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SHORT ROTATION BIOMASS PRODUCED
TREES AS A FEED SOURCE FOR RUMINANTS

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Stephen Robert Baertsche

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Melvin D. Johnson
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THE POTENTIAL UTILIZATION OF SHORT ROTATION BIOMASS PRODUCED TREES AS A FEED SOURCE FOR RUMINANTS

By

STEPHEN ROBERT BAERTSCHE

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ABSTRACT

THE POTENTIAL UTILIZATION OF
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TREES AS A FEED SOURCE FOR RUMINANTS

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Recently, there has been a resurgence in research interest in the potential use of alternative, nonconventional feed sources for animal production. Cellulose is the most abundant energy feed in the world but its full potential is yet to be exploited.

In this study, as examination was made on very short rotation hardwood biomass trees as a potential feed source for ruminants. The specific objectives of this study were to (1) characterize and quantitate the gross chemical composition of rapidly produced tree species (2) quantitate fiber components (celluose, hemicellulose and lignin) (3) to assess the fermentation of these rapidly produced tree species in the rumen by nylon bag technique (4) evaluate dry matter consumption, digestibility, rumen pH, rumen ammonia, VFA profiles and nitrogen balance of poplar biomass vs. alfalfa (5) to evaluate above objectives in terms of differing stages of growth and regrowth.

EXPERIMENT I - CHEMICAL COMPOSITION. The selected chemical analyses indicated that biomass produced trees may be a

nutritious forage source for ruminant animals. Five of the eleven biomass trees averaged over 20% crude protein with the average for all samples being 18.81% crude protein. The estimates of hemicellulose, cellulose, lignin and hemicellulosic sugars indicated that biomass tree samples were generally higher in cellulose, lignin and zylose:arabinose ratios when compared with alfalfa. The mineral contents of the biomass substrates over both harvest periods were comparable with alfalfa in both macro and micro minerals measured. Gross energy values were higher for alfalfa within both the early and late harvest periods. The biomass samples consisting of poplar, honey locust, black locust and aspen were all similar in their gross energy values over both harvests.

EXPERIMENT II - ENSILEMENT STUDY. The fermentation paramenters measured within the ensilement study suggested adequate fermentation and preservation for all samples ensiled except elm, birch and willow which all exhibited significantly higher butyric acid values.

EXPERIMENT III - NYLON BAG DEGRADABILITY. The degradability of samples incubated in the rumen of steers over a 6, 12, and 24 hour period exhibited a higher percentage of sample degraded for the early harvested substrates plus those biomass species which were lowest in lignin within each harvest group. This trend was evident for dry matter, nitrogen, and acid detergent fiber disappearance.

EXPERIMENT IV - INTAKE AND DIGESTIBILITY TRIAL. Within the feeding trial, as the percent of poplar increased from 66.6% to 100%, the intake of dry matter, crude protein, and energy decreased significantly vs. the 100% alfalfa and 33.3% poplar. However, the intake for the 66.6% poplar ration could be considered adequate for dry matter, protein, and energy as this diet was significantly higher ($P < .05$) for intake values than the 100% poplar. The apparent digestibility coefficients suggested that the diets containing poplar were significantly less digestible in dry matter, crude protein, ADF and energy. However, both the 33.3% and 66.6% rations displayed dry matter digestibilities over 60%. Nitrogen retention and retention as percent of total intake were lower in value as the percentage of poplar increased in the diet. Differences in rumen fluid and blood parameters for lambs fed varying levels of poplar tended to be greater for the 100% alfalfa and 33.3% poplar, although no significant differences were reported.

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INTRODUCTION

Demographic projections and world production statistics pessimistically suggest that future food demands cannot be met, unless major advances are made in agricultural technology. Chancellor and Goss (1967), and Hodgson (1974) projected agricultural statistics in the United States for the period 1980-2000 and indicated there must be a two to three fold increase in grain and forage production for the purpose of feeding livestock. With animal agriculture, certain areas of the world have limited production of nutritious roughage or fodder not only in terms of economics but also in procurement (McDaniels and Liebermann, 1979). As a result, there has been a resurgence in research interest in the potential use of alternative, nonconventional feed sources for animal production. Agricultural crop and processing residues, aquatic plants, single cell protein, and recycled animal wastes are among a few of the many resources under investigation. The use of many of these resources, however, has not been without problems, either inherent (i.e. low availability of nutrients) or aquired (i.e. toxicity) (Hintz and Heitman, 1967). In many instances, these by-products must be physically or chemically treated to free the nutrients, or scrutinized for detrimental effects.

While cellulose is the most abundant energy feed in

the world and the ruminant animal is an efficient utilizer of this feedstuff, its full potential has not been extensively exploited (Stone, 1976). Processed whole trees are being fed to cattle in many countries (i.e. United States, U.S.S.R.). However, this procedure has been only marginally successful because mature trees are low in available nutrients due to their high lignin content (Young, 1976; Ievins et al., 1973). In contrast, there has been very little research on the feeding potential of short-rotation rapidly produced trees. The control of the stage of growth and uniform cultivation could improve nutrient content and availability considerably, and with careful selection of species (i.e. leguminous, rapidly growing species), the yields could be comparable to more conventional forages.

Most current research being done on the utilization of trees as an alternative feedstuff for animal production, have utilized either the by-products of the lumbering or wood-pulping industries, and as a result have been marginally successful in demonstrating their potential nutritional value. Probably the largest obstacle in obtaining more desirable production from wood and lumber residues has been that wood itself is not a homogeneous material. Not only are there differences in the composition of the two major wood classifications, softwoods and hardwoods, but also the chemical composition varies in wood taken from different parts of the same tree (Pirie, 1978). Thus, the response of various woods to the same chemical treatment can be quite different. Consideration should be given to both

the source of raw material as well as the treatment applied when comparing the results of studies using mature trees or wood residues.

The purpose of this research in contrast to previous research approaches, was to examine the use of very short rotation hardwood tree biomass as a potential feed source for ruminant production. The specific objectives of this study were to (1) characterize and quantitate the gross chemical composition of rapidly produced tree species; (2) characterize and quantitate fiber components (cellulose, hemicellulose, lignin) of these rapidly produced tree species; (3) to assess the fermentation of these rapidly produced tree species in the rumen by nylon bag technique; (4) to evaluate dry matter consumption, digestibility, rumen pH, rumen ammonia, volatile fatty acid profiles, and nitrogen balance of poplar biomass vs alfalfa in a feeding trial with lambs; (5) to evaluate the above objectives in terms of differing stage of growth and regrowth (early vs late harvest). The ultimate objective and contribution is to identify those tree species which have the best potential as a ruminant feed source when rapidly produced.

LITERATURE REVIEW

Background of Wood Use in Livestock Rations

Wood has evoked little interest as a dietary ingredient for ruminants although it contains 70 to 80% carbohydrate (Butterbaugh and Johnson, 1974). Only in times of national emergencies or dire feed shortages have any great amount of wood or wood residues been fed to ruminants. In the Scandinavian countries, more than 1.5 million tons of sulfite and sulfate pulps from spruce, pine and fir were fed to cattle and horses during World War II when conventional feedstuffs were in low supply (Hvidsten and Homb, 1951; Nordfelt, 1947).

Researchers (Anthony et al., (1969); Kitts et al., (1969); El-Sabban et al., (1971); Dinius et al., (1970) have studied the incorporation of whole trees and residues such as sawdust into ruminant rations and found inclusion of more than 25-30% on a dry matter basis usually depressed intake and gain. With regard to wood residues, most research emphasis has been on the utilization of wood-pulping and lumbering by-products as potential feed sources, and residues such as ammonium sulfite liquor and lignosulfonates, sawdust, bark, slashings and whole mature trees (Butterbaugh and Johnson, 1974; Croyle et al., 1975; Meitner, 1975). These residues however, have only been marginally successful in their potential feed usage, because their nutritive content is either very low or unavailable.

Wood Chemistry

Chemical analyses reveal that wood is a complex carbohydrate substance which consists primarily of cellulose, hemicellulose and lignin. The association of these components gives rigidity to the cell walls making them capable of withstanding the stress, weight and structure of the tree (Stone, 1976). From a nutritional standpoint, only the cellulose and hemicellulose fractions can be utilized by the ruminant and the extent of their utilization is greatly dependent upon the percent of lignin associated with the tree product. The quantities of each of these components will differ from specie to specie, and also the chemical composition of the hemicellulose and lignin fractions. Therefore the feeding value of wood, whether it be residues from lumber or very young tree seedlings, is dependent upon its chemical composition.

Killman and Cote (1968) showed the following table for the gross chemical composition of the two primary classes of wood. The values are expressed on an extractive-free basis. The extractives were removed by treatment with a neutral organic solvent such as alcohol, benzene, acetone or ether, although this treatment rarely renders the wood 100% extractive free. Following this table, the chemical description of the components is described by the above authors.

TABLE 1. CHEMICAL COMPOSITION OF WOOD
(All values in percent of extractive-free wood

	Hardwood	Softwood
Cellulose	40-44	40-44
Hemicellulose	23-40	25-40
O-Acetyl-4-O-methyglucurono-Xylan	20-35	---
Glucomannans	3-5	---
Arabino-4-O-methylglucurono-Xylan	---	10-15
Galactoglucomannans	---	15-25
Lignin	18-25	25-35
Pectin	1	1
Starch	5	5
Ash	.2-.3	.2-.3

The primary constituent of all wood, soft or hard, is cellulose. Cellulose is a high molecular weight polymer consisting of B-D-glucopyranose residues linked together in straight chains by B-1, 4 glycosidic bonds (Stone, 1976). Cellulose is insoluble in water and aqueous alkali but is soluble in, and degraded by strong acids such as sulfuric or hydrochloric (Van Soest, 1963).

Hemicelluloses are low molecular weight polysaccharides soluble in water at elevated temperatures. O-Acetyl-4-O - methylglucurono-Xylan, the primary hemicellulose of hardwoods, consists of a framework of (1-4) - linked B-D-Xylopyranose residues with 4-O-methyl-α-D-glucuronic acid residues as side chains. Glucomannans are made up of randomly distributed B-D-glucopyranose and B-D-mannopyranose residues linked together by (1-4) - glycosidic bonds. The hemicelluloses of softwood are more complex, both in respect to the number of hemicelluloses present and with respect to their structure. Arabino-4-O-methylglucurono-Xylan consists

of a backbone of (1-4) - linked B-D-Xylopyranose units with 4-O-methyl-α-D- glucuronic acid and α-L-arabinofuronose side chains. Galactoglucomannons, the predominant type of softwood hemicelluloses, have a backbone of randomly distributed (1-4) - linked B-D-glucopyranose and B-D-mannopyranose residues with a varying number of α-D-galactopyranose residues as side chains.

Lignin is a three dimensional polymer of phenylpropane units linked together by C-O-C and C-C bonds. In softwoods each unit carries one phenotic oxygen and one methoxyl group, while in hardwoods, only about half of the units contain an additional methoxyl group. Lignin cannot be hydrolyzed by acids but is soluble in strong bases and pulping agents.

The remaining components (pectin, starch, and ash) make up less than 10% of the nonextractable wood. Pectin is more abundant in bark than it is in wood. Its structure is largely unknown but contains galacturonic acids and minor quantities of arabinose and galactose. The most common constituents of the ash components are calcium, potassium and magnesium; existing as carbonates, phosphates, silicates, and sulfates.

Wood Residues in Ruminant Rations

According to Stone (1976) the annual harvest of timber, on a weight basis, totaled some 300 million tons of wood and 47 million tons of bark. About 190 million tons of wood and 27 million tons of bark were delivered as logs to U.S. mills or exported. The remaining 110 million tons of wood

and 20 million tons of bark was left in the forest because it was uneconomical as raw material for the existing industry. Because of the large amounts of available wood residues and the anticipated shortages of conventional roughages, several researchers have investigated the use of raw sawdust and other by-products of the lumber industry.

Some of the early studies by Anthony and Cunningham (1968) utilized raw oak sawdust as the sole source of roughage in finishing rations for growing lambs and steers. They reported that in both lamb and cattle finishing trials, slightly improved gains were obtained by the inclusion of 2.5% oak sawdust fed to steers, but increasing the sawdust level to 10%, reduced gains to those obtained on the all concentrate control. In a subsequent study, Anthony et al. (1969) compared 15% sawdust to 15% coastal bermudagrass hay in a finishing ration to steers. They reported steers fed the hay rations consumed significantly ($P<.01$) more dry matter, had a faster rate of gain, and were more efficient than those fed the oak sawdust.

El-Sabban et al. (1971), also utilizing oak sawdust, investigated the effect of particle size as well as level of oak sawdust in cattle finishing rations. In the first trial, gains of steers fed 5 or 15% fine sawdust and 5 or 15% coarse sawdust were less than those of steers fed 5% ground timothy hay; however, only the 5% fine sawdust produced significantly lower gains ($P<.05$). In the second trial, the level of hay in the control ration was increased to 15%, and compared to this particular treatment, the

inclusion of 5 and 15% fine sawdust resulted in significantly lower gains ($P < .05$). The coarse sawdust tended to produce slightly greater gains than the fine at both levels. In both trials, steers fed 15% sawdust tended to consume more feed and be less efficient than those fed 5% sawdust, but none of the wood containing rations were as efficient as the hay controls. The investigators also noted that the incidence of rumen parakeratosis and liver abcess appeared to be increased by the inclusion of sawdust.

In an attempt to differentiate between hardwoods, Millet et al. (1970) used the modified in vitro technique of Mellenberger et al. (1970) and investigated 24 species of sawdust residues. He reported digestibilities of hardwoods to range from a low of 2% for red alder and sweetgum to a high of 35% for aspen. The softwoods studied were essentially indigestible with 0% for hemlock, pine, and spruce to 5% for Douglas fir. Following this same procedure, Feist et al. (1970) found similar variations between hardwoods and softwood species.

Bender et al. (1970) also utilized the in vitro procedure described by Mellenberger et al. (1970) in determining the effect of ball milling tree residues. They found that milling for 24 hours increased the 48 hour digestibility of aspen from 23.4% to 42.8% and from 15.1 to 50% for white birch, but had little effect on the softwoods fir, hemlock, and spruce. Millet et al. (1970) reported that as ball milling time was increased from zero to 240 minutes, the 48 hr. in vitro digestibility of red

oak increased from 5 to 45% while the digestibility of aspen increased from 20% to 55%. It appeared that the first 20 to 30 minutes of milling appeared to have the major influence on digestibility. In regard to the digestibility comparisons of hardwoods vs softwoods, their work was in agreement with Bender et al. (1970) in which softwoods were reported to be much less responsive to ball milling than hardwood species.

Mellenberger et al. (1970) determined a correlation of 0.994 between the in vitro and in vivo digestibilities of complete rations containing aspen sawdust. This work signified the value of the in vitro assay in predicting the digestibility of ground wood residues in the rumen itself.

Subsequent work by Mellenberger et al. (1971) reported on a digestion trial using goats. The goats were fed either 0, 20, or 40% untreated aspen sawdust in both high roughage and high concentrate diets. Their results indicated that apparent digestible dry matter, digestible energy, and digestible carbohydrate decreased linearly with both types of rations as the percentage of sawdust increased. Apparent digestibility of the aspen sawdust was calculated by a least-squared plot of the digestion coefficients for the total ration, and then by extrapolating the resulting line to a point at which aspen would constitute 100% of the ration. By this method, it was calculated that the dry matter digestibility of aspen sawdust to be 41% in a high roughage ration and 28% when incorporated into a high concentrate ration.

Kitts et al. (1968) conducted digestion trials with mature wethers using increasing levels of black alder sawdust. They reported that as the level of sawdust increased from 0 to 35%, the dry matter digestibility of a barley based ration decreased from 80.4 to 56.5% while cellulose digestibility decreased from 75.0 to 21.7%. Dinius and Baumgardt (1970) reported that lambs fed rations containing from 0 to 50% oak sawdust maintained a rather constant digestible energy intake because they ate more of the oak rations containing up to 35% sawdust. Beyond this level, total feed intake was not increased enough to maintain a constant digestible energy intake. In a subsequent study with lambs, Welton and Baumgardt (1970) determined that as the level of oak sawdust was increased from 30 to 50%, a significant decrease in ration dry matter digestibility was seen ($P<.01$) but had no effect upon digestible energy intake.

Dinius et al. (1970) reported no significant differences in the dry matter digestibility of high concentrate rations containing 0 or 10% of either aspen sawdust or oak sawdust that had been finely or coarsely ground. Because the inclusion of the 10% sawdust did not significantly lower digestibility when compared to the all concentrate control, they suggested that the sawdust itself was not digested but that its presence resulted in an improved digestibility of the concentrate portion of the ration.

Kinsman et al. (1969) conducted a performance trial in which 32 finishing lambs were fed a 20% dried hardwood

(aspen) sawdust diet. They reported that in general, the ration produced very acceptable growth and carcass performance; however, no control ration was fed with which comparisons could be made. In another performance trial by Marion et al. (1959), they reported that growing steers fed a ration consisting of 34.1% ground mesquite wood plus 9.0% cottonseed hulls had similar gains to a control group fed 43.1% cottonseed hulls. They also reported that in a field study utilizing pregnant beef cows, those cows wintered on mesquite stems calved normally and were in similar body condition to cows fed cottonseed hulls. Vara et al. (1968) utilized cotton wood sawdust in rations fed to growing bulls. They fed either 14 or 28% cottonwood sawdust and compared these diets to a corn cob control ration, gains were 0.1 and 0.2 kg less, respectively, for the sawdust diets. No significant differences were seen in carcass yield, quality or total feed costs.

Kitts et al. (1968) utilized black alder sawdust in a performance trial with yearling steers. They compared the alder sawdust to mixed hay at 10% of a barley based ration supplemented with either soybean meal or urea. They reported that on either nitrogen source, steers fed the hay diets made slightly greater daily gains and were more efficent, although no significant differences were found. Using cottonwood sawdust, McCartor et al. (1972) reported that steers fed 10% of this material as a roughage source gained significantly less ($P<.05$) and were slightly less efficient than steers fed an all concentrate

control. Gilbert et al. (1973) conducted a feeding trial with finishing lambs utilizing hardwood sawdust as 15% of the total ration dry matter. Compared to a control diet of hay, the sawdust fed lambs exhibited a significant ($P < .05$) reduction in both daily gain and feed efficiency.

Sawdust and wood residues have been used in several experiments to limit energy intake by cattle. Satter et al. (1970) included a pelleted concentrate containing 32% aspen sawdust in a diet fed to lactating dairy cows. They found that milk production as well as fat test to be equal to that produced on a conventional hay-concentrate dairy ration. Other work in this area was conducted by Cody et al. (1972) with young bull calves. They reported that intake could be limited by the inclusion of from 25 to 45% pine sawdust in the total ration. Subsequent studies by the same group showed that dietary sawdust levels of 15% or greater resulted in an increase of rumen parakeratosis and above 25%, sawdust produced rumen distention and ruminal and omasal impaction.

Ground Whole Trees as a Ruminant Roughage Source

The utilization of whole, mature trees has also been investigated as a potential feed source for cattle and sheep. In the U.S.S.R., about 500,000 tons of softwood is processed annually for oils, extracts, and for a ground meal called "muka", which is fed as a roughage at 3 to 8% of the total ration dry matter (Ievins et al., 1973; Young, 1976). Ievins et al. (1973) claimed reduced susceptibility to disease, increased egg production, milk and meat production

and increased vitality in those animals being fed the "muka" as a roughage source. However, these data have not been substantiated because animal performance data was unavailable.

A compositional analysis of softwood and hardwood muka has been done by (Keays and Barton, 1975). This following table suggests that the % protein content of the muka is not adequate for optimum animal performance (weight gain), but may be adequate for maintenance.

TABLE 2. COMPOSITION OF SOFTWOOD AND HARDWOOD MUKA (Keays and Barton, 1975), (Air-Dried Basis)

Component	Spruce Muka	Birch Muka	Alfalfa Meal
Protein, %	8.79	8.0	18.3
Fats, %	6.54	8.2	3.2
Cellulose, %	35.6	18.0	26.2
Nitrogen-free extractives, %	34.0	56.8	41.8
Ash, %	4.4	4.2	9.6
Carotene, mg/kg	139.0	380.0	172.0
Riboflavin, mg/kg	6.0	4.0	13.2
Calcium, %	0.72	0.78	1.13
Phosphorus, %	0.17	0.26	.31
Potassium, %	0.44	0.73	1.34
Magnesium, %	0.59	0.30	0.20
Iron, mg/kg	158.5	101.0	212.0
Manganese, mg/kg	292.0	30.0	29.0
Copper, mg/kg	5.6	8.0	9.9
Zinc, mg/kg	31.5	121.0	16.0
Cobalt, mg/kg	158.0	90.0	360.0

A similar product has been prepared from cottonwood leaves obtained from 3 year old nursery grown Populus species (Dickson and Larson, 1977). This Wisconsin

research showed that the Populus leaves contained 19.5% crude protein, 3.2% soluble protein, 0.16% soluble amino acids, 16.4% total soluble sugars and 21.8% total non-structural carbohydrates, which compared favorably with alfalfa. No animal digestion studies, however, were done to ascertain the actual feeding value of the product. Research by Kamstra (1977) has shown that cattle will consume rations containing up to 48% ground and pelleted whole aspen trees, and the product has been suggested as an emergency feed for cow-calf operations. The above product has also been successfully ensiled by this researcher.

Early work done at the University of Hawaii by Kinch and Ripperton (1962) evaluated the biomass production of Leucaena glauca, or Koa haole, a small leguminous tree, and also examined animal performance. With 4.6 cuttings per year, or about 80 growing days between harvests, annual green forage yield averaged 33 tons per acre (82 tons/hectare), with a crude protein content on a dry matter basis of 27.9%. Animal performance studies, however, showed that detrimental side effects (hair and wool loss, poor reproduction) were apparent with sheep and pigs fed this forage, but not with cattle. This effect was believed to be caused by the trees' high mimosine content, and may in part, have been responsible for the discontinued biomass propagation and cultivation of this tree in Hawaii.

In another study by Enjmann et al. (1969) utilizing ensiled poplar trees fed ad libitum plus 0.23 Kg of soybean meal, they reported that sheep lost weight and that the

addition of 0.34 Kg of oats was necessary to meet the maintenance requirement. Good results have been reported with wintering steers in Canada on diets containing either 20 or 40% silage prepared by grinding freshly cut aspen and poplar trees (Anonymous, 1966).

The utilization by ruminants of either ground whole trees or raw sawdust residues have indicated that this material is unsatisfactory as a significant dietary compoent. According to Guggolz et al. (1971), the inability of ruminants to avail themselves of the energy from such carbohydrate sources may be explained by one or more of the following: (1) Lignin acts as an inert barrier between the carbohydrate and the digesting enzyme, (2) the cellulose is too highly crystalline to be quickly available to enzyme action, or (3) silica inhibits carbohydrate digestibility.

A number of pretreatments to improve the availability of wood carbohydrates have been examined. Summarizing, these treatments can be classified as: (1) irradiation, (2) alkaline delignification, and (3) acid hydrolysis. The above treatments and their effects will now be discussed.

Irradiation of Wood Residues

The irradiation of basswood was investigated by (Lawton et al. 1951). They measured VFA production and dry matter disappearance in vitro and reported that at a treatment of 10^8 roentgens, the digestibility of the wood was comparable to that of hay. At levels above 10^8 roentgens, the in vitro digestibility decreased which

indicated that the wood components were being converted to forms that were no longer readily fermentable. Millett et al. (1970) reported that irradiation with 10^8 roentgens resulted in maximum digestibility, but that hardwoods responded better to irradiation than softwood species. A previous study by Kitts et al. (1968) investigated the in vitro digestibility of hemlock (a softwood) which was subjected to 5 different levels of gamma irradiation. There workers reported an increase in dry matter and cellulose digestibility up to 0.4×10^8 roentgens.

The electron irradiation of either hard or softwoods appears to increase dry matter digestibility; however, this method of wood treatment has not been fully evaluated in feeding trials because of the high costs involved. Millett et al. (1970) reported an estimated cost to be about $150 per ton at the dosage of 10^8 roentgens.

Alkaline Treatment and Delignification

To increase the digestibility of wood and wood residues by ruminant animals, research emphasis has been stressed on the process of delignification to make the carbohydrate fractions more available. Some of the earliest work in this area was by Beckman (1918) in which he patented a NaOH process for treatment of roughages and wood residues.

In the Scandinavian countries more than 1.5 million tons of sulfate and sulfite pulps from spruce, pine and fir were fed to cattle and horses during World War II when feed supplies were short (Hvidsten and Homb, 1951; Nordfelt,

1947). Hvidsten (1949) reported the digestibility of pulp produced from spruce wood by the sulfite method to be about 85.0%. The production of these highly digestible wood pulps demonstrated the ability of wood products and residues to serve as a energy supply for ruminants. However, because of the high costs and producers' unwillingness to accept this feedstuff, the practice of feeding such materials was discontinued after the war.

More recent work has investigated the use of pulping procedures that exert a marked effect on digestibility of the material but that do not remove an appreciable amount of lignin. A study by Stanks (1961) reported that treating aspen sawdust with a mixture of 15% $NaClO.\ 5H_2O$ plus 10% NaOH resulted in an increase in the digestion of cellulose from 11.3 to 73.5 while decreasing the lignin content only 2.4%. Another subsequent result of the above treatment was that 36.4% of the sawdust dry matter could be fermented to short chain acids, primarily succinic and acetic.

Using a similar treatment as Hvidsten (1949), Clarke *et al.* (1971) compared sulfite processed Douglas fir wood pulp to barley in cattle finishing rations. They increased the level of pulp to 70% of the ration and found that at this extreme, a marked decrease in gain resulted with little change in feed efficiency. This suggested a problem of acceptibility more than digestibility. In an *in vitro* study with both softwood and hardwood delignified chemical pulps, Baker *et al.* (1973) found dry matter digestibilities

to range from 72 to 96%. They reported that eighty percent of the samples tested had digestibilities of 90%.

To further verify the increase in dry matter digestibility due to alkaline treatments, Bender et al. (1970) conducted a digestibility trial utilizing NO_2 or NaClO. $5H_2O$ and found increases of 2 to 3 fold for aspen and other hardwood sawdust. However, they concluded that these treatments were too costly to be of practical importance.

The earliest work done utilizing sodium hydroxide as a means of increasing the dry matter digestibility of wood was demonstrated by (Wilson and Pigden, 1964). It had been known that the treatment of low quality forages with sodium hydroxide would increase their dry matter digestibility with the early development of the Beckman process. Wilson and Pigden (1964) utilized ground poplar wood and reported that alkali treatments up to about 9% (9 g NaOH/100 g wood) resulted in a linear increase in in vitro dry matter digestibility. Above this 9% level, however, no further increases in dry matter disappearance could be achieved. As the level of NaOH increased from 0 to 9%, the in vitro digestibility of the wood increased from 3 to 40% while the digestibility of wheat straw increased from 30 to 70%. In a subsequent study, Feist et al. (1970) determined the amount of NaOH required for maximum digestibility of both quaking aspen and northern red oak. They reported values to be between 5 and 6 grams of NaOH per 100 grams of wood for the quaking aspen and red oak.

However, in a following study, the above researchers noted that the relative increase in digestibility was highly species dependent. They reported that the digestibility of basswood increased from 5 to 56% and paper birch from 9 to 38% whereas the digestibility of red oak increased from 3 to only 15% and American elm from 9 to only 14%. Work by Millett et al. (1970) reported similar findings as those by Feist et al. in regard to the amount of NaOH required for maximum digestibility as well as to the high degree of species dependency. They also demonstrated that treatment with NaOH on two softwoods (spruce and fir) had no significant effect in improving dry matter digestibility.

In an attempt to verify the accuracy of an in vitro rumen technique developed earlier by Mellenberger et al. (1970), this same group studied the digestibility of aspen sawdust, aspen bark, and alkali-treated aspen sawdust by goats. In regard to the alkali treatment, aspen sawdust was mixed with NaOH at (5 gm NaOH/100 gm wood) in a rotating digester for 2 hours. By incorporating levels of 0, 5, 10, 30, 45, and 60% of this material into both high roughage and high concentrate diets, they found that as the percentage of treated sawdust increased, the overall digestibility of the ration decreased. This decrease was linear in the high roughage rations only. In making comparisons with similar rations containing untreated sawdust, these researchers concluded that the NaOH treatment had increased the digestibility of aspen sawdust approximately 25%.

The use of anhydrous liquid ammonia to treat woods and

wood residues has been studied by (Millett et al. 1970). This study involved steeping several species of sawdust in anhydrous ammonia under pressure for varying periods of time. It was determined that one hour of steeping and penetration by the anhydrous ammonia was long enough to obtain maximum digestibilities. Millett et al. (1970) also reported that a five day incubation period increased the digestibility of aspen sawdust from 33% for the control to 51% for the ammonia steeped product. In a subsequent study, Mellenberger et al. (1970) found that steeping aspen sawdust in liquid ammonia for 1 hour increased the in vitro digestibility from 20 to 37%.

Tarkow and Feist (1968) attempted to define the mechanism by which alkali treatments increase dry matter digestibility. By the utilization of a calcium ion exchange column, they measured the free carboxyl content of NaOH treated hardwood and demonstrated that the effect of such bases is to saponify the esters of 4-O-methyl-D-glucuronic acid thus breaking the cross links between Xylan chains of the hemicellulose fraction and other polymeric units. As a result of this chemical action, there is a marked increase in the fiber saturation point or swelling capacity of the wood which provides for improved diffusion conditions of water soluble materials as well as improved enzyme substrate interactions.

Feist et al. (1970) and Millett et al. (1970) have reported that the response of wood to alkali treatment is highly species dependent. Results from their studies have indicated

that hardwoods are more responsive to alkali treatments than softwoods. However, the digestibility of all species increases as their lignin content decreases. Work by Baker (1973) showed that at lignin contents of less than 7%, hardwood and softwood residues have essentially equal digestibilities of about 65%. However, at higher lignin contents, hardwood residues are more digestible than softwood residues. Baker (1973) concluded that the differences between these two classes could be explained by the following factors: (1) softwoods contain 25 to 50% more lignin than hardwoods, (2) differences exist in the lignin-carbohydrate association between the two woods and (3) the lignin structure of softwoods differs from that of hardwoods.

In determining differences in chemical structure between softwoods and hardwoods, Bender et al. (1970) reported that softwood lignins are almost exclusively built from guajacyl units while hardwood lignins contain both guajacyl and syringyl units. The significance of this is that the syringyl units might prevent cross-linking and the formation of a three dimensional lignin polymer which, in the softwood species, could effectively block the access of enzyme systems required for digestion.

Acid Hydrolysis of Wood and Wood Residues

As with alkaline treatment, final products of wood hydrolysis with acid are greatly dependent upon the type of hydrolyzing process and the nature of the wood (hardwood vs softwood) that is being hydrolyzed. The following is a summary of acid hydrolysis and its effect upon wood

carbohydrates described by (Wise and John 1952).

A mild form of acid hydrolysis is the treatment of wood with water. When treating wood with water at elevated temperatures, 10 to 30% of the weight of the wood will be solubilized. The similiarity of water hydrolysis and acid hydrolysis is found in the action of hydrolytic degradation of the carbohydrate fraction. Conversely, alkali treatment acts in the manner of lignin solubilization which has already been described. Water hydrolysis will solubilize most of the hemicellulose fraction of wood residues but virtually does not affect the cellulose. The treatment of wood with dilute acids at elevated temperatures will result in at least some of the cellulose being hydrolyzed. However, when hydrolyzing with a concentrated acid followed by dilutions and boiling, 98 - 100% of the cellulose will be converted to glucose. The treatments of using elevated temperatures and acid concentrations that hydrolyze cellulose in a matter of hours, will readily convert hemicellulose and intermediate products into simple sugars in seconds or minutes. Under some hydrolysis conditions, sugar decomposition is also promoted as is seen when cellulose is hydrolyzed rapidly. In the decomposition of sugars, the pentose sugars always break down more rapidly than the hexoses.

Wise and John (1952) reported that the monosaccharide fraction are converted to organic acids which may represent up to 50% of the weight of the sugar originally formed with the remainder of the sugar being converted to humus material and gases. About 50% of zylose is converted to furfural,

and yields on a dry matter basis of the original wood range from 2.0% for softwoods to about 4.5% for hardwoods. The hexose sugars yield levulinic acid, among other substances, upon decomposition. An intermediate formed in this breakdown is 5-hydroxymethylfurfural, but this compound is highly unstable and is readily converted to levulinic acid. The products produced from sugar decomposition appear in the residue as a resinous tar due mainly to the polymerization of furfural, hydroxymethylfurfural, and levulinic acid. The solid portion of the residue is composed of approximately 15-30% lignin and about 10% extraneous substances such as tannin decomposition products, oils, and waxes. Considerable amounts of cellulose may remain in the residue depending upon the conditions and efficiency of the hydrolyzing process.

The practical aspect of acid hydrolysis on wood was described in the production of wood molasses. This process involved the percolation of a dilute solution of hot sulfuric acid, under pressure, through a column of sawmill wastes. The acid solution drawn from the bottom of the percolators is then neutralized and the resulting material filtered to remove the solid fractions. The remaining sugar or molasses is 50-60% dry matter. Work by Jones (1949) reported that wood sugar molasses fed to dairy cattle was equal in energy value to cane molasses when incorporated into rations for both growing heifers and lactating cows. Barrentine and Leveck (1949) compared oak wood molasses to ground white corn in beef cattle finishing rations and reported the feeding value of wood molasses to be equal to corn when

up to 25% of the corn dry matter was replaced by molasses dry matter. Wood molasses studies have exhibited favorable results; however, the high costs of production and limited use of the remaining residue after hydrolysis has limited its use by producers.

As was mentioned previously, some of the early work at feeding acid and pressure treated wood products to livestock was done during and after World War I in Germany and Scandanavia. A review by Schneider (1943) stated that the chemical treatment of sawdust and bark can increase its digestibility, but these feeds when included in rations almost invariably depress the digestibility of one or more nutrients.

Sherrard and Blanco (1921) conducted early studies with dilute acid hydrolysis of wood. They digested white pine sawdust with 1.8% sulfuric acid for 15 minutes under a steam pressure of 120 PSI and neutralized the resulting material with lime. When compared to the original sawdust material, the hydrolyzed product contained 20% less cellulose, the same amount of lignin, about 12% less crude fiber, and 16-18% more reducing sugars. They used the above material in a ration for lactating dairy cows and found adequate dry matter intake. However, no milk production or breeding data were presented.

In a digestion trial with sheep, Archibald (1926) determined the feeding value of hydrolyzed wood produced by Sherrard and Blanco's (1921) procedure. Archibald reported the average dry matter digestibility to be about 46% for

white pine hydrolyzed sawdust and 33% for a similar product made from Douglas fir. Using these digestibilities, he calculated the net energy of the hydrolyzed wood products using the formula derived by Armsby (1917). The eastern white pine hydrolyzed sawdust had an apparent net energy value of 18.6 therms/100 lbs. but the net energy value of the Douglas fir hydrolyzed sawdust was a negative quantity, indicating that more energy was used up in the process of digestion than the material contained. In a second trial, Archibald compared 20% of the two wood products to 20% starch in rations for lactating dairy cows. They reported that fat content was not affected by treatment and there were little differences in body weight change, however, milk production was 4% less for cows fed Douglas fir hydrolyzed sawdust and 1% less for cows fed pine hydrolyzed sawdust when compared to starch controls.

Bender et al. (1970) studied the effect of steam heating of seven hardwood samples at 175°C for 2 hours on in vitro digestibility values. They reported this treatment increased 48 hour in vitro digestibilities by an average of 21.3% but had little or no effect on three softwood samples tested. In a subsequent study, Kitts et al. (1968) reported that the above increases in digestibility were not reflected in animal performance data. They compared 15 and 20% alder sawdust that had been treated under 2,000 psi of pressure and heated at 117°C to an untreated sawdust, and 15 or 20% hay in beef cattle growing rations. The hay fed cattle gained significantly faster ($P<.01$) and made more

efficient gains ($P<.05$) than those receiving either of the sawdust rations, while no differences were found between treated and untreated sawdust.

Studies by Butterbaugh et al. (1972) compared increasing levels of a 4:1 mixture of hardwood to pine sawdust that had been hydrolyzed with 0.8% H_2SO_4 to alfalfa meal and reported that as the level of wood residue increased in the ration, dry matter and organic matter digestibility decreased ($P<.05$), but there were no effects upon nitrogen or cellulose digestibility. Work by Hudson (1971) utilized pine sawdust that had been hydrolyzed with 0.8% H_2SO_4 also. He conducted a digestibility study with lambs and found that the inclusion of 15% of this material resulted in a significant decrease ($P<.01$) in both dry matter and nitrogen digestibility. Following this study, Hudson conducted a nitrogen balance trial and comfirmed the depression in nitrogen digestibility of his first study, and demonstrated a significant decrease ($P<.05$) in the % intake nitrogen retained and % absorbed nitrogen retained as a result of replacing alfalfa pellets with 15% hydrolyzed pine sawdust residue.

Butterbaugh (1972) conducted a growth trial with lambs utilizing increasing levels of the 0.8% H_2SO_4 sawdust residue. He reported that as the level of this low acid product increased, weight gains decreased, but the amount of non-wood dry matter required per Kg of gain decreased indicating that some of the wood residue was being utilized as an energy source. In a similar study, Hudson (1971) had reported a

decrease in weight gains but had found that in both steer and lamb trials, treating the pine residue with either 2.5% NaOH or 2.5% NaOH plus heat would overcome the depression in gains but had no effect in overcoming the reduced efficiency observed when this material was fed without further treatment.

Utilizing rats in growth trials and metabolism studies, Hudson (1971) utilized the same hydrolyzed pine sawdust as was used in the studies with ruminants. He reported that the feeding of hydrolyzed sawdust resulted in depressed gains and performance in monogastrics as was seen in ruminants. Additional treatments of the wood residue with NaOH, NH_4OH, or combinations of either of these bases with heat was only partially effective in overcoming the depressing effects caused by this product. From his results, it was also included that the optimum levels of treatment were 2.5% for NaOH and 2.0% for NH_4OH on a dry matter basis. However, as Hudson increased the dietary crude protein level to 24%, it was demonstrated that the detrimental effects of the sawdust upon animal performance were eliminated. He found that the supplementation of methionine or lysine, or both, was an effective means of increasing the performance of rats fed hydrolyzed sawdust with greater gains made when a combination of the two were fed.

In subsequent work by Butterbaugh (1972), he conducted a digestibility trial with a 4:1 mixture of hardwood to pine sawdust that had been hydrolyzed with 2.3% H_2SO_4. His study found that in high alfalfa meal diets, dry matter,

organic matter, and nitrogen digestibilities were significantly depressed by the inclusion of 20 or 35% of this hydrolyzed product, but that the decrease in nitrogen digestibility was partially overcome by the supplementation of soybean meal. Johnson et al. (1973) utilized this same material and treatment in a digestibility study with sheep and reported that when hydrolyzed sawdust replaced cottonseed hulls at levels of 25 and 50%, dry matter and organic matter digestibilities decreased but that the depression was not as severe as when hydrolyzed sawdust replaced alfalfa meal. In contrast with the alfalfa diets, the nitrogen digestibility increased when hydrolyzed sawdust replaced cottonseed hulls.

In a performance study of growing steers, Johnson et al. (1973) wintered steers on high alfalfa meal diets containing 0, 20, 30, and 40% of a 2.3% acid hydrolyzed sawdust. They noted that as the level of wood residue increased, gains and the efficiency of gains decreased. Subsequently, Butterbaugh (1972) conducted a growth trial with lambs and reported that lambs consuming a basal alfalfa meal diet gained faster and were significantly more efficient ($P<.05$) than lambs receiving diets containing 20 and 35% hydrolyzed sawdust. Johnson et al. (1973) found that adult ewes maintained on rations containing 25 and 50% hydrolyzed sawdust lost weight while the ewes on a control ration of cottonseed hulls gained approximately 3 pounds each over the 2 month period. Both Johnson et al. (1973) and Butterbaugh (1972) have reported that adding

acid hydrolyzed sawdust above 25%-30% dry matter will reduce both dry matter digestibility and animal performance. However, Butterbaugh and Johnson (1974) fed increasing levels of rations treated with .8% H_2SO_4 and noted that rations containing up to 75% of the low acid treated residue were consumed well by growing lambs. There were no significant differences in weight gains of lambs fed the 25 or 50% residue rations when compared to the basal ration of alfalfa meal. However, feed efficiency tended to increase as the levels of wood residue increased over 25% of the diets. When supplemented with soybean meal, the 75% ration significantly decreased the dry matter/Kg gain requirements and increased weight gains.

Summary

Most current research on the utilization of trees as an alternative feed source for animal production, have utilized only the by-products of the lumbering industry and as a result have been only marginally successful in demonstrating their potential nutritional value. It is a well known fact that for effective utilization of wood residues, the carbohydrate fraction be accessible to the action of rumen microorganisms. However, to establish this criteria, these wood by-products must usually be physically and chemically treated to destroy the highly lignified polysaccharide complexes, which resist fermentive and digestive processes. This added treatment is often economically unfeasible.

It is the purpose of this research to contrast previous research approaches. We will concern ourselves with the utilization of very short rotation tree production (hardwoods) as a potential feed source for animal production, specifically the ruminant.

MATERIALS AND METHODS

Four different experiments were performed: (1) a selected chemical analyses of ten biomass trees and an alfalfa control over two harvest periods (early vs. late harvest), (2) a measurement of the ensilement characteristics, chemical composition, and rumen degradability of ensiled biomass and alfalfa samples (early harvest), (3) a determination of rumen degradability of biomass trees and alfalfa (early and late harvest) utilizing the dacron bag technique (Orskov and Mehrez, 1977), and (4) a digestion trial with wether lambs to determine ration digestibility, dry matter intake, nitrogen retention, rumen fluid pH, rumen ammonia, and blood urea nitrogen levels feeding varying levels of poplar vs. alfalfa meal pellets.

EXPERIMENT I - Chemical Composition of Biomass and Alfalfa Samples

A. Harvest of Biomass Trees and Alfalfa

In the spring and summer of 1979, ten hardwood tree species were harvested twice from the Michigan State University Tree Research Center. These materials were weighed on a freshly cut basis from premeasured plots and random samples of each specie were taken to analyze for dry matter and chemical composition. Potential dry matter yields were also calculated from this data. Both early and late harvest of alfalfa

Figure 1. Two biomass species utilized in the study. Above - Black locust, Below - Honey locust. Notice high leaf to stem ratio on the plants.

Figure 2. Black Alder - this specie and black locust on preceding page fixate nitrogen.

meal samples were harvested on the Harold Lietzke farm in St. Johns, Michigan. The alfalfa samples were collected and handled in the same manner as the biomass produced trees.

B. Collection of Feed Samples for Analyses

All samples of the biomass trees and alfalfa were ramdomly collected at several areas from each storage container and a composite was made for each specie. Samples were ground through a 1 mm screen using a Wiley Mill[1] prior to all chemical analyses with the exception of obtaining dry matter values.

C. Dry Matter Percent

All samples were analyzed for percent dry matter by recording initial wet weight and then drying the samples in an oven for 24 hours or longer. After complete drying, weights were recorded as percent of wet sample.

D. Crude Protein and N Levels

All samples were analyzed for N content using a semi-micro Kjeldahl digestion method with a Technicon Autoanalyzer II Sampler and Colorimeter. A 10% copper sulfate solution was used as a catalyst to assist in breaking down the organic matter. Potassium sulfate was added to raise the boiling point of the digestion process. The carbon and hydrogen

[1]Thomas - Wiley Mill, Arthur Thomas Co., Philadelphia, Pa.

of the organic matter were oxidized to carbon dioxide and water while the nitrogen was converted to ammonium sulfate. The procedure used was Official Methods of Analysis of the Association of Official Agricultural Chemists (1970).

E. Gross Energy of Samples

Gross energy values for each ration were obtained by utilizing the Parr[1] Adiabatic Oxygen Bomb Calorimeter. A previously weighed sample of each specie was placed in a combustion capsule. The capsule was placed in an oxygen bomb containing 25 atmospheres of oxygen. The oxygen bomb was covered with 2000 g of water in an adiabatic calorimeter. After the bomb and calorimeter had been adjusted to the same temperature, the sample was ignited with a fuse wire. The temperature rise was measured under adiabatic conditions. By multiplying the hydrothermal equivalent of the calorimeter times the temperature rise minus some small corrections for the fuse wire oxidation and acid production, the caloric content of the sample was calculated.

F. Ash Values of Feed Samples

Ash percentage was determined by igniting pre-weighed plant samples at 600° C in a muffle furnace to burn off all of the organic material. The inorganic material which does not volatize at this temperature is regarded as ash.

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[1]Parr Instrument Co., Moline, Illinois

Calculations were made on a dry matter basis with the weight of the residue ash expressed as a % of the original dried sample.

G. Ether Extract Determination of Feed Samples

Ether extract values were evaluated based on the principle that ether is continuously volatized, then condensed and allowed to reflux through the feed sample, extracting ether soluble materials. The extract was then collected in a beaker. When the process was completed, the ether was evaporated under a hood and collected in another container and the remaining ether extracted residue was dried and weighed. The final calculations were made on a dry matter basis with the weight of the ether extract expressed as a % of the dried original sample.

H. Fiber Analysis Values of Samples

Neutral Detergent Fiber- this procedure attempts to divide the dry matter of feeds very near the point which separates the nutritively available and soluble constituents from those which are incompletely available or dependent on microbial fermentation.

The specific procedure used was described by Van Soest and Wine (1967). A previously weighed sample was placed in a Berzelius beaker for refluxing. The following reagents were added in order: neutral detergent solution, decalin, and sodium sulfite. The mixture was heated to boiling for five to ten minutes and then reduced and refluxed for

60 minutes.

Previously tared crucibles were placed on a filtering apparatus. Beakers were swirled and contents were poured into each crucible and a vacuum was applied. The remaining mat was washed twice with acetone, and dried at 105° C overnight and weighed.

Calculations were made on the dry matter basis with the weight of the dried NDF fraction expressed as a % of the original dry sample weight.

Acid Detergent Fiber - this fraction supposedly represents ligno-cellulose in feedstuffs. The residue also includes silica, however. The difference between the cell walls and acid detergent fiber is an estimate of hemicellulose, although this difference does include some protein attached to cell walls. The acid detergent fiber is used as a preparatory step for lignin determination.

The procedure used was that of Van Soest (1963). A previously weighed sample was placed into a Berzelius beaker for refluxing. Reagents of acid-detergent solution and decalin were added and the mixture was heated to boiling for 5 minutes. The heat was then turned down and the material was refluxed for exactly 60 minutes. The volume was then filtered on a previously tared crucible to which a vacuum had been applied. The remaining mat was washed twice with acetone and then dried at 105° C overnight and weighed. The calculations were made on a dry matter basis with the weight of the dried ADF fraction expressed as a % of the original dried sample.

Permanganate Lignin - this procedure of fiber determination utilized the acid detergent fiber procedure as a preparatory step. The detergent removed the protein and other acid-soluble material which would interfere with the lignin determination. The principle of the procedure is that the acid detergent fiber residue is primarily lignocellulose of which the cellulose is dissolved by the permanganate solutions. The remaining residue consists of lignin and acid-insoluble ash; however, with samples containing large amounts of cutin this also is measured as part of the lignin.

This is an indirect method for lignin, utilizing permanganate, and allows the determination of cellulose and insoluble ash in the same sample. The insoluble ash is an estimate of silica content, which in many forages is a factor in reducing digestibility.

The crucibles from the acid detergent fiber procedure were placed in a glass tray with one end of the tray 2 to 3 cm. higher so the acid could drain away. To each crucible 30 to 40 ml. of the permanganate solution was added. The mats of the material were broken up with a stirring rod to allow better sample contact with the solution.

The samples were left in contact with the solution for 90 minutes. New solution was continually added at all times during the digestion process. At the end of digestion time, the permanganate solution was promptly suctioned off. Approximately 20 ml. of demineralizing solution was then added and allowed to stand until the solution color changed. At the end of this time, this solution was filtered off and

the digestion was considered complete by the completely white color indicated. The calculations were made on a dry matter basis with the weight of the dried lignin fraction expressed as a % of the dried ADF fraction.

I. Derivatization of Hemicellulosic Sugars to Alditol Acetates

The 10 biomass samples and alfalfa sample from the first harvest were delignified with sodium chlorite and hydrolyzed with trifluroacetic acid. The hydrolyzed sugars were derivatized to their corresponding alditol acetates and analyzed on the gas chromatograph.

Summary of Procedure of Alditol Acetates

A 50-60 mg delignified sample (F) was transferred to a 18 X 150 mm heavy duty Wheaton tube containing 10 ml of 1 N trifluroacetic acid. Myoinositol (5-7 mg) (G) was added to each tube as an interval standard. Each delignified sample was run in triplicate. The tubes were sealed with slotted stoppers and aluminum seals and hydrolyzed at 120° C for 60 min in an autoclave. After the hydrolysis, the samples were filtered through a preweighed scintered glass crucible (No. 3). The filtrate was then collected and poured into a 50 ml round bottom flask. The residue was washed with 50 ml of deionized distilled water and dried for 24 hours. The filtrate was evaporated to dryness under a stream of filtered air in a 60° C water bath. The hydrolyzed hemicellulose sugars in the filtrate were reduced to their respective alditols with sodium borohydride (1 g) in 1 N ammonia (50 ml) for 1 hour with occasional swirling. The

FLOWCHART FOR ALDITOL ACETATE ANALYSIS

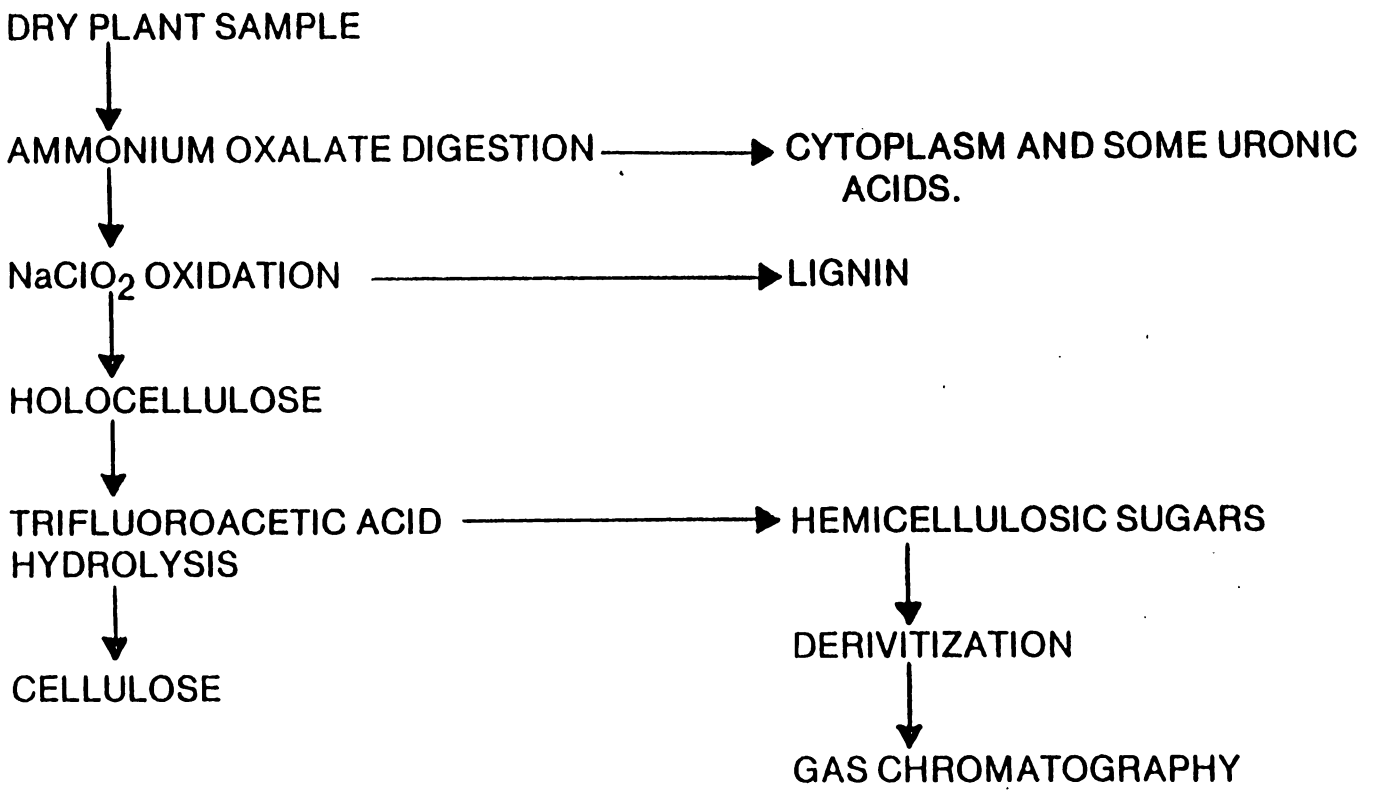
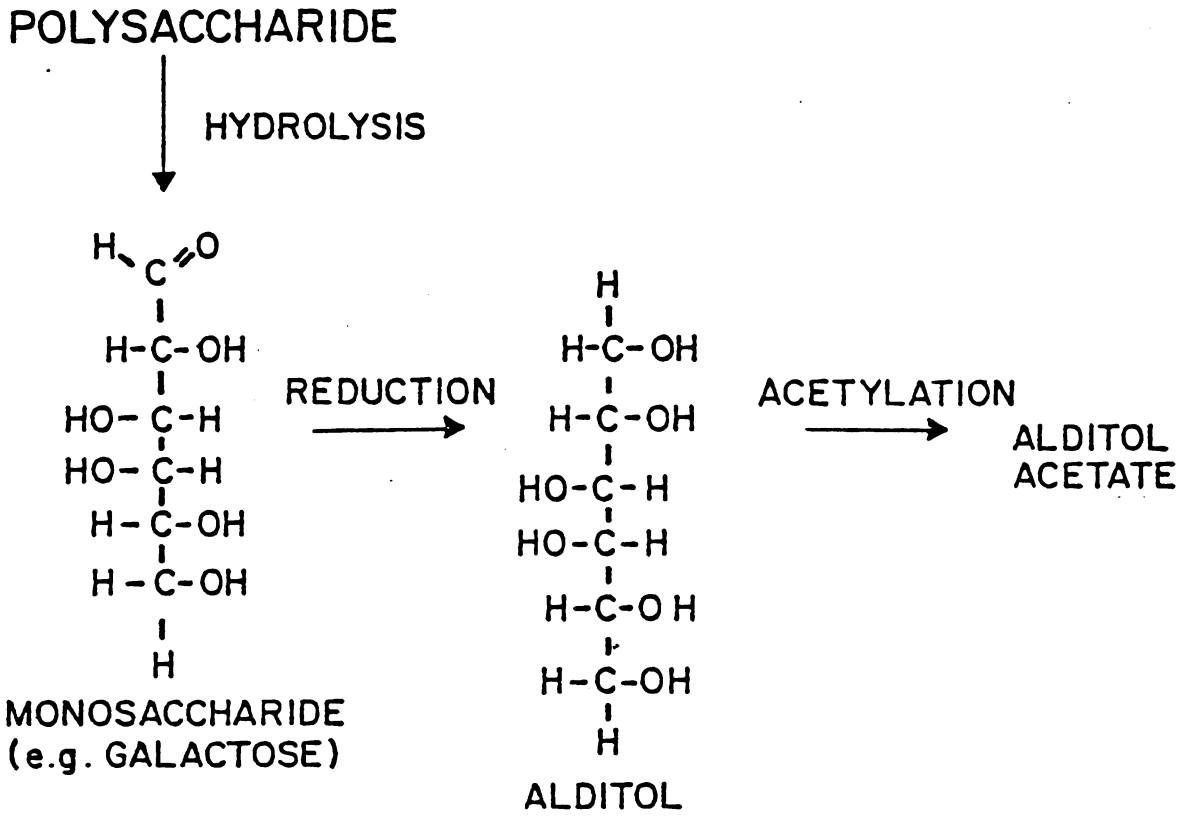


Figure 3.

POLYSACCHARIDE – ALDITOL – GAS CHROMATOGRAPHY ANALYSIS



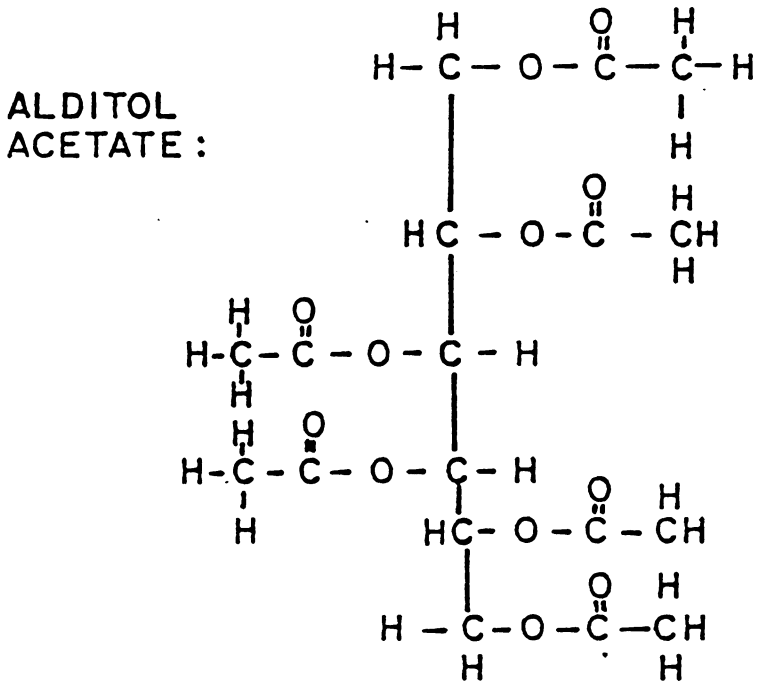


Figure 4.

The reduction was stopped with glacial acetic acid until the reaction stopped. Ten milliliters of methanol was then added and evaporated to dryness under a stream of filtered air in a 60° C water bath. Five more 10 ml methanol additions were made and evaporated to dryness as before. Acetic anhydride (4 ml) was then added and the round-bottom flask was sealed and wired down. The mixture was then heated at 120° C for 1 hr. in an autoclave.

GLC Quantification of Alditol Acetates

A 3-5 ul sample of the autoclaved mixture was injected into a gas chromatograph Hewlett Packard 5840A Gas Chromatograph equipped with a hydrogen flame ionization detector. A stainless steel column (120 X 0.3 cm) packed with 0.2% polyethelene glycol adipate, 0.2% polyethelene glycol, succinate, and 0.4% silicone X F - 1150 on Gas-Chrom P (100-120 mesh) was used. Other GLC parameters were as follows: Column temperature, programmed between 135-200° C with a 10-min holding at 135° C after injection of the sample followed by 1° C/min increase in temperature; helium flow rate of 30 ml/min, injection temperature of 210° C, detector temperature of 250° C, attenuation of 32 X and range of 1 mV.

Calculations of Results

The following formula was used to calculate the percent hemicellulosic sugars:

$$\% \text{ sugar} = C \times \frac{\text{wt. of sugar}}{\frac{BC/D}{\text{Sample wt} \times A}} \times$$

100 wt. of cellulose in E = JE/F wt. of sugar in E = GIE/FH

Where A, dry matter of ground sample; B, oxalate fiber residue scrappings; C, weight of oxalate fiber at 0 min; D, weight of oxalate fiber at 30 min; E, weight of holocellulose sample (50 mg); G, weight of myoinositol; H, myoinositol GLC peak area; I, sugar GLC peak area; J, weight of cellulose.

J. Mineral Analysis of Biomass Trees and Alfalfa

Determination of Ca, P, K, Na, Mg, Fe, Zn, Al, Cu, Mn - these elements were all evaluated using a SMI III Direct Current Spectrophotometer[1] in the MSU Natural Resources Analytical Laboratory. The method of sample preparation was described by Walsh (1971). The plant tissues were finely ground after drying at approximately 12 hours. A sample of 1.0-1.5 gm. of dried plant tissue was weighed and placed into a porcelain crucible. This was ashed in a muffle furnance at 500° C for 2 to 4 hours. The ash was then dissolved in 5 ml of 20% (2N) HCL to place the residue sample in complete solution. The solution was filtered through an acid-washed filter paper into a 50 ml flask and collected for analysis on the SMI III.

[1]Spectramics Inc., Lexington, Mass.

EXPERIMENT II - Silage Fermentation Study

A. Harvest of Biomass Trees and Alfalfa

At the time of first harvest, three samples per tree species and an alfalfa control were harvested, wilted to 30-40% DM, chopped uniformly as possible, and packed in laboratory glass silos for ensiling. Each sample was sealed tightly and had CO_2 gas bubbled through the sample for 2 minutes each. The samples were stored at the MSU Agricultural Fermentation Laboratory during the 24 day ensilement period.

B. Silage Analysis

A schematic diagram of analysis conducted is shown in the following figure. Immediately after removal from the experimental silos, total nitrogen was determined by macro-Kjeldahl procedures and percent dry matter determined by oven drying for 24 hours at 55^{o} C.

Silage extracts were prepared by homogenizing a 25 gm aliquot of the sample in a Sorvill homogenizer with 100 ml of distilled and deionized water for one minute and straining through two layers of cheesecloth. A 20 ml aliquot of the extract was used for determining pH and soluble nitrogen. The pH was determined on a Beckman Model 4500 pH meter.

The remainder of the extract was deproteinized using one ml of 50% sulfosalicylic acid (SSA) and nine ml of extract. The sample was then centrifuged at 18,000 rpm for 10 minutes and stored in a refrigerator for later analysis. Volatile fatty acid content of the silage was determined by

Schematic Diagram of Laboratory Analysis
Conducted on Silage Samples

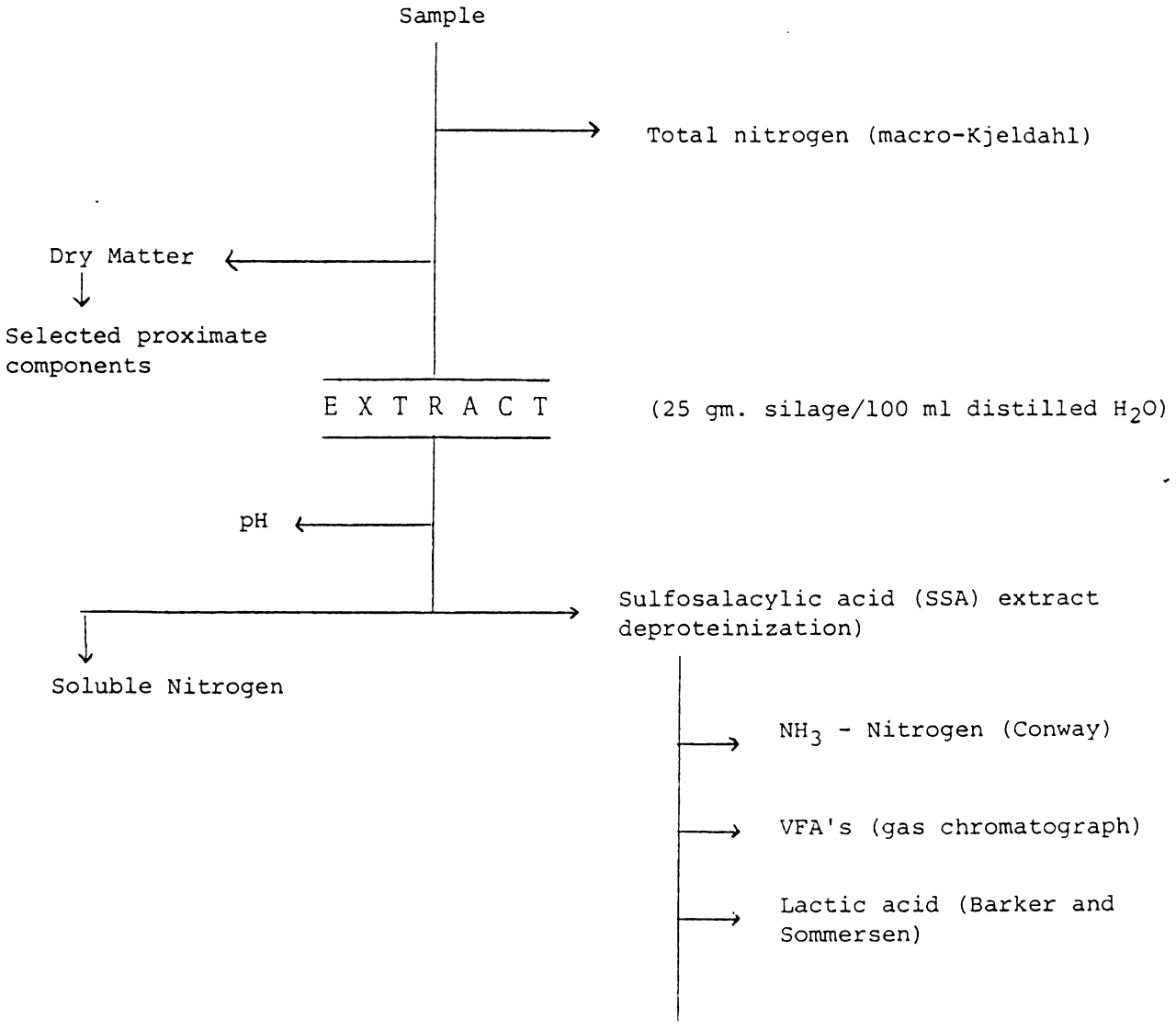


FIGURE 5.

Bergen et al. (1968)

Figure 6. ENSILEMENT STUDY - All biomass species were harvested and packed in triplicate. All samples were gassed with CO_2.

injecting samples of the deproteinized silage fluid described above into a Hewlett Packard 5840A Gas Chromotograph. Colorimetric procedures of Barber and Sommerson (1941) were used to determine lactic acid content of the deproteinized sample.

EXPERIMENT III - Rumen Degradation Using Dacron Bag Technique

A. Design of Study

Four rumen fistulated crossbred steers weighing approximately 363 Kg were utilized in the study. The steers were housed in the metabolism room of the Beef Cattle Research Center for the duration of the period. Each steer was fed an equal amount of grass-legume hay morning and night with trace mineral salt blocks and water presented free choice.

The degradability of each potential feedstuff was measured over a time period of 6-12-24 hours using the artificial bag technique described by (Orskov and Mehrez, 1977). Degradability of dry matter, nitrogen and ADF was measured on each specie. Each feedstuff was incubated in the rumen of each of the four steers in duplicate giving a total of eight values per treatment.

B. Experimental Procedure

Dacron bags containing 2000 holes/cm^2 were employed in the study. Each bag was made to a size of 12 X 5 cm and was stitched with rounded corners in order to avoid accumulation of the test feed and to facilitate easy removal of the residues. The bags were washed and dried to a

Figure 7. ABOVE: Nylon bags (2000 holes/cm^2) were tied to teflon paddle. Elastrator bands were placed over top of bag to insure proper seal of bag. FOLLOWING PAGE: Nylon bag containing known amount of sample was suspended into the rumen of a cammulated steer.

Figure 7a.

constant weight at 100° C. The required number of bags, each containing a known amount of samples, (3-4 gms) were each tied to a steel leader on a hard plastic paddle. The bags were soaked in water for approximately 5 minutes and then suspended in the rumen. At the end of each incubation interval, the bags were removed from the rumen and washed thoroughly under running tap water until the rinsing water was colorless. They were then dried to a constant weight at 100° C. The proportion of dry matter which had disappeared was calculated from the amount incubated and that left in the bag after incubation. Acid detergent fiber and nitrogen values were then calculated from the remaining residue.

EXPERIMENT IV - Digestion Trial

A. Design of Study

A 4 X 4 Latin Square design was employed to compare the dry matter intake, digestible energy intake, and digestion coefficients for dry matter, crude protein, digestible energy, and acid detergent fiber. Other parameters measured included rumen fluid pH, blood urea nitrogen, and rumen ammonia values. The four treatment diets included 100% alfalfa, 33.3% poplar - 66.6% alfalfa, 66.6% poplar - 33.3% alfalfa, and 100% poplar. The experimental design and rations are show in Table I.

B. Equipment Used

Metabolism Cages - sheep digestion cages were used which permitted the feeding of a known amount of feed and

TABLE 3. EXPERIMENTAL DESIGN FOR RATIONS AND METABOLIC TRIAL

	Feeding Period			
	1	2	3	4
Lamb Number				
1	A[1]	B	C	D
2	D	A	B	C
3	C	D	A	B
4	B	C	D	A

[1]Ration Code:
A - 100% alfalfa
B - 33.3% poplar - 66.6% alfalfa
C - 33.3% alfalfa - 66.6% poplar
D - 100% poplar

water and the quantitative collection of urine. Urine Containers - plastic containers were used to collect the daily urine volumes under the metabolism cages. Five liter plastic bottles were used to store the urine during the collection period. Feces Collections - feces were collected in collection bag harnesses and emptied both morning and night and wet weights were taken. Covered plastic buckets were used to store the feces during the collection period until subsequent analysis for dry matter, nitrogen, gross energy and acid detergent fiber content was performed. Scales - a portable Toledo scale was used to weigh the feed, feces, urine, and lambs at the beginning and end of each feeding trial. Preparation of Feed - previously weighed mixtures of the various rations were delivered to the Harold Lietzke Farm Pellet Mill at St. Johns, Michigan for processing. After pelleting the rations, the pellets were stored in dry plastic containers and sealed to avoid moisture and other contamination.

C. Feeding Program

Four Suffolk wethers weighing approximately 40-50 Kg were housed in the metabolism room at the MSU Beef Cattle Research Center during the entire experiment. The sheep were fed ad libitum once a day at 8:00 a.m. and were adjusted to new diets for 14 days prior to each 7 day collection period. Daily DM intake was reduced to 90% of the ad libitum feeding after the first 7 days of the adjustment period to insure adequate consumption. Fresh

water was given to the lambs both in the morning and night during the collection period. Trace mineralized salt was provided free choice to all the lambs during the entire study. The 7-day fecal collections were weighed and mixed thoroughly and subsampled for later analyses. Urine was collected in plastic bottles containing 20 ml concentrated sulfuric acid and an aliquot sample of daily urine was saved for nitrogen (N) analysis.

D. Preliminary Period

The purpose of the preliminary period was to acclimate the lambs with the metabolism cages, make the necessary equipment adjustments to insure that the feces and urine were collected properly, and adjust the animal to its intake of feed in relation to the excretion of feces and urine. A preliminary period of 14 days for each lamb was used to assure maximum consumption of each ration until the conditions of the experiment were met.

E. Preparatory Treatment

All lambs were shorn, vaccinated with Type D toxoid for enterotoxemia, drenched with Loxon for internal parasites, and all feet were trimmed. Rumen cannulas were inserted in each lamb 2 months in advance of the initial collection period.

F. Collection Period

The collection period for feces and urine ran for 7 consecutive days with the feed intake carefully measured.

Each afternoon before the collection was initiated, the cages and collection area was cleaned thoroughly. Each collection period began on the morning after the animal had been eating a constant amount of feed for the preliminary period. During the collection period, a random sample of the feed that was weighed out for feeding was saved for analysis. Feces and urine were removed from their containers, weighed, and stored in a freezer for subsequent analysis.

F. Rumen Fluid pH, Rumen Ammonia, and Volatile Fatty Acids

Rumen fluid samples were taken from each lamb at the end of each collection period and were analyzed for pH level by a Beckman Model 4500 pH meter. This rumen fluid was then strained through cheesecloth and samples were analyzed for rumen ammonia values in mg % on the Orion Ammonia Ion Electrode Model 95-10. VFA analysis was conducted using the Hewlett Packard 5840A Gas Chromatograph.

G. Blood Urea Nitrogen

Blood samples were collected in 10 ml heparinized vacutainers from the jugular vein of each of the lambs. The samples were then centrifuged at 3,000 rpm to separate plasma and cell contents and the plasma obtained was frozen. Urea nitrogen was determined using the Conway procedure (Conway, 1960). Conway dishes were prepared by adding 1 ml boric acid solution to their inner well and 1 ml of glycerol to the depression around the outside of the plate. Exactly .5 ml of the plasma was pipetted into the

one side of the outer well and then diluted with distilled water. A urease solution was added to the plate to convert the urea in the sample to NH_3. After the enzyme reaction, K_2 CO_3 was added to all the urease plates to release the ammonia. The plates were allowed to diffuse one hour on the rotator. They were then titrated, recorded, and calculated in mg/100 ml.

H. Statistical Analyses

All of the data from the digestion study, N balance, and the measured rumen and blood parameters were analyzed for treatment differences by the Latin Square analysis of variance method on the Hewlett Packard 9825A. Separation of mean values was conducted using the Studentized range test found in Statistical Tables by (Rahlf and Sokal, 1974).

RESULTS

Harvests of Biomass Trees and Alfalfa. Table 4 lists the eleven species which were utilized in this study. Ten hardwood tree species were selected for their rapid growth rate and ability to regenerate after cutting. Alfalfa (Medicago sativa) was selected as a control for comparison with the tree species. Alfalfa was chosen for a control because it represented a commonly used feedstuff that is high in nutrient value and could serve as a standard for rating the biomass tree species.

The approximate projected yields of alfalfa and biomass species are presented in Table 5. Values are given in both tons/acre and metric tons/hectare with alfalfa yielding the highest values with 4.5 and 10.1 respectively. Based on dry matter weights after two harvests, values for the biomass trees ranged from a low of 4.0 for willow to 8.5 for poplar in metric tons/hectare. Four of the biomass species, aspen, black alder, black locust, and honey locust all yielded over 7.0 metric tons/hectare.

Selected proximate analysis for biomass and alfalfa species are shown in Tables 6 and 7. Table 6 represents the early harvested samples while Table 7 exhibits the values for the same species harvested 8-9 weeks later. Field harvested dry matters for the (early harvest) ranged from 27.49

TABLE 4 . GENUS SPECIES FOR ALFALFA AND BIOMASS TREES

Common Name	Scientific Name
Alfalfa	Medicago sativa
Ailanthus	Ailanthus altissima
Aspen	Populus tremuloides
Black Alder	Alnus rubra
Black Locust	Robinia pscudoacacia
Birch	Betula papyrifera
Elm	Ulmus americana
Green Ash	Fraximus pennsylvanica
Honey Locust	Gleditsia triacanthos
Poplar	Populus deltoides
Willow	Salix nigra

TABLE 5. APPROXIMATE PROJECTED YIELDS OF ALFALFA AND BIOMASS TREES[1]

Plant Identification	U.S. Equivalent Tons/Acre	Metric Units Metric Tons/Hectare
Alfalfa	4.5	10.1
Aspen	3.4	7.6
Black Alder	3.1	7.0
Black Locust	3.2	7.2
Birch	3.0	6.7
Elm	2.5	5.6
Green Ash	2.2	4.9
Honey Locust	3.3	7.4
Poplar	3.8	8.5
Willow	1.8	4.0

[1]Yields are reported on a dry matter basis.

TABLE 6. (EARLY HARVEST) SELECTED PROXIMATE ANALYSES OF BIOMASS TREES AND ALFALFA[a]

Plant Identification[c]	Dry Matter[b]	Composition of Dry Matter			
		Crude Protein,%	Ash,%	Ether Extract,%	Gross Energy (Kcal/gm)
Alfalfa	28.21	22.13	7.64	3.44	4.64
Ailanthus	27.73	17.24	7.2	3.01	3.71
Aspen	29.82	19.44	6.91	3.64	4.10
Birch	28.22	15.21	5.23	3.82	4.15
Black Alder	27.49	20.83	6.87	4.01	4.01
Black Locust	30.31	23.87	8.95	3.11	4.21
Elm	29.98	16.26	6.24	2.87	4.11
Green Ash	27.84	17.84	8.24	3.14	4.01
Honey Locust	28.55	22.43	5.51	3.58	4.40
Poplar	29.46	21.72	6.22	3.26	4.51
Willow	31.37	13.31	7.42	2.74	3.55

[a]Values are the averages of three determinations.

[b]Dry matter values are on a fresh cut basis.

[c]Samples are listed in alphabetical order.

TABLE 7. (LATE HARVEST) SELECTED PROXIMATE ANALYSES OF BIOMASS TREES AND ALFALFA[a]

Plant Identification[c]	Dry Matter[b]	Composition of Dry Matter			
		Crude Protein,%	Ash,%	Ether Extract,%	Gross Energy (Kcal/gm)
Alfalfa	29.82	20.48	8.22	2.79	4.55
Ailanthus	28.24	16.55	7.81	2.51	3.43
Aspen	29.11	17.43	7.42	3.08	4.04
Birch	31.42	15.11	5.32	4.11	4.21
Black Alder	32.22	18.74	6.82	3,48	3.88
Black Locust	31.97	22.31	8.84	3,01	4.24
Elm	30.42	15.49	7.21	2.55	3.77
Green Ash	29.78	15.14	8.43	2.84	3.71
Honey Locust	28.24	20.23	6.41	3,11	4.12
Poplar	30.23	19.44	6.82	2.94	4.44
Willow	32.26	9.86	7.81	2.42	3.46

[a]Values are the average of three determinations.

[b]Dry matter values are on a fresh cut basis.

[c]Samples are listed in alphabetical order.

for black alder up to 31.37 for willow. In comparison with the (late harvest), values for field dry matter were higher ranging from 28.24 for both ailanthus and honey locust to a high of 32.26 for willow.

Crude protein values for the (early harvest) ranged from a low of 13.31 for willow up to 23.87 for black locust. Five of the eleven species averaged over 20% with an average for all biomass species being 18.81% crude protein. In contrast, crude protein values for the (late harvest) averaged 17.03 and had a range of 9.86% for willow up to 22.31% for black locust. Alfalfa contained 20.48% and exhibited the second highest value for both harvests.

Ash values for the (early harvest) ranged from 5.23% for birch to a high of 8.95% for black locust. Biomass species averaged 6.87% compared to 7.64% for alfalfa. In the late harvested samples, black locust and birch had the highest and lowest ash values with 8.84% and 5.32%, respectively. Biomass species on the average had an ash content of 7.28% compared to 8.22% for alfalfa.

Ether extract values recorded a range the early harvest samples of 2.74% for willow compared with 4.01% for black alder. Overall averages of ether extract for the biomass species recorded 3.31% to 3.44% for alfalfa. Regarding the late harvest values, birch and willow displayed the highest and lowest values with 4.11% and 2.42% respectively. Biomass species averaged 3.01% compared with 2.79% for alfalfa.

Gross energy values are also reported in Tables 6 and 7. Gross energy was highest for alfalfa at 4.64 Kcal/gm and

lowest for willow at 3.55 Kcal/gm for the early harvest. Overall the biomass species averaged 4.07 compared with 4.64 Kcal/gm for alfalfa. Values of gross energy for the late harvest were lower overall compared to the early harvest. Among the biomass species, poplar and ailanthus had the highest and lowest gross energy values respectively with 4.44 and 3.43 Kcal/gm. Biomass species averaged 3.93 Kcal/gm in comparison with alfalfa at 4.55 Kcal/gm.

The fiber fractions as determined by the detergent system are shown in Tables 8 and 9 for the early and late harvests respectively. Among all biomass species in the first harvest, NDF ranged from 54.81% for elm down to 39.83% for honey locust. Alfalfa was found to be 38.23% while the average for the biomass species was 45.12%. NDF values for the late harvest were higher overall with an average value of 48.4 for the biomass species and 42.42% for the alfalfa. Within the late harvest biomass species, elm was again highest at 58.31% with the low value being 42.93% for honey locust.

ADF values were also determined as part of the fiber components. ADF represents the lignin and cellulose fraction of each sample. In the early harvest, elm was found to contain 35.5% ADF with honey locust being lowest at 23.39%. Honey locust was similar in value to alfalfa at 23.82% ADF. Overall, the average ADF value for the biomass species was 28.3% within the early harvest. Within the late harvest, biomass species averaged 33.3% while alfalfa was 29.01%. Biomass species ranged from a low of 24.45% for honey locust

TABLE 8. FIBER ANALYSIS OF ALFALFA AND BIOMASS TREES[a] (EARLY HARVEST)

Plant Identification[b]	NDF,%	ADF,%	Lignin,%	Hemicellulose,%	Cellulose,%
Alfalfa	38.23	23.82	5.11	14.21	18.71
Ailanthus	46.14	33.90	12.17	12.24	21.73
Aspen	42.37	27.14	9.22	15.23	17.92
Birch	47.46	26.23	8.51	21.23	17.72
Black Alder	42.67	25.48	8.19	17.19	17.29
Black Locust	41.44	24.02	7.11	17.42	16.61
Elm	54.81	35.5	10.12	19.31	25.38
Green Ash	44.62	29.11	8.41	15.51	20.7
Honey Locust	39.83	23.39	5.46	16.44	17.98
Poplar	42.54	28.73	9.54	13.81	19.19
Willow	49.41	29.34	10.47	20.07	18.87

[a]Values are the average of three determinations.

[b]Values are listed on a dry matter basis.

TABLE 9. FIBER ANALYSIS OF ALFALFA AND BIOMASS TREES[a] (LATE HARVEST)

Plant Identification[b]	NDF,%	ADF,%	Lignin,%	Hemicellulose, %	Cellulose, %
Alfalfa	42.42	29.01	7.28	13.41	21.73
Ailanthus	53.37	39.26	15.53	14.11	23.63
Aspen	44.58	32.17	10.83	12.01	21.34
Birch	48.49	34.16	9.64	14.08	24.77
Black Alder	45.62	28.01	9.44	17.21	20.97
Black Locust	44.83	31.07	8.44	13.76	22.13
Elm	58.31	39.34	13.36	18.97	25.98
Green Ash	44.82	33.31	11.15	11.10	22.16
Honey Locust	42.93	24.45	6.74	18.48	17.71
Poplar	44.67	33.14	12.23	11.23	21.21
Willow	56.39	38.22	14.24	18.17	23.98

[a]Values are the average of three determinations.

[b]Values are listed on a dry matter basis.

to 39.34% for elm.

Lignin values were determined on all species within each harvest. Within the early harvest biomass species, elm was highest in lignin at 13.36% with the lowest value being honey locust, at 5.46%. The average value for lignin within the biomass samples was 9.24% while alfalfa was the lowest sample measured at 5.11%. Values for late harvest biomass species were higher in lignin than the early harvest with an average value of 10.63%. Values for the biomass species ranged from 6.74% for honey locust to 15.53% for ailanthus. Alfalfa was found to contain 7.28% lignin.

Hemicellulose values were determined by subtracting ADF from NDF. Within the (early harvest) biomass species, values ranged from 12.24% in ailanthus to 21.23% for birch. The average value for biomass species was 16.84% compared to 14.21% for alfalfa. Regarding the late harvest, values for biomass samples ranged from 11.10 for green ash up to 18.97 for elm. The overall average of the biomass species for this harvest was lower than the early harvest at 14.9%, but was greater than alfalfa at 13.41%.

Cellulose values were determined by subtracting % lignin from % ADF. Within the early harvest biomass species, values ranged from 16.61% for black locust to a high of 22.14% for elm. The average value for the biomass species was 19.01% compared with 18.71% for alfalfa. In the late harvest group, the range for % cellulose ranged from 17.71 for honey locust to 29.22 for elm. Biomass samples averaged 22.71 compared to alfalfa at 21.73.

Mineral contents of the biomass species and alfalfa are shown in Tables 10 and 11. In the early harvest calcium values for the biomass samples averaged 0.922% compared to alfalfa at 1.51%. Values varied on the biomass samples from .589% for aspen to 1.41% for black locust. Phosphorus values were higher for four of the biomass trees when compared with alfalfa. The biomass samples averaged .214% with alfalfa measuring .303%. The range biomass species was from .101% for birch to .332% for honey locust. Potassium values for all biomass samples ranged from 2.11% for willow to 3.94% for honey locust. The overall average for the biomass species was 3.07% and was higher than the value for alfalfa at 2.11%. Values for sodium averaged .057% and this value was lower than .12% reported for alfalfa. The range for the biomass species was .043% for willow up to .074% for elm. Magnesium values exhibited higher values for all of the biomass species with an average of .519% compared to alfalfa at .302%. The range for the biomass species ran from .394% for birch to .655% for ailanthus. Iron values ranged on the biomass species from 151.2 ppm for poplar up to 274.2 ppm for black alder. All biomass samples measured higher values for iron than did alfalfa at 135.7 ppm. The average value for iron for the biomass species was 195.4 ppm. Zinc values for the early harvest were quite variable with values for the biomass species ranging from 37.2 ppm up to 132.1 ppm. Alfalfa was again low for all samples measured at 33.1 ppm with the average for all biomass samples at 81.5 ppm. Aluminum levels were lowest for alfalfa at 31.2 ppm with an average of

TABLE 10. MINERAL CONTENTS OF BIOMASS TREES AND ALFALFA - (EARLY HARVEST)

Plant Identification	Ca	P	K	Na	Mg	Fe	Zn	Al	Cu	Mn
	%					ppm				
Alfalfa	1.51	.303	2.11	.12	.302	135.7	33.1	31.2	10.6	27.1
Ailanthus	.888	.315	3.64	.059	.655	269.2	37.2	137.1	4.13	91.6
Aspen	.589	.110	3.88	.069	.424	174.2	110.0	98.1	8.41	151.2
Birch	.684	.101	1.74	.054	.394	194.1	112.1	124.3	10.2	144.1
Black Alder	.704	.118	2.58	.044	.589	274.2	66.7	91.2	4.75	152.4
Black Locust	1.41	.311	3.87	.064	.524	184.1	62.2	92.4	8.21	112.2
Elm	1.18	.313	2.47	.074	.588	175.2	40.2	82.3	5.32	68.2
Green Ash	.874	.264	3.17	.057	.440	177.6	57.2	136.6	5.05	95.2
Honey Locust	1.25	.332	3.94	.054	.515	210.1	132.1	121.4	7.74	101.3
Poplar	.611	.182	3.31	.051	.554	151.2	95.4	58.4	7.15	174.4
Willow	1.04	.103	2.11	.043	.513	144.2	101.9	122.1	8.23	65.4

TABLE 11. MINERAL CONTENTS OF BIOMASS TREES AND ALFALFA - (LATE HARVEST)

Plant Identification	Ca	P	K	Na	Mg	Fe	Zn	Al	Cu	Mn
	%					ppm				
Alfalfa	1.41	.256	2.14	.14	.287	121.5	34.4	26.2	8.23	22.4
Ailanthus	.814	.321	3.12	.045	.611	271.3	31.3	131.0	4.71	85.1
Aspen	.483	.112	3.14	.048	.411	151.2	92.4	72.2	6.23	132.4
Birch	.612	.091	1.47	.051	.378	204.2	101.4	112.4	9.14	131.1
Black Alder	.632	.102	2.02	.031	.571	211.3	52.7	82.9	7.43	161.9
Black Locust	1.37	.277	3.51	.051	.510	165.1	68.3	84.4	8.11	104.1
Elm	1.07	.302	2.22	.079	.531	162.3	28.3	64.7	6.41	57.4
Green Ash	.887	.252	3.01	.042	.410	171.3	51.5	124.2	5.49	83.1
Honey Locust	1.04	.347	3.29	.061	.501	185.4	112.1	112.4	9.84	87.2
Poplar	.541	.148	3.15	.039	.561	123.2	82.5	48.2	6.22	148.1
Willow	.983	.118	2.03	.059	.481	121.9	88.1	131.9	7.15	51.7

106.4 ppm for the biomass species. The biomass species ranged from 58.4 ppm for poplar to 137.1 ppm for ailanthus. Copper values were low for all species analyzed with alfalfa being highest overall with 10.6 ppm. Values for the biomass samples ranged from 4.13 ppm for ailanthus to 10.2 ppm for birch with an overall average of 6.91 ppm. Manganese values were all higher than alfalfa at 27.1 ppm. The average value for the biomass samples was 115.6 ppm with values ranging from 65.4 ppm for willow to 152.4 ppm for black alder.

Mineral contents of the late harvest are presented in Table 11. Calcium values for alfalfa were found to be the highest at 1.41% compared to the average for biomass at .843%. Biomass samples ranged from .483% for aspen to 1.37% for black locust. This range and average for the biomass samples was lower than for the early harvest. Phosphorus ranged from .091% for birch to .347% for honey locust with an average of .207%. The range and average values for biomass species were approximately the same for both the early and late harvest. Alfalfa had a phosphorus value of .256%. Potassium values for biomass species averaged 2.7% compared to 2.14% for alfalfa. Biomass samples ranged from 1.47% for birch to 3.51% for black locust. The average value and range for the biomass samples were lower than for the early harvest. Sodium values displayed a similar trend with alfalfa measuring the highest value of all samples with .14%. The average value for the biomass samples was .050% with a range of .031 for black alder to .079% for elm. Values for magnesium were all higher for biomass species with an average

of .496% compared to alfalfa at .287%. This trend was similar to results from the (early harvest). Ranges for the biomass samples were found to be .378% for birch and .611% for ailanthus. Iron values displayed a similar trend as magnesium. All biomass values for iron were higher than alfalfa with an average value of 176.72 ppm compared to 121.5 ppm for alfalfa. Values for biomass samples ranged from 121.9 ppm for willow up to 271.3 ppm for ailanthus. Zinc levels varied within the biomass species displaying a range of 28.3 ppm for black locust to 101.4 ppm for birch. The average for biomass samples was 70.8 ppm compared with 34.4 ppm for alfalfa. Aluminum displayed a wide range of values with biomass samples at 48.2 ppm for poplar up to 131.9 ppm for willow. Average for the biomass species was 96.43 ppm with alfalfa containing 26.2 ppm. Copper values were similar to the early harvest and were consistent for biomass and alfalfa samples. Values ranged from 4.71 ppm for ailanthus up to 9.84 ppm for honey locust. Average for the biomass samples was 7.07 ppm compared to alfalfa 8.23 ppm. Manganese averaged 104.21 ppm for biomass species and was considerably higher than alfalfa at 22.4 ppm. The range for biomass species was 51.7 ppm for willow up to 161.9 ppm for black alder.

Hydrolysis of the delignified plant tissue with trifluoroacetic acid and derivitization to the corresponding alditol acetate yielded a pattern of the hemicellulosic sugars (Table 12) which includes glucose, galactose, mannose, xylose, arabinose, rhamnose, and possible ribose. In these

TABLE 12. HEMICELLULOSE COMPONENTS DETERMINED BY ALDITOL ACETATES[a,b]

Item	Hemi-Cellulose	Glucose	Galactose	Arabinose	Xylose	Mannose	Rhamnose	Uronic Acids	Xylose Arabinose Ratio
Alfalfa	14.46	25.64	5.37	9.92	20.46	9.14	2.31	32.15	2.06
Ailanthus	12.24	11.75	6.78	10.14	58.44	1.42	.84	12.14	5.76
Aspen	15.23	16.88	10.14	10.56	33.67	6.13	1.41	21.18	2.24
Birch	21.23	13.44	11.12	11.71	37.64	2.19	.41	23.31	3.21
Black Alder	17.19	17.17	12.97	12.41	31.19	4.87	.10	21.54	2.51
Black Locust	17.42	28.78	9.65	7.37	22.43	2.11	1.15	28.63	3.04
Elm	19.31	21.21	10.31	6.80	41.67	3.87	.71	16.43	6.12
Green Ash	15.51	19.08	10.94	13.09	27.11	4.34	1.22	24.28	2.09
Honey Locust	16.44	24.04	10.01	8.41	20.67	5.73	.86	30.27	2.45
Poplar	17.81	13.11	15.11	7.46	32.11	4.91	1.76	26.45	2.96
Willow	20.07	12.19	14.74	8.84	44.16	2.64	.47	17.04	4.19

[a]Hemicellulose is expressed as a percent DM.

[b]Sugars expressed as a percent of hemicellulose.

calculations, uronic acids, which may include those from pectins, were included in the hemicellulose fractions. Uronic acids in the ammonium oxalate and T.F.A.A. filtrates were determined by colorimetry. Glucose, galactose, arabinose, xylose, mannose, and rhamose were present in all substrates examined.

Glucose values for the biomass species ranged from 11.75% for ailanthus up to 28.78% for black locust. Alfalfa contained 25.64% glucose and was higher than the average for biomass samples at 17.76%. Galactose values were higher for all of the biomass species averaging 11.17% when compared to alfalfa at 5.37%. Alfalfa at 5.37% was lower in galactose than each of the biomass species. The biomass species ranged from 6.78% for ailanthus to 15.11% for poplar. Arabinose values for the biomass substrates averaged 9.67% compared to 9.92% for alfalfa. Biomass species ranged from 6.8% for elm up to 13.09% for green ash. Xylose values were highest for ailanthus, birch, elm, and willow. The average for xylose on the biomass samples was 34.9% compared to alfalfa at 20.46%. Alfalfa had the lowest value for xylose with honey locust next at 20.67%. The range in values for the biomass species was 20.67% for honey locust to 58.44% for ailanthus. Mannose levels were highest overall for alfalfa at 9.14%. The average for the biomass trees was 3.82% with aspen and ailanthus having the highest and lowest values at 6.13% and 1.42%, respectively. Rhamnose values for the biomass species ranged from .10% for black alder to 1.76%

for poplar. Overall, alfalfa had the highest value at 2.31% compared to .893%, the average for biomass species. Uronic acid values were highest for alfalfa at 32.15%. The uronic acids averaged the highest for all fractions measured with an average biomass value of 22.12%. Highest and lowest values for biomass species were honey locust and ailanthus with values of 30.27% and 12.14%, respectively. The xylose-arabinose ratio was calculated because it has been used as an indicator of plant maturity. The ratio ranged from 2.09 for green ash to 6.12 for elm in the biomass samples. Overall, alfalfa had the lowest ratio at 2.06 compared with the biomass average of 3.45.

Silage Fermentation Study - Samples from each of the 10 biomass trees and alfalfa were collected at the time of the early harvest and ensiled in 1 liter bottles. Selected proximate components of the substrates after ensiling are shown in Table 13. Dry matter values for the biomass samples ranged from 31.23% for black locust up to 42.17% for willow with the overall average for biomass samples at 35.02%. The dry matter value for alfalfa was 33.41%. Black locust and honey locust had the two highest crude protein values within the biomass trees at 23.19% and 22.07%, respectively. Poplar, black alder, and aspen were also measured high levels of crude protein at values of 21.68%, 20.44%, and 19.17%. Overall, the biomass species ranged from 12.41% for willow up to 23.19% for black locust. Alfalfa measured 22.84% and was higher than the overall biomass average at 18.52%. Ash

TABLE 13. SELECTED PROXIMATE ANALYSES OF ENSILED BIOMASS TREES AND ALFALFA[a]

Plant Identification[b]	Dry Matter	Composition of Dry Matter			
		Crude Protein,%	Ash,%	Ether Extract,%	Gross Energy (Kcal/gm)
Alfalfa	33.41	22.84	7.41	3.59	4.40
Ailanthus	31.22	18.55	6.24	2.94	3.65
Aspen	34.21	19.17	6.72	3.31	3.87
Birch	36.84	14.77	5.11	4.52	4.09
Black Alder	34.11	20.44	7.21	4.14	3.94
Black Locust	31.23	23.19	7.83	3.21	4.23
Elm	41.34	15.43	7.17	2.45	3.71
Green Ash	32.36	17.51	7.84	2.94	3.83
Honey Locust	31.46	22.07	6.21	3.41	4.12
Poplar	35.26	21.68	6.59	3.19	4.29
Willow	42.17	12.41	7.14	2.57	3.31

[a]Values are the averages of three determinations.

[b]Samples are listed in alphabetical order.

values were consistent throughout all substrates measured. Green Ash and birch had the highest and lowest values for biomass species at 7.84% and 5.11% respectively. The overall average for the tree species was 6.8% compared to alfalfa at 7.41%. Ether extract values were highest overall for birch and black alder at 4.52% and 4.14% respectively. The overall average was 3.27% with alfalfa recording 3.59%. The range for the biomass species was 2.45% for elm to 4.52% for birch. Gross energy revealed alfalfa to have the highest value overall at 4.40 Kcal/gm. The range for the biomass samples was from 3.31 Kcal/gm for willow up to 4.29 Kcal/gm for poplar. The average value for the biomass species was 3.90 Kcal/gm.

Fiber analysis was performed on all ensiled species and is shown in Table 14. NDF values ranged from 36.49% for honey locust to 54.46% for elm. The average was 43.87% for all biomass species. Alfalfa measured the lowest overall at 36.47%. ADF, which represents the lignin and cellulose fractions, ranged from 24.39% for birch up to 36.88% for elm. The average for the biomass samples was 28.74% compared to alfalfa at 21.47%. Lignin, which is the indigestible fraction of the plant tissue was highest overall for ailanthus at 13.98%. The average value for all biomass species 9.7% with alfalfa measuring 6.27%. The biomass samples ranged from 6.04% for honey locust to 13.98% for ailanthus. Hemicellulose fractions ranged from 11.87% for aspen to 17.58% for elm within the biomass samples. The overall average was 15.13% compared to alfalfa at 15.0%. Cellulose, which

TABLE 14. FIBER ANALYSIS OF ENSILED ALFALFA AND BIOMASS TREES[a]

Plant Identification[b]	NDF,%	ADF,%	Lignin,%	Hemicellulose,%	Cellulose,%
Alfalfa	36.47	21.47	6.27	15.0	15.2
Ailanthus	47.05	30.86	13.98	16.19	16.88
Aspen	40.44	28.57	9.21	11.87	19.36
Birch	45.19	24.39	8.67	20.8	15.72
Black Alder	43.59	28.43	9.22	15.16	19.21
Black Locust	43.26	26.36	7.04	16.9	19.32
Elm	54.46	36.88	12.17	17.58	24.71
Green Ash	40.92	27.42	9.07	13.5	18.35
Honey Locust	36.49	25.84	6.04	10.65	19.8
Poplar	39.68	27.56	9.86	12.12	17.7
Willow	47.66	31.10	12.11	16.56	18.99

[a]Values are the average of three determinations.

[b]Values are listed on a dry matter basis.

is calculated by subtracting % lignin from % ADF, was highest overall for elm at 24.71%. The range in values was from a low of 15.72% for birch up to 24.71% for elm. Alfalfa contained the least cellulose at 15.2% and was considerably lower than the biomass average of 19.04%.

Table 15 contains mineral contents of the ensiled biomass and alfalfa samples. Values for the minerals followed the same trend as the analysis Table 10. Alfalfa was higher in calcium, phosphorus and sodium than any of the biomass species. However, black locust, honey locust and elm all had values of over 1.0% calcium.

The nitrogen distribution of the ensiled alfalfa and biomass samples are shown in Table 16. Total N% for the biomass samples was highest for black locust (3.71%), honey locust (3.53%) and black alder (3.27). Alfalfa was second among all the species at 3.65%. Values ranged from 1.98% for willow up to the overall high of 3.71% for black locust. The average nitrogen value was 2.96% for the biomass samples. Crude protein results were previously discussed in Table 14 and were calculated by multiplying the % N X 6.25. The soluble nitrogen fraction revealed a value of 1.72% for alfalfa which was highest overall. Honey locust had the second highest value at 1.62% and willow was lowest at .74%. The average value for the trees was 1.38% soluble nitrogen. Insoluble nitrogen, calculated by subtracting soluble nitrogen from total nitrogen was highest for black alder at 2.23 and black locust at 2.17%. It should be noted, however, that these two species were two of the highest in total nitrogen.

TABLE 15. MINERAL CONTENTS OF ENSILED ALFALFA AND BIOMASS TREES

Plant Identification	Ca	P	K	Na	Mg	Fe	Zn	Al	Cu	Mn
	%					ppm				
Alfalfa	1.62	.184	2.34	.141	.372	129.4	32.8	50.4	13.6	33.5
Ailanthus	.975	.169	3.88	.061	.756	275.2	32.5	145.0	6.39	123.3
Aspen	.601	.102	4.12	.064	.455	178.1	103.2	95.1	12.9	162.1
Birch	.644	.095	1.98	.047	.422	215.4	86.5	103.1	10.9	150.1
Black Alder	.651	.078	2.98	.032	.472	243.3	64.7	85.7	10.1	157.2
Black Locust	1.40	.153	4.04	.079	.607	238.0	75.9	154.1	12.4	138.4
Elm	1.02	.116	2.97	.083	.581	152.6	47.6	87.6	7.33	85.8
Green Ash	.914	.152	4.10	.065	.518	194.4	66.0	150.2	7.30	110.1
Honey Locust	1.37	.151	4.10	.067	.622	210.1	64.2	133.2	8.23	110.0
Poplar	.640	.198	3.66	.040	.526	166.9	105.4	51.3	8.83	187.0
Willow	1.10	.083	2.35	.053	.485	151.0	105.1	114.0	10.1	74.7

TABLE 16. NITROGEN DISTRIBUTION OF ENSILED ALFALFA AND BIOMASS TREES[a]

Item	Alfalfa	Ailanthus	Aspen	Birch	Black Alder	Black Locust	Elm	Green Ash	Honey Locust	Poplar	Willow
Total N, %	3.65	2.97	3.07	2.36	3.27	3.71	2.47	2.80	3.53	3.46	1.98
Crude Protein, %	22.84	18.55	19.17	14.77	20.44	23.19	15.43	17.51	22.07	21.68	12.41
Soluble N, %	1.72	1.15	1.57	.84	1.04	1.54	1.03	1.10	1.62	1.46	.74
Insoluble N, %	1.93	1.82	1.50	1.52	2.23	2.17	1.44	1.70	1.91	1.85	1.24
NH_3-N, %	.23	.13	.26	.16	.27	.17	.11	.16	.21	.24	.14
(SN)-(NH_3-N), %	1.49	1.02	1.31	.68	.77	1.37	.92	.94	1.41	1.22	.60
Soluble N, % of total N,	47.12	38.72	51.14	35.59	31.80	41.50	41.7	39.28	45.9	44.11	37.37
Insoluble N, % of total N,	52.8	61.2	48.8	64.4	68.19	58.5	58.3	60.7	54.1	55.9	62.6
NH_3-N, % of total N,	6.3	4.37	8.46	6.8	8.25	4.6	4.45	5.11	5.94	7.25	7.07
(SN)-(NH_3N), % of total N,	40.8	34.3	42.7	28.9	23.54	36.9	37.2	33.6	39.9	36.8	30.3

[a]Values are the average of three determinations.

Alfalfa measured 1.93% with the average for biomass species 1.73%. The range for the biomass trees was 1.24% for willow up to 2.23% for black alder. NH_3-N% was measured with the Conway method and ranged from .11% for elm up to .27% for black alder. The average for the tree samples was .20% compared to alfalfa at .23%. Soluble nitrogen as a percent of total nitrogen is also displayed in this table. Aspen was highest overall at 51.14% followed by alfalfa and honey locust at 47.12% and 45.9% respectively. Ranges for the tree species were from 31.8% for black alder up to 51.14% for aspen. The average for the biomass substrates was 40.71%. The insoluble nitrogen as a percentage of total nitrogen was highest overall for black alder at 68.19%. The average for the trees was 59.26% compared to alfalfa at 52.8%. The range for the biomass species was 48.8% for aspen up to 68.19% for black alder. NH_3-N as a percent of total nitrogen was highest for aspen at 8.46% with black alder following at 8.25%. The range for the trees was 4.37% for ailanthus up to 8.46% for black alder. Alfalfa measured 6.3% compared to the average for biomass substrates at 6.23%. The (soluble nitrogen - ammonia nitrogen) as a percent of the total nitrogen ranged from a low of 23.54% for black alder to 42.7% for aspen. Alfalfa recorded 40.8% with the average for the biomass species 34.4%.

The values for pH and organic acids are expressed in Table 17. The biomass trees' pH range was from 4.66 for black locust up to 5.45 for elm. The average pH for the biomass species was 5.09 compared with alfalfa at 4.11.

TABLE 17. pH AND ORGANIC ACID CONTENTS OF ENSILED ALFALFA AND BIOMASS TREES[a]

Item	pH	Organic Acids, % of DM				
		Lactic	Acetic	Propionic	Butyric	Valeric
Alfalfa	4.11	5.35	3.04	.64	.09	.00
Ailanthus	5.15	4.31	3.24	.72	.14	.00
Aspen	4.88	4.07	2.84	.54	.11	.04
Birch	4.87	3.14	1.76	.81	.31	.10
Black Alder	4.84	4.41	2.46	.23	.10	.00
Black Locust	4.66	4.83	2.81	.57	.06	.00
Elm	6.45	3.86	1.46	.68	1.03	.11
Green Ash	4.64	4.17	2.11	.44	.21	.06
Honey Locust	4.91	4.55	2.27	.61	.06	.00
Poplar	4.95	4.64	2.03	.57	.14	.08
Willow	6.40	2.32	1.87	.75	1.14	.14

[a]All analyses are reported as a % of dry matter.

[b]Values are the average of three determinations.

Organic acids were measured using gas chromatography and expressed as a % of total dry matter. Percent lactic acid was highest overall for alfalfa at 5.35% with the low value being 2.32% for willow. In the biomass samples, highest values were recorded for poplar at 4.64%, black locust at 4.83% and honey locust at 4.55%. The average for biomass trees was 4.03%. Acetic acid values on the biomass substrates averaged 2.28% with ailanthus being highest overall at 3.24%. Lowest of the samples was 1.46% for elm. Alfalfa measured 3.04% and was the second highest recorded value. Propionic acid values ranged from .23% for black alder up to .81% for birch. The average for the biomass species was .59% compared to .64% for alfalfa. Butyric acid values were highest for elm at 1.03% and willow at 1.14%. The average for the biomass substrates was .33% with alfalfa recording .09%. Valeric acid values were minimal for most species. Five of the samples displayed no valeric acid and the highest value was willow at .14%.

Nylon Bag Degradability - Dry matter disappearance from nylon bags incubated in the rumen of steers is listed in Table 18 and shown graphically in Figures 7 and 8. Samples from both the early and late harvest were incubated for 6-12-24 hours. Within the 6 hour interval, alfalfa was significantly higher ($P<.01$) in dry matter disappearance (32.14) than poplar (24.67), aspen (23.26), black alder (22.68), ailanthus (18.62), willow (17.83) and elm (14.21). Alfalfa was significantly higher ($P<.05$) than black locust

TABLE 18. DRY MATTER DISAPPEARANCE FROM NYLON BAGS INCUBATED IN THE RUMEN OF STEERS (g/100g incubated)

Hours of Incubation	Alfalfa	Ailanthus	Aspen	Birch	Black Alder	Black Locust	Elm	Green Ash	Honey Locust	Poplar	Willow
	Early Harvest of Biomass Trees and Alfalfa										
6	a,g 32.14	c,d,e,l 18.62	b,c,j,k 23.26	a,b,i,j 25.39	b,d,k 22.68	a,b,h 28.43	e,m 14.21	a,b,h,i 27.59	a,b,h 29.78	b,c,j,k 24.67	e,l 17.83
12	a,g 43.67	e,f,l,m 22.83	c,d,j,k 29.64	d,e,k,l 26.41	b,c,i,j 31.21	b,c,h,i 34.22	f,n 17.31	c,d,i,j 30.39	a,b,h 37.66	c,d,j,k 29.43	e,f,m 21.42
24	a,g 58.43	d,k 29.44	b,c,i 39.91	c,d,j 35.51	b,c,i 38.42	b,h 46.53	d,k 27.31	b,c,i 38.02	a,g 55.97	b,c,i,j 37.26	d,k 28.6
	Late Harvest of Biomass Trees and Alfalfa										
6	a,g 27.05	c,d,k 12.74	a,b,i 22.14	a,h 24.25	b,c,j 18.66	a,b,h,i 23.76	d,l 9.49	a,b,i 22.17	a,g,h 26.9	a,h,i 24.12	c,d,k 14.47
12	a 41.32	d,j 15.12	b,h 27.63	b,c,h 26.12	b,h 27.57	b,h 29.37	d,j 14.5	b,g,h 31.6	b,g 33.77	b,h 28.71	c,d,i 19.07
24	a,g 51.03	d,l 16.88	b,c,i,j 35.08	c,i,j 33.8	c,j 31.13	b,h 42.02	d,k,l 17.84	b,c,i 36.58	a,g 49.85	c,i,j 34.31	d,k 20.54

a,b,c,d,e,f Values with different superscripts are significantly different (P<.01)

g,h,i,j,k,l,m,n Values with different superscripts are significantly different (P<.05)

(28.43), green ash (27.59) and birch (25.39). No significant difference was found between alfalfa and honey locust (29.78) at the 6 hour sampling. Within the biomass species, honey locust, black locust and green ash resulted in the highest values. The average for the biomass samples was 23.24 compared to 32.14 for alfalfa. Measurements at 12 hour resulted in the overall high value of 43.67 for alfalfa. This value was significantly higher ($P<.01$) than black locust (34.22), black alder (31.21), green ash (30.39), aspen (29.64), poplar (29.43), birch (26.41), ailanthus (22.83), willow (21.42), and elm (17.31). Alfalfa was significantly higher ($P<.05$) than honey locust (37.66). The values for the biomass trees ranged in value from 37.66 for honey locust to 17.31 for elm. The average for the biomass species was 28.05 compared to alfalfa at 43.67. Honey locust, black locust and black alder were the highest ranking biomass species, respectively. At 24 hours, alfalfa was again highest overall at 58.43. Alfalfa was significantly higher ($P<.01$) than black locust (42.53), aspen (39.91), black alder (38.42), green ash (38.02), poplar (37.26), birch (35.51), ailanthus (29.44), willow (28.6) and elm (27.31). No significant difference was seen between alfalfa and honey locust (55.11). Honey locust at 55.11 was significantly greater ($P<.01$) than the same species mentioned above for alfalfa. Overall the mean for the biomass trees was 37.21 with the range from 27.31 for elm up to 55.11 for honey locust. Honey locust, black locust, and aspen were the three highest values for the tree species. The late

harvest values appear in Table 18 also. Within the 6 hour time interval, alfalfa was significantly greater ($P<.01$) than black alder (18.66), willow (14.47), ailanthus (12.74), and elm (9.49). Alfalfa was significantly greater ($P<.05$) than black locust (23.76), green ash (22.17) and aspen (22.14). Within the biomass species, the overall average was 19.87 compared to alfalfa at 27.05 and the average for the 6 hour interval within the early harvest at 23.24. No significant difference was found between alfalfa and honey locust, within the six hour interval. Honey locust, birch and poplar were the three highest values for the biomass species. Within the twelve hour interval, alfalfa was the highest value overall at 41.32. This was significantly greater ($P<.01$) than honey locust (33.77), green ash (31.6), black locust (29.37), poplar (28.71), aspen (27.63), black alder (27.57), birch (26.12), willow (19.07), ailanthus (15.12), and elm (14.5). The tree species averaged 25.34 compared to 28.05 for the early harvest samples. The range within the tree species was from 14.5 for elm to 33.77 for honey locust. Within the 24 hour measurement, alfalfa was significantly higher ($P<.01$) than green ash (36.58), black locust (36.55), aspen (35.08), poplar (34.31), birch (33.8), black alder (31.13), willow (20.54), elm (17.84) and ailanthus (16.88). No significant difference was demonstrated between alfalfa and honey locust (49.85). Honey locust was significantly greater ($P<.01$) than the same species as for alfalfa. The average for the biomass trees was 31.25 compared to 37.21 for the early harvest and

51.03 for alfalfa.

The disappearance of nitrogen from the nylon bags is shown in Table 19 and Figures 9 and 10. The values for the six hour interval early harvest found alfalfa to be significantly higher ($P<.01$) at 34.89 than green ash (25.67), aspen (21.48), poplar (21.14), ailanthus (19.16), willow (18.46) and elm (17.59). The biomass species ranged from 17.59 for elm up to 33.46 for black locust with the average being 24.58. Alfalfa was also significantly higher ($P<.05$) than honey locust (31.09), black alder (29.96), and birch (27.8). There was no significant difference between alfalfa and black locust. Within the twelve hour sampling, alfalfa was significantly higher ($P<.01$) than black alder (34.1), aspen (32.3), green ash (31.36), poplar (29.6), birch (29.35), ailanthus (24.61), willow (23.58) and elm (20.45). Alfalfa was also significantly higher ($P<.05$) than honey locust (43.56) and black locust (41.14). Black locust and honey locust were both significantly greater ($P<.01$) than the same species listed for alfalfa previously. The average for the biomass samples was 31.0 compared to alfalfa at 48.03. The 24 hour sampling displayed alfalfa as the highest overall value at 63.15. This value was significantly greater ($P<.01$) than poplar (44.37), aspen (43.14), green ash (42.83), black alder (41.42), birch (38.74), ailanthus (31.3), elm (29.38) and willow (28.21). Both honey locust and black locust at 58.93 and 57.22 respectively were significantly greater than the same species listed for alfalfa. However, alfalfa was

TABLE 19. NITROGEN DISAPPEARANCE FROM NYLON BAGS INCUBATED IN THE RUMEN OF STEERS (g/100g incubated)

Hours of Incubation	Alfalfa	Ailanthus	Aspen	Birch	Black Alder	Black Locust	Elm	Green Ash	Honey Locust	Poplar	Willow
	Early Harvest of Biomass Trees and Alfalfa										
6	a,g 34.89	c,d,l,m 19.16	c,d,l 21.48	a,b,c,j,k 27.8	a,b,i,j 29.96	a,g,h 33.46	d,m 17.59	b,c,k 25.67	a,b,h,i 31.09	c,d,l 21.14	d,l,m 18.46
12	a,g 48.03	d,e,f,k 24.61	c,i,j 32.3	c,d,e,j 29.35	b,c,i 34.1	a,b,h 41.14	f,l 20.45	c,d,i,j 31.36	a,h 43.56	c,d,e,j 29.6	e,f,k,l 23.58
24	a,g 63.15	c,d,k 31.3	b,i 43.14	b,c,j 38.74	b,i,j 41.42	a,h 57.22	d,k 29.38	b,i 42.83	a,h 58.93	b,i 44.37	d,k 28.21
	Late Harvest of Biomass Trees and Alfalfa										
6	a,g 28.4	c,i 15.43	a,b,h 23.25	a,b,h 24.35	a,g 28.08	a,g,h 27.64	c,i 15.74	b,c,i 18.79	a,b,g,h 26.82	b,c,i 18.23	c,i 16.33
12	a,g 43.06	d,e,k 22.28	c,d,i 30.51	d,j 26.71	b,c,h 35.32	c,d,i 34.81	c,i 16.31	d,j 26.16	a,b,h 37.91	c,d,i,j 28.86	d,e,k 21.17
24	a,g 53.34	c,k 26.34	b,i,j 38.24	b,j 36.07	b,i 40.57	a,g,h 49.51	c,l 21.68	b,j 35.51	a,b,h 45.63	b,j 35.92	c,k,l 24.65

a,b,c,d,e,f Values with different superscripts are significantly different (P<.01)

g,h,i,j,k,l Values with different superscripts are significantly different (P<.05)

greater (P<.05) than both honey locust and black locust. The average for the biomass species was 41.55 with the range from 28.21 for willow up to 58.93 for honey locust. Within the late harvest, values for the six hour biomass smaples ranged from 14.53 for ailanthus up to 28.08 for black alder. Alfalfa was significantly greater (P<.01) than green ash (18.79), poplar (18.23), willow (16.33), elm (15.74), and ailanthus (15.43). Black alder (28.08), black locust (27.64) and honey locust (26.42) were also significantly greater (P<.01) than the same species as alfalfa. Alfalfa and black alder were significantly greater (P<.05) than birch (24.25) and aspen (23.25). The overall average for the biomass species was 21.42 compared to alfalfa at 28.4. Within twelve hours, the range for the biomass samples was 16.31 for elm up to 37.91 for honey locust. Alfalfa was significantly higher (P<.01) than black alder (35.32), black locust (34.81), aspen (30.51), poplar (28.86), birch (26.71), green ash (26.16), ailanthus (22.28), willow (21.17) and elm (16.31). Overall, the biomass species averaged 28.0 compared to alfalfa at 43.06. Alfalfa was significantly greater (P<.05) than honey locust, black alder, and black locust. Within the biomass samples, honey locust, black alder, and black locust were significantly greater (P<.05) than the other true species. Within the 24 hour interval, alfalfa was again the highest value overall at 53.34. Alfalfa was higher significantly (P<.01) than black alder

(40.57), aspen (38.24), birch (36.07), poplar (35.92), green ash (35.51), ailanthus (26.34), willow (24.65) and elm (21.68). Alfalfa was also significantly higher ($P<.05$) than honey locust but was not significantly greater than black locust at 49.51. The range for the biomass species was from 21.68 for elm to 49.51 for black locust with an average of 35.41.

ADF disappearance over 6-12-24 intervals is listed in Table 20 and shown graphically in Figures 11 and 12. Within the early harvest, the six hour study found alfalfa to the highest overall value at 14.27. This was significantly greater ($P<.01$) than aspen (8.21), elm (6.42), willow (6.21) and ailanthus (5.37). The overall average for the biomass species was 9.03 compared to alfalfa at 14.27. Alfalfa was also significantly greater ($P<.05$) than black alder (10.64), birch (10.18), green ash (9.51) and poplar (9-24). The range for the biomass species was from 6.21 for willow to 12.97 for honey locust. Within the 12 hour study, the average biomass value was 12.12 compared the overall high of 19.73 for alfalfa. Alfalfa was significantly greater ($P<.01$) than birch (12.9), green ash (12.27), aspen (12.11), poplar (11.62), elm (10.9), black alder (10.53), ailanthus (9.52) and willow (8.94). Black locust was significantly greater ($P<.01$) than elm, black alder, ailanthus, and willow. Alfalfa was significantly greater ($P<.05$) than honey locust at 15.18. The range for the biomass samples ranged from 8.94 for

TABLE 20. ADF DISAPPEARANCE FROM NYLON BAGS INCUBATED IN THE RUMEN OF STEERS (g/100g incubated)

Hours of Incubation	Alfalfa	Ailanthus	Aspen	Birch	Black Alder	Black Locust	Elm	Green Ash	Honey Locust	Poplar	Willow
	Early Harvest of Biomass Trees and Alfalfa										
6	a,g 14.27	d,i 5.37	b,c,d,h,i 8.21	a,b,c,h 10.18	a,b,c,h 10.64	a,b,g,h 11.57	c,d,i 6.42	a,b,c,d,h 9.51	a,b,g,h 12.97	a,b,c,d,h 9.24	c,d,i 6.21
12	a,g 19.73	c,d,i,j 9.52	b,c,d,h 12.11	b,c,d,h 12.9	c,d,i,j 10.53	a,b,g,h 17.31	c,d,i,j 10.9	b,c,d,h 12.27	a,b,c,h 15.18	b,c,d,i,j 11.62	d,j 8.94
24	a,g 23.01	d,e,k 10.25	c,d,e,i,j,k 13.85	b,c,d,h,i 15.44	b,c,d,e,i 14.72	a,b,g 21.64	b,c,d,e,i,j 14.29	b,c,h,i 16.46	a,b,g 20.6	b,c,d,e,i,j 14.27	d,e,j,k 11.17
	Late Harvest of Biomass Trees and Alfalfa										
6	a,g 13.43	d,l 2.48	b,i,j 8.15	b,i,j 8.21	b,c,d,i,j,k 7.04	a,b,h,i 10.61	b,c,d,j,k 6.04	b,c,i,j 7.94	a,b,h,i 10.39	b,c,i,j 7.81	c,d,k,l 3.43
12	a,g 16.09	d,e,l 4.11	b,c,i,k 10.33	a,b,c,h,i 12.35	b,c,i,k 10.22	a,b,g,h 15.47	c,d,e,k 7.21	c,d,e,k 8.39	a,b,c,g,h 14.05	c,k 9.14	e,l 3.81
24	a,g 18.97	d,e,k 7.04	c,d,e,j 10.56	a,b,c,h,i 14.64	b,c,i,j 12.10	a,b,g,h 16.07	c,d,e,j 10.38	b,c,d,i,j 11.81	a,b,g,h 16.58	b,c,d,j 11.64	e,k 6.28

a,b,c,d,e,f Values with different superscripts are significantly different (P<.01)

g,h,i,j,k,l Values with different superscripts are significantly different (P<.05)

illow to 17.31 for black locust. In the 24 hour sampling, the biomass trees ranged from 10.25 for ailanthus to 21.64 for black locust with an overall average of 15.07 for the biomass spcies. Alfalfa (23.01) was highest overall but not significant differenct was shown between it and black locust (21.64) and honey locust (20.6). Alfalfa and black locust were significantly higher ($P<.01$) than aspen (13.85), willow (11.17) and ailanthus (10.25). Alfalfa, black locust and honey locust were significantly higher ($P<.05$) than green ash (16.46), birch (15.44), black alder (14.72), elm (14.29) and poplar (14.29).

Utilizing the late harvest samples, the six hour biomass samples averaged 7.21 compared to the early harvest at 9.03. At six hours, alfalfa was the highest value overall at 13.43. This value was significantly higher ($P<.01$) than birch (8.21), aspen (8.15), green ash (7.94), poplar (7.81), black alder (7.04), elm (6.04), willow (3.43) and ailanthus (2.48). The range for the biomass trees ranged from a low of 2.48 for ailanthus up to 11.61 for black locust. Black locust and honey locust were significantly greater ($P<.05$) than the other biomass species tested. Within the twelve hour period, alfalfa, black locust and honey locust displayed no significant differences. The values for the biomass species ranged from 3.81 for willow to 15.47 for black locust with an average of 9.50 compared to 12.12 for the early harvest. Alfalfa was significantly higher than aspen (10.33), black alder (10.22), poplar (9.14), green ash (8.39), elm (7.21), ailanthus (4.11) and

willow (3.81). Within the trees, black locust and honey locust were significantly greater (P<.05) than aspen and black alder. At 24 hours, the extent of ADF disappearance ranged from 6.28 for willow up to 16.58 for honey locust. Alfalfa was again highest overall at 18.97. This was significantly greater (P<.01) than black alder (12.10), green ash (11.81), poplar (11.64), aspen (10.56), elm (10.38), ailanthus (7.04) and willow (6.28). No significant difference was seen between alfalfa and black locust (16.58) and honey locust (16.07). The overall average for the biomass late harvest species was 11.71 compared to 15.07 for the early harvest.

Feeding Trial Results - The chemical composition of the four diets fed during the lamb feeding trial are found in Table 21. All of the diets were pelleted and their dry matters ranged from 93.71% for (100% poplar) to 94.12% for the (66.6% poplar - 33.3% alfalfa) ration. Ash values ranged from 6.87% for (100% poplar) to 7.42 for (100% alfalfa). Crude protein values were similar in value and ranged from 18.21% for (100% poplar) to 19.71% for (100% alfalfa). Ether extract was highest for (100% alfalfa) at 3.57% and lowest for (100% poplar) at 3.14%. Gross energy values in Kcal/gm ranged from 4.16 for 100% poplar to 4.53 for 100% alfalfa.

The fiber analysis of the four treatment diets is found in Table 22. % NDF ranged from 39.12% for (100% alfalfa) to 43.92% for (100% poplar). The range for ADF

TABLE 21. CHEMICAL COMPOSITION OF TREATMENT DIETS[a]

Item	Alfalfa (100%)	Alfalfa (66.6%) Poplar (33.3%)	Poplar (66.6%) Alfalfa (33.3%	Poplar (100%)
Dry Matter, %	94.04	93.52	94.12	93.71
Ash, %	7.42	7.25	6.84	6.87
Crude Protein, %	19.71	18.87	18.74	18.21
Ether Extract, %	3.57	3.46	3.33	3.14
Gross Energy, Kcal/gm	4.53	4.49	4.37	4.16

[a]Dry matter was taken after pelleting - subsequent measurements on ash, crude protein, ether extract and gross energy are analyses on a dry matter basis.

TABLE 22. FIBER ANALYSIS OF TREATMENT DIETS FOR LAMB TRIAL[a]

Diet Identification[b]	NDF,%	ADF,%	Lignin,%	Hemicellulose	Cellulose,%
Alfalfa (100%)	39.12	27.67	6.87	11.45	20.81
Alfalfa (66.6%) Poplar (33.3%)	41.64	29.74	9.04	11.9	20.70
Poplar (66.6%) Alfalfa (33.3%)	41.88	30.12	10.81	11.76	19.31
Poplar (100%)	43.92	33.31	12.37	10.61	20.94

[a]Values are the average of three determinations.

[b]Values are listed on a dry matter basis.

was from 27.67% for (100% alfalfa) to 33.31% for (100% poplar). Lignin values were lowest for (100% alfalfa) at 6.87 compared to the high value of 12.37% for the 100% poplar. The hemicellulose and cellulose fractions were determined by difference with hemicellulose values ranging from 10.61% for (100% poplar) to 11.9% for the (66.6% alfalfa - 33.3% poplar) ration. Cellulose values ranged from 19.31% for the (66.6% poplar - 33.3% alfalfa) ration to 20.94% for the (100% poplar).

The affect of feeding increasing levels of poplar on nutrient intake, apparent digestibility and nitrogen retention is shown in Table 23. For simplication, codes for the diets are (100% alfalfa - 1), (66.6% alfalfa - 33.3% poplar - 2),(66.6% poplar - 33.3% alfalfa - 3), (100% poplar - 4).

Dry matter intake was significantly higher ($P<.01$) for rations 1, 2, and 3, than ration 4. Dry matter intake values ranged from 72.81 for diet 4 up to 87.74 for ration 1. Crude protein intake was significantly higher ($P<.05$) for diets 1 (17.29) and 2 (16.41) than diet 4 (13.26). No significance was demonstrated between rations 1, 2 and 3 and between 3 and 4. The intake of acid detergent fiber values demonstrated no significant difference between any of the treatment means. Gross energy intake was significantly higher (Kcal) ($P<.01$) for diet 1 than both diets 3 and 4. It was also significantly greater ($P<.05$) than diet 2. Values on gross energy intake ranged from 318.93 for diet 4 up to 396.58 for diet 1. Digestible energy intake, which was calculated by multiplying the digestible energy

TABLE 23. EFFECT OF FEEDING FOUR LEVELS OF POPLAR ON NUTRIENT INTAKE AND APPARENT DIGESTIBILITIES

Item	Alfalfa (100%) - 1	Alfalfa (66.6%) Poplar (33.3%) - 2	Poplar (66.6%) Alfalfa (33.3%) - 3	Poplar (100%) - 4
Nutrient intake (g/Kg BW $^{0.75}$)				
Dry Matter	87.74^{a,e}	86.93^{a,e}	83.57^{a,f}	72.81^{b}
Crude Protein	17.29^{e}	16.41^{e}	15.65^{e,f}	13.16^{f}
Acid Detergent Fiber	24.27	25.71	25.16	24.25
Gross Energy, Kcal	396.58^{a,e}	385.84^{a,f}	365.19^{b}	318.93^{c}
Digestible Energy, Kcal	255.78^{a}	233.96^{b}	198.44^{c}	160.13^{d}
Apparent digestibility (%)				
Dry Matter	69.86^{a,e}	65.54^{a,f}	62.02^{a,f}	53.86^{b}
Crude Protein	62.23^{a,e}	59.18^{a,b,e}	55.04^{a,b,f}	52.11^{b,f}
Acid Detergent Fiber	45.89^{a,e}	44.29^{a,b,e}	38.28^{a,b,f}	35.27^{b,f}
Energy	64.6 ^{a,e}	60.64^{a,f}	54.34^{b,g}	50.21^{b,h}
Nitrogen Retention				
N Retention, g/day	12.12^{e}	11.72^{e,f}	9.65^{f,g}	7.31^{g}
$\overline{N}$ Retention, % of total N intake	32.37^{e}	29.43^{e}	25.17^{f}	25.31^{f}

^{a,b,c,d} Values with different superscripts are significantly different ($P<.01$)

^{e,f,g,h} Values with different superscripts are significantly different ($P<.05$)

coefficient times the gross energy intake was highest for diet 1 at 255.78 kilocalories. This value was significantly higher ($P<.01$) than the other three rations in the trial. Diets 2, 3, and 4 were also all significantly different from each other at ($P<.01$).

Apparent digestibility coefficients are also shown in Table 23. Dry matter digestibility ranged from 53.86% for diet 4 up to 69.86 for diet 1. Diet 1 was significantly greater ($P<.01$) than diet 4 and also greater ($P<.05$) than diets 2 and 3 at 65.54% and 62.02% respectively. Crude protein digestibility was also highest for diet 1 at 62.23% and was significantly greater ($P<.01$) than diet 4 at 53.86%. Ration 1 was also significantly higher ($P<.05$) than ration 3 at 44.04%. Acid detergent fiber had the lowest overall values for the digestibility coefficients measured. Values ranged from 35.27% for diet 4 up to 45.89% for diet 1. Diet 1 was significantly greater ($P<.01$) than diet 4 and at ($P<.05$) than diet 3 at 38.28%. No significant difference was seen between diets 1 and 2 or 3 and 4. The coefficient of digestible energy was highest for diet 1 at 64.6% compared with the lowest value for diet 4 at 50.21%. Overall diet 1 was significantly higher ($P<.01$) than diet 3 (54.34%) and diet 4. There was also significant differences ($P<.05$) between each of the treatment means.

Nitrogen retention and retention as a percentage of the total intake are also shown in Table 23. Nitrogen retention in grams/day was highest for diet 1 at 12.12 and ranged down to 7.31 for diet 1. Diet 1 was significantly

higher ($P<.05$) than ration 4 at 7.31 and ration 3 at 9.65. There was no significant difference between diets 1 and 2 or 3 and 4. The nitrogen retention as a percentage of total nitrogen intake ranged from 25.31% for diet 4 up to 32.37% for diet 1. Diets 1 and 2 were significantly greater ($P<.05$) than both rations 3 and 4 at 25.17% and 25.31% respectively.

The values for rumen pH, rumen NH_3, and blood urea nitrogen values are shown in Table 24. Rumen pH values ranged from 6.23 for diet 1 up to 6.77 for diet 4. No significant differences were found between any of the treatment means. Blooc urea nitrogen values were highest for ration 1 at 24.21 and lowest for diet 4 at 22.87. No significant differences were reported. The values for rumen NH_3 ranged from 11.43% for diet 4 up to 12.13% for alfalfa. Again, no significant differences were found between treatment means.

Rumen fluid organic acid composition was shown in Table 25. Values are given for acetic, propionic, butyric and valeric acid. Values for acetic acid ranged from 10.32 for ration 4 up to 11.35 for ration 1. No significant differences were found between treatment means. Propionic acid values ranged from 3.31 for diet 4 up to 5.20 for diet 1. These values were different significantly ($P<.05$). Values for diets 2 and 3 were not significantly different than both diets 1 and 4. Butyric acid values ranged from 1.92 for diet 4 up to 2.12 for diet 1. No significant differences were found between treatment means. Valeric acid values were the lowest organic acid values measured.

TABLE 24. RUMEN pH, RUMEN NH_3, AND BLOOD UREA NITROGEN VALUES[1,2]

Item	Alfalfa (100%) - 1	Alfalfa (66.6%) Poplar (33.3%) - 2	Poplar (66.6%) Alfalfa (33.3% - 3	Poplar (100%) - 4
Rumen pH	6.23	6.55	6.41	6.77
Blood Urea Nitrogen mg%	24.21	23.32	22.14	22.87
Rumen NH_3 mg%	12.13	11.88	12.01	11.43

[1]All values were sampled 2 hr. after feeding.

[2]No significant differences between treatment means.

TABLE 25. RUMEN FLUID ORGANIC ACID COMPOSITION[a]

Item	Alfalfa (100%) - 1	Alfalfa (66.6%) Poplar (33.3%)- 2	Poplar (66.6%) Alfalfa (33.3%)- 3	Poplar (100%) - 4
Acetic	11.35	10.80	10.81	10.32
Propionic	5.20[a]	4.97[ab]	4.47[ab]	3.31[b]
Butyric	2.12	2.02	1.81	1.92
Valeric	.14	.12	.13	.11

[a]Values are expressed as (mmole/100 ml)

[a,b]Values with different superscripts are significantly different (P<.05)

The values ranged from .11 for diet 4 up to .14 for diet 1. No significant differences were found between treatment means.

DISCUSSION

Comparison of Nutrient Composition of Biomass Species and Alfalfa over Early and Late Harvest Periods - It is imperative in animal agriculture that every effort be exerted to maximize the nutritional value and palatability of forages for livestock. The selected proximate components for the biomass species and alfalfa over two consecutive harvest periods were determined. The nutrient composition for the early harvested samples was higher in all parameters measured which suggested that harvesting the tree crops and alfalfa earlier in the growing season would produce a feedstuff higher in nutrient value. This is in agreement with work by Reid et al. (1959) in which they studied maturity of forage crops and its subsequent effect upon both nutrient composition and animal performance. They found that as alfalfa and perennial grasses matured during the growing season, the % crude fiber increased linearly and the % crude protein decreased linearly. In subsequent animal performance studies, they demonstrated significantly lower ($P < .05$) milk production and digestibility values for the later harvested forages. Huber (1980) has suggested that for maximum nutrient composition, lower lignin, and highest milk production, legumes and grasses should be harvested at about 10% bloom, perennial grasses (orchardgrass, timothy, ryegrass) just prior to budding,

and summer annuals (such as sudan and sudex) at .9 to 1.3 meters in height. From this study, the earlier harvest of biomass trees yielded a higher nutrient composition.

Fiber Analysis of Early and Late Harvest Samples - The study and analysis of plant cells and their cell wall components has long been the object of extensive research in nutrition. The fractionation of fiber components for both early and late harvested biomass species and alfalfa were conducted. The values for neutral detergent (NDF), acid detergent (ADF), and lignin are direct measurements on the sample. As reported earlier, there was a change in the cell wall constituents of each species over the harvest periods. Neutral detergent fiber, which represents the plant cell walls minus pectins, demonstrated a 7.2% increase from the early to late harvest. Huber (1980) demonstrated a 10% increase in the NDF fractions of alfalfa as the plant matured from the first cutting to the third cutting. ADF, which represents the cellulose and lignin fraction of the plant tissue was also considerably higher for the late harvest compared to the early harvest. With the biomass tree species, the average ADF value was 17.6% higher for the late harvest than the early harvest. The values for lignin displayed a 24.8% increase from the early to late harvest biomass species. Lignin in the cell wall has been shown to have a detrimental effect on the digestibility of the cell wall (Van Soest, 1966). Therefore, the higher lignin values for the late harvest species would suggest that the cell walls of the

later harvested tree species would be less digestible than the cell walls of the early harvested species and alfalfa. The values for cellulose in the later harvest were 19.46% higher than the early harvested biomass tree species. This would be expected because of the late harvest biomass trees' higher overall ADF values. It should be remembered that % cellulose is calculated by difference (% ADF-% Lignin). With higher lignin values associated with the late harvested trees, it would be expected that these trees would be less degradable in the rumen (Orskov and Mehrez, 1976).

The mineral contents were higher throughout for the early harvested samples. Both the macrominerals (Ca, P, K, Na, Mg) and microminerals (Fe, Zn, Al, Cu, Mn) were higher in value than the late harvest. Linn et al. (1975) reported that aquatic plants harvested early into the growing season were higher in calcium, phosphorus, and magnesium.

Hydrolysis of the delignified plant tissue with trifluoroacetic acid and derivatization to their corresponding alditol acetates is shown in Table 12. The sugars measured were: glucose, galactose, mannose, xylose, arabinose, rhamnose, and ribose. Uronic acids were also measured because they have been found as a component of the cell wall (Buchala and Wilkie, 1973). All of the sugars were found in varying levels in each species measured. Collings et al. (1978) determined that alfalfa to be 24.8% of the hemicellulose fraction while our results reported 25.64%. Galactose values in alfalfa hemicellulose was found to be

4.59% Collings et al. (1978) compared to 4.37% in this study. Black locust and honey locust were similar in sugar composition to alfalfa except for mannose and rhamnose which were both considerably higher for alfalfa. Buchala and Wilkie (1973) investigated wheat straw hemicellulose with gas chromatography and reported that plant digestibility is related to the amount of xylose in the plant. The xylose: arabinose ratio has been used as an indicator of plant maturity and digestibility (Collings et al., 1979). The highest values for both xylose and xylose-arabinose ratios were elm, ailanthus, and willow, respectively. Collings et al. (1978) reported values of 2.57 and 1.12 for the xylose: arabinose ratios of ladino and red clover, and 6.08 for wheat straw.

Silage Fermentation Study - To avoid weather damage and to more efficiently harvest forage crops, many livestock producers will ensile their forage crop. All of the biomass species and alfalfa were ensiled in laboratory glass silos to study their fermentation characteristics. The freshly cut material was wilted to 30-45% dry matter because direct cut haylage will undergo excessive fermentation due to high moisture and will result in lower intake and palatability to livestock (Yu and Thomas, 1980). These workers also determined that wilting forages to above 50% dry matter will result in poor packing and excessive heating, causing the protein and energy content to be less digestible and destroying essential vitamins.

The dry matter values listed in Table 14 for the ensiled samples were all within the acceptable 30-45% range. Crude protein, ash, ether extract and gross energy values were similar to the chemical composition of the early harvested plant samples listed in Table 6. Fiber and mineral analyses on the ensiled plants was also similar to values listed for the early harvested samples in Tables 8 and 10 respectively.

The nitrogen distribution of the biomass species and alfalfa is shown in Table 16. Soluble nitrogen for alfalfa at 1.72% and as a % of total nitrogen at 47.12% was similar to the values reported by (Linn et al., 1975). Yokoyama et al. (1978) reported corn silage values of .48% and 44.6% for soluble nitrogen and soluble nitrogen (as a % of total nitrogen values). The higher soluble nitrogen values should result in an increase in degradability of nitrogen in the rumen. This factor is discussed later in the nylon bag degradability study.

The values for pH and organic acids are shown in Table 17. Barnett (1954) described good quality haylage to exhibit a pH of 3.8 to 4.3, contain 5-7% lactic acid as a percent of total dry matter, and less than 1% of total dry matter as butyric acid. Two of the species which exhibited higher pH and higher butyric acid values were willow and elm. Both of these species appeared to have a brownish color at the conclusion of the ensilement period which is known as carmelization. This results in a reduction of available nutrients, a breakdown of fat soluble vitamins and a decrease

in soluble carbohydrates for energy. The organic acid contents and pH values of alfalfa silage were characteristic of a forage that has undergone proper fermentation. The alfalfa sample had a pH below 4.2, was adequate in lactic acid content for preservation and contained little or no butyric acid. Excluding willow and elm, all the other biomass tree species appeared to contain enough soluble carbohydrates to ensile properly.

Nylon Bag Degradability - The dry matter degradability measured over 6, 12, and 24 hours are shown in Table 18. Alfalfa, honey locust, and black locust were higher within each of the time intervals for both the early and late harvest. Recent work by Orskov and Mehrez (1977), showed dry matter disappearances of 38.6%, 48.7%, and 65.12% for alfalfa samples incubated in the rumen of mature steers. These values corresponded with values found in early harvested samples of alfalfa in this study. The values for the late harvested samples were all lower over the same time interval of 6, 12, and 24 hours compared to the early harvest. This is largely due to the increased lignin content for all of the species associated with advanced plant maturity. The three lowest values for rumen degradability, ailanthus, willow, and elm, all had the highest lignin values and also the highest xylose:arabinose ratios. Both of these parameters are associated with decreased digestibility of the plant cell wall. Van Soest (1966, 1977) has pointed out

that increased lignin in the cell wall will have a detrimental effect upon digestibility of dry matter. Also, Collings et al. (1978), stated that increased values for xylose:arabinose ratios will decrease the digestibility of plant cell walls. Work by Baker (1973) demonstrated with hardwood species at lignin contents less than 8%, in vitro dry matter digestibilities ranged from 56 to 65%. However, at higher lignin contents, in vitro digestibilities tended to drop to 30-40%.

The disappearance of nitrogen from nylon bags is shown in Table 19. As with dry matter disappearance, alfalfa, black locust, and honey locust were significantly higher in nitrogen disappearance than the other biomass tree species. The explanation for this could be that each of these particular tree species were higher in crude protein and soluble nitrogen, and contained a large percentage of their nitrogen in the soluble form. These three species were also highest in dry matter degradability which would enhance the disappearance of nitrogen from these substrates. Orskov and Mehrez (1977) reported values of 37.14, 52.31, and 67.31 for nitrogen degradability of alfalfa over a 6, 12, and 24 hour period respectively. The values for the late harvested samples were all lower over the same time interval when compared to the early harvested samples. The possible explanation for this could be the inability to solubilize the nitrogen of the plant cell because of the higher lignin values associated with the later harvested samples.

The degradability of ADF (cellulose and lignin) over the 6, 12, and 24 hour period is shown in Table 20. Overall, alfalfa, black locust, and honey locust were higher than the other species in both the early and late harvest. As reported earlier, these three species are also lowest in % lignin which would explain their higher degradability over time. The three lowest values overall for both harvest groups were willow, ailanthus, and elm which were reported to have the highest lignin values within the samples. Between the two harvests, the earlier harvest averaged a higher % disappearance than the late harvest samples. As was stated for nitrogen and dry matter disappearance, the % lignin of the ADF fraction increased for all tree species in the second harvest and this would explain the lower values reported for ADF degradability over the 6, 12, and 24 hours.

Feeding Trial Results - The results from feeding four levels of poplar to mature wether lambs are shown in Table 23. The comparison of poplar to alfalfa in increasing increments (0, 33.3, 66.6, 100%) significantly depressed the daily consumption of dry matter, crude protein, gross energy, and digestible energy per $KgBw^{0.75}$ in the 66.6% and 100% poplar rations compared to the control of 100% alfalfa. Animals fed the 33.3%, 66.6%, and 100% poplar tended to consume slightly more ADF per $KgBw^{0.75}$ as compared to the 100% alfalfa ration. This was probably due to the higher concentration of ADF in the diets containing 33.3, 66.6 and 100%

poplar. Similar reductions in crude protein and digestible energy intakes were reported by Binius and Baumgardt (1968) and Al-Rabbat and Heaney (1978) when sheep were fed concentrate mixtures diluted with various levels of diluents (40-50%) or 64% steamed aspen in high roughage diets as compared to those receiving the control diets. However, Heaney and Bender (1970) did not observe any reduction in dry matter intake per $KgBw^{0.75}$ by sheep receiving a 60:40 steamed aspen and ground alfalfa hay. Dinius and Oltjen (1971) suggested that the depression in the consumption of dry matter could probably be due to the rumen fill and slower turnover of rumen contents.

The inclusion of poplar in the diets of lambs significantly reduced the dry matter, crude protein, acid detergent fiber, and gross energy digestibilities when compared to the control diet. Al-Rabbat and Heaney (1978) did not observe any differences in the digestibility of acid detergent fiber of diets containing up to 60% aspen. They suggested the slower turnover rate in the rumen of sheep receiving these diets would allow for prolonged microbial action on the dietary fiber.

Nitrogen retention in g/day and as a percent of the total intake is presented in Table 23. Nitrogen retention in g/day was significantly lower ($P < .05$) for the 66.6 and 100% poplar rations compared to 100% alfalfa. However, it should be noted that all the rations exhibited a positive N balance. This was in contrast to work by Coombe and

Briggs (1974) where sheep fed pelleted diets containing 64% and 84% waste paper displayed a negative nitrogen balance. Nitrogen retention as a percentage of total N intake was significantly greater ($P < .05$) for both the 100% alfalfa and 33.3% poplar than for 66.6% and 100% poplar. Sharma et al. (1979) found no significant differences ($P < .05$) in nitrogen retention as a percent of total nitrogen in lambs fed 15, 30, and 45% steamed aspen pellets compared to 100% alfalfa.

The values for rumen pH, rumen NH_3, and blood urea nitrogen are shown in Table 24. No significant differences were found in rumen pH. The 100% alfalfa ration and 33% poplar tended to be lower in pH and this is probably due to the higher amounts of volatile fatty acids produced by these rations. Sharma et al. (1979) reported no significant differences within their experimental rations which ranged up to 45% aspen. Fritschel et al. (1976) observed higher ruminal pH for mature ewes receiving 70% pulp fines or aspen bark in pelleted rations. Increase in rumen pH was also recorded by Cheng and Hironaka (1973) and Sharma and Ingalls (1974) in the rumen of cows and Holstein steers after feeding ground aspen diets.

Values for blood urea nitrogen displayed no significant differences across the treatment means. The 100% alfalfa ration and 33.3% poplar ration tended to be higher, however, than both the 66.6 and 100% poplar diets. Conversely, Sharma et al. (1979) reported that lambs fed 30 and 45%

pelleted aspen rations had significantly higher values for blood urea nitrogen values than the alfalfa control. However, their rations besides containing aspen, were supplemented with urea and could explain the higher values reported. The ruminal fluid ammonia levels were also not different significantly with alfalfa and the 66.6% poplar rations displaying the highest values.

The concentrations of volatile fatty acids are displayed in Table 25. The molar concentration of acetic acid in the ruminal fluid displayed no significant difference for the treatment diets. The 100% alfalfa had the highest overall value at 11.35 with the lowest being 10.32 for 100% poplar. Sharma et al. (1979) reported no significant differences in acetic acid levels of lambs fed diets of 0, 15, 30, and 45% aspen. Propionic acid values were significantly greater for 100% alfalfa in comparison to 100% poplar. There were no significant differences between the 100% alfalfa, 33.3% poplar, and 66.6% poplar rations. Following a similar trend as the acetic acid volume, butyric and valeric acids displayed no significant differences between treatment means. These organic acid values were in agreement with Fritschel et al. (1976) who observed no differences in the total VFA concentrations and molar percentages of VFA's in the ruminal fluid of sheep fed pulp fines or aspen bark in pelleted diets. Conversely, Clarke and Dyer (1973) using Douglas fir sawdust in the diets of finishing steers reported depressed total VFA concentrations in comparison to an alfalfa control.

GENERAL CONCLUSIONS

Further evaluations of biomass species need to be conducted before commercial livestock enterprises adopt them in practice. Growth trials measuring average daily gains, feed efficiency and carcass composition should also be considered. Growth and yield trials for each biomass sample should be done on a large scale to better predict the potential value as a feedstuff. The costs and methods of harvesting, pelleting costs, and acceptability by producers are all practical parameters that should be investigated before biomass produced trees can be adapted to commercial animal agriculture.

The results of this particular study have led the author to make the following ranking of biomass trees based on their potential of dry matter yield, nutrient composition and degradability in the rumen:

1.) Honey Locust
2.) Black Locust
3.) Poplar
4.) Aspen
5.) Black Alder
6.) Green Ash
7.) Birch
8.) Elm
9.) Ailanthus
10.) Willow

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VITA

STEPHEN ROBERT BAERTSCHE

1952	Born December 16, in Kenton, Ohio
1971	Graduated from Hardin Northern High School, Dola, Ohio - Valedictorian, Senior Class President
1971-1975	Attended The Ohio State University; Majored in Animal Science
1974	Elected into Ag Towers Scholastic Honorary, OSU President's Scholarship Recognition Honoree, Member of OSU Livestock Judging Team
1975	B.S. Animal Science, The Ohio State University
1975-1980	Graduate work in Animal Nutrition, Michigan State University, East Lansing, Michigan
1975-1980	Served as Extension Specialist in Michigan State Animal Husbandry Department for Graduate Assistantship
1980	Candidate for Ph.D. degree in Animal Husbandry
1980	Accepted Extension Specialist position with The Ohio State University, Columbus, Ohio