8})	101.2[ab]	75.5[a]	131.4[b]	94.9[ab]	183.9[c]
Classification (% of total)					
Holotrich					
Isotricha prostoma	0.2	1.1	0.3	0.6	1.8
Isotricha intestinalis	0.2	0.9	0.1	0.3	0.3
Dasytricha ruminatium	1.2	4.1	3.7	2.6	6.2
Entodiniomorph					
Diplodinium	1.4	1.9	0.9	3.2	0.2
Entodinium	7.5[a]	9.6[a]	11.6[ab]	20.7[bc]	30.2[c]
Small entodiniomorph[d]	73.3[a]	64.9[ab]	72.4[a]	57.8[b]	53.3[b]
Large entodiniomorph[e]	3.3	4.2	0.8	5.4	3.0
Entodinium candatum	4.6	4.3	7.1	3.2	1.9
Entodinium dendatum	8.3	8.8	3.1	6.2	0.9
Ophryscolex	0.0	0.2	0.0	0.0	2.2

[a, b, c] Means bearing different superscripts differ significantly ($P<.05$).
[d] Small entodiniomorph were similar in size to the smaller forms of *Entodinium* and *Diplodinium*. However, it was not possible to positively identify the genera to which these organisms belonged; therefore they were grouped separately.
[e] The larger entodiniomorph includes all the larger forms of protozoa not identified as *Entodinium, Diplodinium, Ophryscolex,* or holotrichs.

However, a gain of 0.5 kg/day is an acceptable wintering growth rate. Clarke *et al.* (1971) reported that 332 kg Hereford steers fed 50% and 70% Douglas-fir wood pulp gained 1.44 and 1.36 kg per day during a 70-day finishing experiment. Feed efficiency, in terms of kilogram feed required per kilogram gain, equaled 7.15 and 5.76.

Ewe Acceptance Trial. Ewes accepted the 77% aspen parenchyma cell fines ration well. Dry matter intake increased from 1.5 kg/ewe/day at the start of the experiment to 1.8 kg/ewe/day at the end. Of the 30 ewes, 21 gained and nine lost weight during the experiment. The overall average weight change was 0.056 kg gain/ewe/day.

Due to the small particle size of the pulp fines, the ration was rather dusty. During the experiment, two ewes were diagnosed as having chronic pneumonia; it is possible that the dustiness of the ration may have been the precipitant. Pelleting the ration would probably have eliminated much of the problem.

This experiment was designed to estimate animal acceptability of a ration containing

TABLE 8. BACTERIA POPULATION OF RUMINAL INGESTA FROM' STEERS FED VARYING LEVELS OF PULP FINES

Bacteria	% pulp fines in ration				
	0	20	35	50	65
Total bacteria/ml (x 10^{-8})	39.9[b]	14.5[a]	41.8[b]	45.1[b]	50.6[b]
Morphology (% of total)					
Gram-negative					
Spirilla	0.0	0.0	0.0	0.4	0.0
Straight rods[d]	15.8[a]	20.2[a]	21.9[ab]	17.9[a]	30.2[b]
Curved rods[d]	3.4	4.4	4.9	4.4	8.5
Curved rods[e]	1.5	6.6	8.3	3.0	6.7
Cocci	39.7[bc]	51.1[c]	22.7[a]	35.7[ab]	31.6[ab]
Gram-positive					
Straight rods[f]	14.3	7.5	9.2	8.4	9.4
Straight rods[g]	0.5	0.7	0.0	0.0	0.0
Curved rods	3.1	0.7	0.0	0.0	0.0
Cocci	21.7[bc]	8.6[a]	31.8[c]	29.1[c]	12.0[ab]

[a, b, c] Means bearing different superscripts differ significantly ($P<.05$).
[d] Rods greater than 2 μ in length.
[e] Rods 2 μ or less in length.
[f] Rods greater than 1 μ in length.
[g] Rods 1 μ or less in length.

TABLE 9. GROWTH RATE AND FEED INTAKE OF STEERS FED PULP FINES

Item	% pulp fines in rations	
	0	50
Average daily gain, kg	0.77[a]	0.54[b]
Daily feed intake, % of body weight	2.84	2.48
Feed/gain ratio	9.44	11.69

[a], [b] Means bearing different superscripts differ significantly ($P<.05$).

large amounts of fines. Longer term studies are needed to determine if relatively slow-developing nutritional deficiencies would eventually appear with prolonged feeding of this kind of ration. These ewes were neither pregnant nor lactating; thus their nutritional requirements were minimal. Pregnant or lactating ewes might need a more nutritive ration than could be provided by this formulation.

The relatively high level of copper in the pulp fines (table 4, 40 ppm) is potentially toxic for sheep. No signs of copper toxicity, however, were observed. Longer term studies are necessary to reveal effects of mineral imbalance.

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