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THE CHEMICAL COMPOSITION OF
SEWAGE GROWN AQUATIC PLANTS
AND THEIR DIGESTIBILITY BY SHEEP

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THE CHEMICAL COMPOSITION OF SEWAGE GROWN AQUATIC PLANTS AND THEIR DIGESTIBILITY BY SHEEP

By

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ABSTRACT

THE CHEMICAL COMPOSITION OF SEWAGE GROWN AQUATIC PLANTS AND THEIR DIGESTIBILITY BY SHEEP

By

Stephen Robert Baertsche

Aquatic plants have been used for many purposes. Different species of marine algae have been utilized in fertilizers and as stabilizers in plastics, ice cream, and candy. Recently, due to their relatively high protein content, animal nutritionists have begun to evaluate the possible use of various aquatic plants as alternative sources of livestock feed. The quality and the quantity of available nutrients from these aquatic plants has been of primary interest in recent years. Analytical values for certain aquatic plants show high values for crude protein and minerals. In this study two different aquatic plants, _Cladophora_ algae and _Elodea_ _canadensis_, were examined in regard to both their chemical composition and their digestibility by sheep.

EXPERIMENT I - CHEMICAL COMPOSITION. Samples of the two aquatic plants were collected from three Michigan State University sewage treatment lakes, sun dried, ground through a 20-mesh screen with a Wiley mill, and analyzed for proximate constituents. Dry matter and crude protein values showed the least variation, with values ranging from 92.9% to

95.1% for dry matter and 17.8% to 18.1% for crude protein. Ether extract and gross energy values were lowest for the two aquatic plants when compared to dehydrated alfalfa and an alfalfa soybean mixture. Mineral analyses revealed higher concentrations of both macro- and microminerals for both of the aquatic plants on a dry matter basis. Algae contained 5.3% calcium and elodea 4.5% calcium while alfalfa contained 1.7% calcium. All samples had similar amounts of neutral detergent fiber, while the alfalfa contained a higher percentage of acid detergent fiber. Permanganate lignin values were highest for algae at 5.2% and alfalfa at 5.1%

EXPERIMENT II - DIGESTION TRIAL. A 4 x 4 Latin square design was employed using four crossbred wether lambs. The diets consisted of 100% alfalfa meal, 95% alfalfa - 5% soybean meal, 70% alfalfa - 30% algae, and 70% alfalfa - 30% elodea on a dry basis. Digestibility coefficients were calculated for dry matter, crude protein, gross energy, and acid detergent fiber. Dry matter and crude protein digestibilities were significantly higher for the alfalfa-algae ration when compared to the alfalfa-elodea ration, but were not significantly different when compared with other rations. Digestible energy and acid detergent fiber coefficients were significantly higher for the alfalfa-algae ration when compared with the alfalfa-elodea and alfalfa-soybean meal ration.

Nitrogen retention, rumen fluid pH, blood urea nitrogen, and rumen NH_3 were also examined. No significant differences were found between any of these treatment means.

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INTRODUCTION

For the livestock producer, it is becoming an increasing problem to purchase or produce cereal grains and leguminous crops economically and not in direct competition with human needs. One solution to this problem would be the alternative utilization of aquatic plants such as algae and elodea which have recently been shown to have a possible feed potential. Research by Hintz and Heitman (1967) has found that certain species of algae contain as much as 73% crude protein. Because of this high crude protein content, research is currently being conducted to evaluate certain aquatic plants as potential protein sources.

The high fiber content of many aquatic plants has caused their digestibility in monogastric species to be low (Hintz and Heitman, 1967). However, when mixed with common forages such as alfalfa and cereal grains, ruminant animals such as cattle and sheep performed as well as controls fed 100% alfalfa or 100% grain (Linn et al., 1975).

Another important characteristic of aquatic plants is their high mineral content. Linn et al. (1975) evaluated 21 different species of aquatic plants and found an average content of 1.62% for calcium and 0.27% for phosphorus. It has also been determined that aquatic plants are considerably higher than alfalfa in microminerals (Linn, et al., 1975).

The purpose of this study was to evaluate the chemical composition and digestibility of two different species of aquatic plants. The two aquatic plants, algae and elodea, were grown and harvested from sewage treatment lakes at Michigan State University. The plants were washed, sun-dried, and then stored for chemical analyses. Trials incorporating these plants at 30% of the total dry matter were also carried out with lambs to investigate the digestibility of each of the plants.

LITERATURE REVIEW

Because of their possible potential as a protein supplement and as a livestock feed, several species of algae and other aquatic plants have been evaluated and studied for a number of years. These autotrophic, aquatic plants use carbon dioxide and solar energy, synthesize protein, contain variable levels of vitamin C and B complex, and some species are even able to fix gaseous nitrogen (Oswald et al., 1959). Kleiber (1961) calculated that algae are 1000 times more efficient in the utilization of solar energy than cereal crops. In fact, studies by Oswald et al. (1959) have shown that Chlorella algae could yield more than ten times the amount of protein than soybeans on a per unit basis. Besides being more efficient in utilizing solar energy and land area, these aquatic plants, at the same time, serve the function of removing organic matter and other waste from water, which would result in environmental pollution.

Algae has been used for many different purposes. Marine algae is processed to obtain iodine, and some species and genera are utilized in the production of agar (Chapman, 1962). Several alginates (polymers of manuronic acid) which are obtained from marine algae are used as thickeners or stabilizers in various products such as ice cream, plastics, and candy (Maass, 1962). Marine algae has been used by developing and certain Asian countries as a fertilizer and a source of human food. (Schmid and Hoppe, 1962; Zaneveld, 1959). In recent years, Marimura and Nobuko (1954) have suggested that due to its high protein content, unicellular algae such as Chlorella be used as a food source to alleviate protein deficiencies. Other abstract uses include suggestions by Boiko et al. (1962) and Lachance and Vanderveen (1963) that species of unicellular algae be stored for space travel because of its high protein content and light weight.

Even though sewage-grown algae could be used as an alternative protein supplement, there have been very few studies reported in which it has been fed to the ruminant. Hintz et al. (1966) performed a study with three different species of algae Chlorella, Scendesmus obliques, and Scendesmus quadricauda which were grown on sewage and fed to cattle, sheep, and hogs. The mixture fed was shown to contain 51% crude protein which was 73% digestible for cattle and sheep and 54% digestible when fed to pigs. Their results showed that the algae supplied sufficient protein to supplement barley for growing-finishing pigs. Lambs receiving an alfalfa-algae pelleted ration also gained better than when alfalfa was fed alone ($P < .01$) on a dry summer range (Hintz et al., 1966).

In another study, algae was shown to be an adequate protein supplement for pigs fed barley (Hintz and Heitman, 1967). In this regard, lysine is a limiting amino acid in barley (Reimer *et al.*, 1964). *Chlorella* algae was found to be rich in lysine and equal to dried skimmilk powder when added to wheat flour and fed to rats (Mitsuda *et al.*, 1961). Fink and Herold (1955) found that *Sendesmus obliguus* was as good as milk protein for growth of rats, and Witt *et al.* (1962) found that replacing 75% of the fish meal of a barley-fish meal ration with *Sendesmus obliguus* did not decrease the growth rate of pigs. On the basis of feeding trials with lambs, Hintz *et al.*, (1966) showed that mixing alfalfa with algae at proportions of 60% alfalfa to 40% algae in the ration produced better gains in comparison to lambs grazed on dry summer range pastures ($P < .05$).

Hintz and Heitman (1967) found algae supplemented with certain B-vitamins and substituted for fish meal produced equal gains and feed conversion efficiency when fed to pigs. No significant differences ($P < .05$) were found in carcass characteristics between pigs fed on the algal diets and those fed diets containing the fish meal. Digestibility studies indicated that the algae was low in digestible energy, but that its crude protein was 70% digestible.

Hintz and Heitman (1967) also demonstrated the need for B-vitamin supplementation when *Chlorella* algae was used in feeding trials with swine. This response to vitamin B_{12} was interesting because Round (1965) reported that Chlorella synthesized vitamin B_{12} and Fisher and Burlew (1953) reported *Chlorella pyrensidosa* contained 10-45 mg. of vitamin B_{12} per pound. It would be interesting to conduct further studies to determine why swine given algae in their diet respond to vitamin B_{12} with better gains. Hintz and Heitman (1966) suggested several possible reasons for this response, (1) algae interferes with vitamin B_{12} formation, or (2) low utilization because of the low algae digestibility, (3) the incidence of coprophagy may be decreased because of the high concentration of algae in the feces, and (4) true B_{12} versus pseudo B_{12} which would not be available to the animal.

The adverse effect of aquatic vegetation on the environment is an increasingly serious worldwide problem which is affecting normal lake and water ecosystems and their use by man. Bates and Hentges (1976) reported that in 1970, the state of Florida spent more than one million dollars on partially effective efforts to keep its 4000 square miles of infested waters free of aquatic weeds. The development of sound control methods will require innovative thinking and creative research. The control measures to combat serious aquatic weed infestation may be placed into three broad classifications: chemical, biological, and mechanical with eventual use for livestock or human consumption.

Gerloff _et al_. (1965) and Boyd (1968, 1969) found that chemical composition of aquatic plants varied over 100% depending upon season, location, environment, and level of nutrification. If and when such variations would occur, animal feed formulations would have to be adjusted. Also Bates and Hentges (1976) stated that freedom from herbicide

and pesticide residues, naturally occurring or environmentally induced plant toxins, and pathogenic organisms is essential if the material is to be safely utilized.

Hentges et al. (1972) found that the Hydrella spp. appeared to be as well tolerated by cattle and sheep as water hyacinth, but neither was adequate as 100% of the ration. It was most effective when provided at less than 33% of the organic matter in pelleted diets. Ensilage studies have shown that the wet press residue of water hyacinth will make an excellent silage when combined with additives which provide fermentable carbohydrates and absorb moisture, thereby preventing run-off of nutrients (Baldwin et al., 1974). Bates and Hentges (1976) concluded from their studies that dehydrated aquatic weed press residues have a nutritional value as a ruminant feed, but that it must represent only a small portion of the total diet and be carefully compounded with supplemental feed ingredients to balance its deficiencies.

Alfalfa is recognized as the most valuable forage crop with annual yields of over two to three tons per acre (Akeson and Stahmann, 1966). In fact, it has been calculated that 300,000 square miles of alfalfa could supply the minimum protein requirements of the human race with a large quantity left over for livestock (Morrison and Pirie, 1961). In contrast, water hyacinth under intensive cultivation could easily produce three times as much protein per acre (Boyd, 1970; Steward, 1970). This represents a tremendous potential for aquatic plants if harvesting costs could be kept at a minimum.

Linn _et_ _al_. (1975) conducted chemical analyses on 21 species of dried aquatic plants which were harvested from inland lakes in Minnesota and found that all contained sufficient quantities of nutrients to be considered as livestock feedstuffs. Although considerable variation existed among the 21 species, 14 species contained more than 10% protein and all species contained less than 40% crude fiber. Ca and P contents averaged 1.62% and .27% respectively. Neutral detergent and acid detergent fiber contents of the 21 species averaged 42.3% and 32.6% respectively.

Linn _et_ _al_. (1975a) ensiled the mixed aquatic plant species (approximately 50% _Myciophyllus_, 30% _Ceratophyllum_, 10% _Potamogeton_, 5% _Vallisneria_, and 5% unknown) with organic acids (acetic, formic, propionic), corn, or alfalfa. After 47 days of fermentation the silages had pH values below 4.1 and lactic acid values above .6% of the dry matter. Ensiling mixtures of aquatic plants and alfalfa resulted in silages with similar characteristics as the aquatic plant silages alone. Addition of alfalfa to sterilized aquatic plants at ensiling resulted in a silage of similar characteristics as the alfalfa silages.

Linn _et_ _al_. (1975b) in another study, completed a Digestibility trial with sheep utilizing the aquatic plants harvested from the Minnesota lakes. Their studies were

conducted with two species of dried aquatic plants (Myriophyllum exalbescens and Potamogeton pectinaces) and an ensiled mixture of aquatic plants (approximately 50% Myriophyllum, 30% Ceratophyllum, 10% Patamogeton, 5% Vallisneria, and 5% unknown) to determine the digestibility of aquatic plants by lambs. Both the dried Myriophyllum exalbescens and Potamogeton pectinaces were found to be unpalatable (less than 6000 g. of dry matter were consumed daily). This problem of palatability could be attributed to the "bitter principle" which was reported by Marimura and Nobuko (1954) when algae and aquatic plants were fed to humans in their experiment. Linn et al. (1975) also found that mixing an equal proportion (50:50) of the two species with dehydrated alfalfa resulted in dry matter and crude protein digestibilities, as determined by difference, of 43.8% and 46.0% for Myriophyllum and 43.4% and 44.1% for Potamogeton. Energy digestibility was found to be higher for the Myriophyllum than Potamogeton. In the same study, lambs fed diets of ensiled aquatic plants, aquatic plants plus corn, or aquatic plants plus alfalfa silage had dry matter digestibilities for the complete diet of 41.4%, 42.0% and 38.5% respectively. Lambs fed the ensiled diets of alfalfa or alfalfa plus corn had dry matter digestibilities of 61.9% and 66.2% respectively. Nitrogen and energy digestibilities were lower for lambs fed the rations that contained the aquatic plants than for lambs fed alfalfa silage or alfalfa silage plus corn.
Rumen fluid pH was greater and molar percentages of acetic

acid were lower for lambs fed rations that contained aquatic plants than for those fed alfalfa silage ($P<.05$). Propionic acid was greatest in rumen fluid from lambs fed the aquatic plant plus corn ration.

Research by Baldwin et al. (1974) found water hyacinth press residues ensiled with three concentrations of preservatives and evaluated the physical and chemical properties of the products along with cattle acceptability. Favorable fermentation of water hyacinths and preservatives was achieved and the silage had the desired acidity, aroma, and texture. Cattle immediately accepted the silages. Although the plants ensiled in each of five experiments were harvested at different times of the year and at different stages of plant growth, and at different locations, the results of the preservative comparisons on chemical composition and cattle acceptability were consistent in all experiments.

In further experimentation, Baldwin et al. (1975) harvested two aquatic plants consisting of Panglograss (Digitaria decumbens) and water hyacinth (Eichornia crassipes) which were fed to sheep to compare voluntary feed intake and nutrient digestibility. They found that dry matter intake of panglograss silage was higher ($P<.05$) than for water hyacinth silage. They also found that the digestibility of dry matter ($P<.01$) was higher for panglograss silage.

Heffron et al. (1977) harvested aquatic plants from Cayuga Lake in New York which was dried and milled and incorporated into a pelleted ration replacing 35% by weight of the alfalfa meal fraction. The ration was fed to pregnant goats and sheep for 130 days and results showed no significant differences ($P<.05$) in feed intake, rate of weight gains or ration digestibility between the animals fed the aquatic ration and those fed the control ration. Heffron et al. (1977) found the aquatic ration to be significantly higher in ash and lower in fat, fiber, and energy than was the control ration. Ewes and nannies fed the aquatic rations had normal offspring and pathologic and histologic examination of the animals' tissue revealed no apparent differences between those fed the aquatic and control rations.

Salveson (1971) and Stephens (1972) also worked with pelleted aquatic plants containing 33% of total ration dry matter. Results using dried press water hyacinths met the maintenance requirements for organic matter, dry matter, digestible protein and digestible energy of yearling steers. In some experiments,however, voluntary feed intake by cattle of processed aquatic plant products was lower than expected (Hentges, 1970; Salveson, 1971; Stephens, 1972).

Economically, it is not feasible to dehydrate these aquatic plants with present known methods; therefore, the ensiling of these plants has been an alternative. Linn et al. (1975) found the water content as high as 90% in fresh aquatic plants and this resulted in feeding problems. They used partially dried plants and then ensiled with alfalfa hay to ensure adaquate carbohydrate for fermentation. Hentges et al. (1073) in other studies attempted to ensile unprocessed fresh hyacinths, chopped pressed hyacinths and chopped pressed hyacinths plus molasses. All attempts at ensiling failed because of inadequate fermentation and spoilage. Even though more expensive in processing, dehydration followed by pelleting seems to be the most effective means in which to ensure adaquate consumption and dry matter intake for cattle and sheep. Bagnall et al. (1977) evaluated harvesting methods for aquatic plants. They chopped, mechanically dewatered, dehydrated, and pelleted the plants to determine whether they could be processed effectively and efficiently in existing processing systems and components. Hydraulic pressing removed 60% to 80% of the water and 18% to 32% of the dry matter. They also found that the pressed products were difficult to dry rapidly and pellet.

The resistance of complex algae cell walls to digestibility has been one of its major problems preventing utilization of algae as a human or livestock feed (Shefner et al., 1962). Their studies showed even ruminants were not able to efficiently digest the extracellular carbohydrate, and the nonprotein, nonfat organic matter. Hintz et al. (1966) reported that algae is not a high energy feed, because of the low digestibility of the carbohydrate fraction and the high ash content. However, it appears that algae have considerable potential as a livestock feed, because of the high content of crude protein plus significant amounts of carotene, phosphorus, and calcium.

Gunnison and Alexander (1975) stated that the cell wall probably is the major determinant of the resistance or susceptibility of algae to microbial decomposition. Although considerable work has been done to determine which components of the cell walls of algae is resistant to microbial decomposition, (Ballesta and Alexander, 1971; Bloomfield and Alexander, 1967), Gunnison and Alexander (1975) have demonstrated *in vitro* that algae were species specific to microbial destruction. They observed that *Staurastrum* sp., *Fisherella musciola*, and *Pediastrum duplex* were particularly resistant to attack under conditions where other algae were readily destroyed and their contents liberated.

Several studies have been done to investigate environmental factors and their effects upon algae and aquatic plant growth. Hartel (1975) studied the environmental control of algal standing crops in two nonstratified prairie lakes in South Dakota and Minnesota for 3 years. In both lakes physical factors (light, temperature, wind stress, and rainfall) were more frequently correlated with changes in algal standing crops than were nitrogen and phosphorus. Both lakes showed occasional positive correlations with nitrogen. Phosphorus was positively correlated during only one season in the deeper of the two lakes and never in the shallower. This limiting factor concept has been useful in the understandingof lake algae dynamics because it frequently indicated causes for changes in population density (Hutchinson 1944, Lund *et al.*, 1963, Megard 1972). Population changes in nature can rarely be explained on the basis of only one factor (Hall, 1971). Therefore, several different environmental factors such as wind, temperature, and mineral content of the water play a role in algae population of the lakes.

MATERIALS AND METHODS

Two different experiments were performed: (1) a complete chemical analyses of the two aquatic plants, Cladophora algae and Elodea canandensis, which were used in the study, and (2) a digestion trial to determine ration digestibility, nitrogen retention, plus rumen fluid pH, rumen ammonia, and blood urea nitrogen values.

EXPERIMENT I - Chemical Composition

A. Harvest of Aquatic Plants and Alfalfa

In the summer of 1976, 454 kg of two aquatic plants, Cladophora algae and Elodea canandensis were harvested mechanically from three of four Michigan State University sewage treatment lakes (ponds # 1,2, and 3). These samples were washed with water to remove sand, snails, and other extraneous debris that had adhered to the algae and elodea from the lakes. A wringer washing machine was used to wash the plants and remove excess water. Both species of plants were then sun-dried or air dried over screens. Some of the plant material was forced air dried, with no heat applied and stored in sealed plastic containers for future use. Alfalfa meal was harvested and pelleted in June, 1976, on the Harold Lietzke farm in St. Johns, Michigan.

B. Collection of Feed Samples For Analyses

All samples of the aquatic plants and alfalfa were randomly collected at several areas from each storage container and a composite was made for each plant. Samples were ground through a 20 mesh screen using a Wiley Mill[1] prior to all chemical analyses with the exception of obtaining percent dry matter values.

C. Dry Matter Percent

All plant samples were analyzed for percent dry matter by recording initial wet weight and then drying the samples in an oven at 65^{o} C for 24 hours or longer. After complete drying, weights were recorded as percent of wet sample. Dry matter values for the aquatic plants were taken on the pelleted rations and would be greater than if taken directly from the lakes.

D. Crude Protein and N Levels

All plant samples were analyzed for N content using a semi-micro Kjeldahl digestion method with a Sargent Specto-Electro titrator for NH_3 titration. 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

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

hydrogen 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 Feed Samples

Gross energy values for each ration were obtained by utilizing the Parr[1] Adiabatic Oxygen Bomb Calorimeter. A previously weighed sample of each ration was placed into a combustion capsule. The capsule was placed in an oxygen bomb containing 25 to 30 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

[1]Parr Instrument Co., Moline, Illinois

not volatize at this temperature is regarded as ash. Calculations were made on a dry matter basis with the weight of the residual 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 Feed 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 a 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 5 to 10 minutes and then reduced and refluxed for 60 ninutes.

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 suposedly represents ligno-cellulose in feedstuffs. The residue also included 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 solution. 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 grasses 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 2-3 cm higher so the acid could drain away. To each crucible, 30 to 40 ml of the permanganate solution was added. The mats of 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 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. Mineral Analysis of Alfalfa and Aquatic Plants

Determination of Ca, Mg, Mn, Fe, Cu, B, Zn, Al - these elements were evaluated using atomic absorption spectrometry. Atomic absorption is an analytical method based on the absorption of ultraviolet or visible light by atoms in the vapor state. When a sample solution is aspirated into the flame, the solvent is evaporated or burned, and the sample compounds are thermally decomposed and converted into a gas of the individual atoms that are present. The large majority of these are in the ground state although a few of the atoms become excited and emit light. The neutral atoms absorb light from the hollow-cathode source that emits the characteristic wavelength of the single element to be determined. The analysis was performed on an IL 252/IL 353 Atomic Absorption/Emission Spectrophotometer[1] and values were reported on a dry matter basis. The procedure used was found

[1] Instrumentation Laboratory Inc., Lexington, Mass.

in (A.D.A.C., 1970).

Determination of Phosphorus - this procedure was based on the principle that the orthophosphate ion reacts with ammonium molybdate to form a phosphomolybdate compound. The phosphomolybdate compound is reduced to molybdenum blue with 1 - amino - 2 napthol - 4 - sulfonic acid. The blue color formed is in direct proportion to the orthophosphate present.

Calculations for % phosphorus are shown in the equation below:

$$\frac{\text{mg phosphorus in aliquot x 10}}{\text{mg aliquot ash solution x wt ashed sample}}$$

The procedure used was by (Fiske and Subbarow, 1925).

Determination of Na - the evaluation of Na was determined using flame emission spectrometry. Flame emission spectrometry will produce characteristic emission spectra for the various metallic elements. Measurement of a selected spectral line by means of a spectrometer provides the basis for a very useful quantitative analytical method especially for Na. The analysis was performed on an IL 252/ IL 353 Atomic Absorption/Emission Spectrophotometer[1] and values were reported on a dry matter basis. The procedures used were (A.O.A.C., 1970) and Instrumentation Laboratory Manual, 1975.

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[1]Instrumentation Laboratory Inc., Lexington, Mass.

EXPERIMENT II - Digestion Trial

A. Design of Study

A 4 x 4 Latin square design was employed to compare the 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, 70% alfalfa - 30% algae, 70% alfalfa -30% elodea, and 95% alfalfa - 5% soybean meal. The experimental design and rations are shown in Table 1.

B. Equipment Used

Metabolism Cages - sheep digestion cages were used which permitted the feeding of a known amount of feed and water and the quantitative collection of urine. Urine Containers - plastic containers were used to collect the daily urine volumes under the metabolism cages. 5 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. Scales - a portable Toledo scales was used to weigh the feed, feces, and urine. Preparation of Feed - previously weighed mixtures of the various rations were delivered to the Harold Lietzke pelleting mill at St. Johns, Michigan

TABLE 1

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 - 70% alfalfa - 30% algae
C - 70% alfalfa - 30% elodea
D - 95% alfalfa - 5 % soybean meal

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

A daily aliquot (1.3 kg) of the pelleted rations was weighed out the afternoon before it was to be fed. This made for quicker feeding during the morning and an accurate method for measuring any uneaten feed that remained. All animals were fed at the same time each day (between 7:00 and 8:00 a.m. and 5:00 and 6:00 p.m.). 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. Four Suffolk wethers weighing 27.2 kg were housed at the MSU Beef Cattle Research Center during the entire experiment. The metabolic study began in November and was terminated in February. Environmental conditions were uniform throughout the entire study.

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 external parasites, and all feet were trimmed. Rumen cannulas were inserted in each lamb 1 month in advance of the collection period.

F. Collection Period

The collection period for feces and urine ran for 7 consecutive days with the feed intake carefully controlled. 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 at least 10 days. During the collection period, a random sample of the feed that was weighed out for feeding was saved for analysis. This sample was saved two days before the collection of feces and was ended two days before the collection of feces stopped. Feces and urine were removed from their containers, weighed, and stored in a freezer at 4° C. All feces defecated during the collection period were saved and stored in a freezer. Urine collection containers had 20 ml of 1 M H_2SO_4 added each day. All the urine was collected and an aliquot of the total was saved for chemical analysis. Calculations used for digestion coefficients and N balance:

1.) Apparent digestion coefficients were found for the following nutrients:

$$\text{APPARENT DIGESTION COEFFICIENT} = \frac{\text{nutrient in feed - nutrient in feces}}{\text{nutrient in feed x 100}}$$

2.) N-Balance - a balance is the relation of material in the feed to the output of the same material. For most nutrition work, the feed, feces, and urine are considered.

Balance = material in feed - material in feces and urine

F. Rumen Fluid pH and Rumen Ammonia

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 digital pH meter. This rumen fluid was then strained through cheesecloth and random samples were analyzed for rumen ammonia values in mg %. The Orion Ammonia Ion Electrode model 95-10 was used for this analysis.

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_2CO_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/100ml.

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 9825 A. Separation of mean values was conducted using the Studentized range test found in Statistical Tables by(Rohlf and Sokal, 1974).

RESULTS AND DISCUSSION

EXPERIMENT I - Chemical Composition

The concentrations of selected constituents in the dried aquatic plants, dehydrated alfalfa meal, and dehydrated alfalfa meal plus soybean meal are presented in Table 2. The dry matter values given for the aquatic plants were those obtained after the plants were sun sun dried. These would differ greatly from dry matter values obtained when the aquatic plants are taken directly from the water. Dry matter values of the freshly harvested plants were 10 - 15%. However, after being sun dried, the aquatic plants were both similar in dry matter content to the alfalfa and alfalfa-soybean mixture. Individual values ranged from 92.9% for the alfalfa-elodea mixture to 95.12% for the alfalfa meal.

Concentrations of ash in the dry matter of aquatic plants plus alfalfa meal were considerably higher than the alfalfa or alfalfa plus soybean meal diets. Part of the reason for this large difference is explained by the fact that aquatic plants plus alfalfa meal were considerably higher than the alfalfa or alfalfa plus soybean meal diets. Part of the reason for this large difference is explained by the fact that aquatic plants included more than just plant materials. The aquatic plants were contaminated with sand, soil, and

TABLE 2

CHEMICAL COMPOSITIONS OF DEHYDRATED ALFALFA, AQUATIC PLANTS, AND TREATMENT DIETS[a]

Item	Alfalfa (100%)	Algae (100%)	Elodea (100%)	Alfalfa (70%) Algae (30%)	Alfalfa (70%) Elodea (30%)	Alfalfa (95%) Soybean (5%)
Dry matter, %	95.12	94.21	94.3	93.4	92.9	94.9
Ash, %	8.07	19.12	21.79	16.51	13.18	8.59
Crude protein, %	17.89	17.84	17.94	17.88	17.91	18.12
Ether extract, %	3.84	2.46	2.82	3.14	3.32	3.92
Gross energy K cal/gm	4.34	3.54	3.12	4.01	3.87	4.41

[a]All analyses are on a dry matter basis.

crustaceans, therefore, a higher ash value could be expected. The aquatic plants were hand-washed to minimize this contamination, but not all of the residuals could be removed. Linn et al. (1975) reported similar results for aquatic plants and found that their submersed plants were usually higher in ash than emergent plants, indicating that some minerals may have adhered to these plants or that they are just higher in mineral content. Individual values ranged from 8.09% for the alfalfa meal to 21.79% for the 100% elodea. We noted the encrustation of minerals on the stems and leaves of the aquatic plants.

Crude protein content, on a dry matter basis, showed the least variance with values ranging from 17.84% for algae to 18.12% for the alfalfa-soybean mixture. These values are higher for the aquatic plants than have been found in several previous studies. Linn et al. (1975) reported an average value of 12.98% for the 21 aquatic plants they evaluated. However, Hintz et al. (1966) evaluated several different species of sewage grown algae that contained about 50% crude protein on a dry matter basis. This suggests that different aquatic species vary greatly in their nutrient content.

Ether extract concentrations in the aquatic plants were very similar but did not approximate those of common forages. Ether extract values ranged from a low of 2.46% for algae to a high of 3.92% for the alfalfa-soybean mixture. Other studies by Linn et al. (1975) and Hintz et al. (1966) have reported similar observations for aquatic plants versus common forages, although considerable variation occurred among species. Submersed plants generally contained less ether extractable material than emergent plants (Linn et al., 1975).

Gross energy values were again similar in value for the aquatic plants but were substantially lower when compared to the values for alfalfa and the alfalfa-soybean meal mixture. Gross energy values in this study ranged from 3.12 K cal/gm of dry matter for the 100% elodea to 4.41 K cal/gm for the alfalfa-soybean mixture. Work by Linn et al. (1975) and Hintz et al. (1966) reported higher nitrogen-free extract values with their aquatic plants than common forages. This could be attributed to the lower crude fiber, ash, and protein contents of the aquatic plants.

Little variation was found in cell wall (NDF) constituents between the aquatic plant species and the common forages and their mixtures shown in Table 3. Polisini and Boyd (1972) reported that emergent plants have a rigid structure and correspondingly a high concentration of cell walls. Therefore, it could be assumed that emergent plants are probably less digestible than either floating or submersed plants. Linn et al. (1975a) have reported average values for NDF of 42.32% for the 21 aquatic plants evaluated from several Minnesota lakes. The values obtained in this study were 35.44% for elodea and 39.42% for the algae sample. These values are similar to the results of other studies

TABLE 3

FIBER ANALYSIS OF ALFALFA, AQUATIC PLANTS, AND TREATMENT DIETS [a]

Item	Alfalfa (100%)	Algae (100%)	Elodea (100%)	Alfalfa (70%) Algae (30%)	Alfalfa (70%) Elodea (30%)	Alfalfa (95%) Soybean meal (5%)
NDF, %	38.41	39.42	35.44	39.31	37.32	38.21
ADF, %	29.51	24.79	22.44	27.67	27.14	29.12
Permanganate Lignin, %	5.12	5.24	4.47	5.15	4.92	5.01
Hemicellulose, %	8.90	14.63	13.00	11.64	10.18	9.09
Cellulose, %	23.23	19.31	17.81	23.51	21.23	22.45

[a]All analyses are on a dry matter basis.

which evaluate these two aquatic plants.

Acid detergent fiber (ADF) or lignocellulose contents of the aquatic plants were lower than that for alfalfa. Values ranged from a low of 22.44% for the elodea sample to a high of 29.51% for the alfalfa. Lignin values were similar for all the samples. It should be noted that aquatic plants do not possess true lignin as terrestrial plants. Thus, the main contribution to the difference in ADF was the variation in % cellulose of the samples. In studies by Linn et al. (1975a) and Heffron et al. (1977), the aquatic plants studied were significantly higher in ADF than that for the alfalfa. Their results were due to high lignin values that contributed to a portion of the increased ADF values. Since their cell wall constituents were approximately equal, they found that the aquatic plants had a higher lignin content than the alfalfa hay. Lignin in the cell wall has been shown to have a limiting effect on its digestibility (Van Soest, 1966). In this study, however, the higher ADF value for alfalfa hay was due to the greater cellulose content and not to lignin. Hemicellulose (NDF minus ADF) contents of the aquatic plants were variable with values ranging from 8.9% for alfalfa to 14.63% for algae. Cellulose contents were similar in value among treatment diets and were comparable to those reported by Boyd (1968) and Linn et al. (1975).

Mineral contents of the aquatic plants and alfalfa are shown in Table 4. Calcium values are much higher for the

TABLE 4

MINERAL CONTENTS OF ALFALFA AND AQUATIC PLANTS[a]

Minerals Evaluated	Ca	P	Mg	Na	Mn	Fe	Cu	B	Zn	Al
Sample	%	%	%	%	PPM	PPM	PPM	PPM	PPM	PPM
Alfalfa	1.71	.31	.37	.21	55	220	7.8	---	---	---
Algae	5.28	1.53	.80	.0023	462	2,820	24.8	135.6	150	3,720
Elodea	4.57	.95	.54	.0272	98	924	8.4	34.8	108	1,172

[a]All analyses are on a dry matter basis.

two aquatic plants, algae containing the highest amount of 5.28%. Elodea is also very high in calcium with 4.57% compared to the low value of 1.71% for alfalfa. These values for the calcium content of aquatic plants is similar to values reported by Linn et al. (1975a). Based on their concentrations, both the algae and elodea would appear to be good sources of calcium.

Phosphorus values were considerably higher for the aquatic plants with algae at 1.53%, elodea at .95%, and alfalfa at .31%. These values also corresponded with aquatic plant mineral analyses conducted by (Boyd, 1968).

Magnesium values on the aquatic plants when compared to alfalfa were slightly higher. Linn et al. (1975) found magnesium values on aquatic plants to be similar to those of land forages, although there was considerable variability among the 21 aquatic plants tested. Sodium contents of the aquatic plants were much lower than the alfalfa samples. Values were 0.21% for the alfalfa, 0.0023% for algae, and 0.0272% for elodea. Sodium was the only element to be found higher for the alfalfa samples when compared to the aquatic plants. Manganese values were higher in aquatic plants than the alfalfa with algae being highest with a value of 462 ppm. The aquatic plants also contained high concentrations of iron. Algae contained 2,820 ppm of Fe while elodea was next with 924 ppm and alfalfa with 220 ppm. Copper values displayed a similar trend as the algae had the greatest value at 24.8 ppm with elodea at 8.4 ppm.

Boron, zinc, and aluminum were also evaluated for their respective concentrations in the sewage grown aquatic plants. These elements have been found to be high in concentration in plants grown on sewage lakes and were determined to check for possible toxic levels. Algae was considerably higher in all three elements and measured 3,720 ppm aluminum, 136 ppm boron, and 150 ppm of zinc. The elodea was 1,172 ppm aluminum, 34.8 ppm boron, and 108 ppm zinc.

The results of these proximate analyses indicate that aquatic plants may be useful forages for ruminants. Although considerable variation did exist between the two species studied, both aquatic plants were high in crude protein and low in crude fiber, indicating a high nutritive value. Also, values for hemicellulose, cellulose, and lignin contents suggested that many of the aquatic plants should be highly digestible.

EXPERIMENT II - Digestion Trial

In this study, the two aquatic plants evaluated were fed in a mixture of 70% alfalfa - 30 % elodea or algae and the digestibility coefficients of the aquatic plants were calculated by difference. Previous research by (Crouch, 1964; Hentges, 1970; Vetter, 1972) have reported palatability problems when diets containing 100% aquatic plants were fed to lambs. Their research showed an upper limit of 30-40% of aquatic plants on a dry matter basis was the maximum

amount that could be added to the ration. Linn et al. (1975) found that the palatability problems which they observed when lambs were fed rations that contained 100% aquatic plants were alleviated by mixing it 50:50 with dehydrated alfalfa. It was for this reason that a mixture of 70% alfalfa-30% aquatic plants was chosen for the study. Also, we did not harvest enough of the aquatic plant materials to use in greater proportions.

Dry matter, crude protein, energy, and acid detergent fiber digestibility values are shown in Table 5. Apparent dry matter digestibilities for the respective diets of 100% alfalfa, 70% alfalfa-30% algae, 70% alfalfa-30% elodea, and 95% alfalfa-5% soybean meal were 55.3%, 57.8%, 54.4%, and 54.0% respectively. Dry matter digestibility was significantly higher ($P<.05$) for the alfalfa-algae ration than for the alfalfa-elodea and the alfalfa-soybean meal. By difference, the dry matter digestibility for algae was 63.6% and for elodea was 52.3% shown in Table 6. Algae was significantly higher than both elodea and alfalfa-soybean meal ($P<.01$). These results were not in agreement with those found by Linn et al. (1975) in which 100% alfalfa hay was higher in digestible dry matter than aquatic plants. The higher ash contents of the aquatic plants would be a probable cause for decreased dry matter digestion in elodea but did not seem to have this effect on algae.

Crude protein digestion coefficients for the alfalfa-algae mixture (53.5%), alfalfa (51.4%), and alfalfa-soybean

TABLE 5

DIGESTIBILITY COEFFICIENTS AND NITROGEN RETENTIONS FOR RATIONS

Item	100% Alfalfa	70% alf. 30% algae	70% alf. 30% elodea	95%alf. 5% SBM
Dry matter, %	55.3[ab]	57.8[a]	54.4[b]	54.0[b]
Crude protein, %	51.4[ab]	53.5[b]	49.8[a]	50.9[ab]
Energy, %	57.4[ab]	58.5[a]	54.2[b]	55.4[ab]
ADF, %	52.4[ac]	53.5[a]	48.2[b]	50.5[ab]

[a,b,c]Means within a row with different superscript letters differ significantly ($P<.01$).

TABLE 6

DIGESTIBILITY COEFFICIENTS DETERMINED BY DIFFERENCE

Item	Alfalfa	Algae	Elodea	Alf.-SBM
Dry matter, %	55.3^{b}	63.6^{a}	52.3^{b}	54.0^{b}
Crude protein, %	$51.4^{a,e}$	58.4^{b}	$46.3^{c,d}$	$50.9^{a,c,e}$
Energy, %	57.4^{a}	61.0^{b}	47.0^{c}	55.4^{a}
ADF, %	$52.4^{a,b,e}$	$55.6^{a,d}$	38.4^{c}	50.5^{b}

[a,b,c] Means within a row with different superscript letters differ significantly (P<.01).

[d,e] Means within a row with different superscript letters differ significantly (P<.05).

meal (50.9%), were all greater in apparent protein digestibility than the alfalfa-elodea mixture (49.8%). However, only the alfalfa-algae ration was significantly greater than the alfalfa-elodea mixture (P<.05). When computed by difference, algae had the highest apparent digestibility at 58.4% and was significantly greater (P<.01) than either alfalfa (51.4%), alfalfa-soybean meal (50.9%), and elodea (46.3%). These coefficients were similar to values for other aquatic plants reported by Linn et al. (1975b) and by (Heffron et al., 1977). However, Hentges et al. (1972) reported that the protein in Florida elodea and water hyacinth was less digestible than the protein in fresh bermuda grass.

Average digestion coefficients for energy were 57.4%, 58.5%, 54.2%, and 55.4% for the dehydrated alfalfa, alfalfa-algae, alfalfa-elodea, and alfalfa-soybean meal respectively (Table 5). The energy digestion coefficient for the alfalfa-algae mixture was significantly higher (P<.05) than the alfalfa-elodea ration. This value was in agreement with Linn et al. (1975) who found higher coefficient values for energy in aquatic plants when compared to dehydrated alfalfa and also a type of submersed aquatic plant of the elodea family. Digestion coefficients by difference for energy found algae to be significantly greater than dehydrated alfalfa, elodea, and alfalfa-soybean meal (P<.01) (Table 6). Both alfalfa and alfalfa-soybean meal were significantly greater (P<.05) than the elodea sample in energy digestibility. Energy digestion coefficients are ash-free values

and thus, energy digestion coefficients for the aquatic plants were higher relative to the dehydrated alfalfa than existed for dry matter digestibility. Even though the elodea was lower in ADF and lignin contents, the algae ration had a surprisingly higher energy digestion coefficient.

ADF digestion coefficients followed a similar trend as the other parameters measured. Both the alfalfa-algae and 100% alfalfa rations were higher ($P<.05$) than for both the alfalfa-elodea and alfalfa-soybean meal diets. When calculated by difference, all three samples of alfalfa, algae, and alfalfa-soybean meal were significantly higher ($P<.01$) than elodea in ADF digestion coefficients. Even though elodea was similar in its amount of acid detergent fiber and lignin when compared to the other samples; however, it was consistently lower in digestible nutrients on all parameters measured.

Nitrogen retentions on each of the treatments are also shown on Table 7. Values ranged from 2.8 gm/day for the alfalfa-elodea ration to 3.1 gm/day for both 100% alfalfa and the alfalfa-soybean mixture. No significant differences were found between any of the treatment means. Probable explanations for these similarities could be the similar crude protein values for each of the forages. Linn et al. (1975) found negative nitrogen retentions for lambs fed aquatic-plant containing rations. Their negative nitrogen retentions of lambs fed aquatic plant-containing rations reflected the low nitrogen and digestible energy intakes

TABLE 7

NITROGEN RETENTION[1]

Item	100% Alfalfa	70% alf. 30% algae	70% alf. 30% elodea	95% alf. 5% SBM
N intake, g/day	31.0	30.4	30.30	31.4
Fecal N, g/day	8.8	9.0	9.63	8.8
Urinary N, g/day	19.1	18.4	17.87	19.5
N retention, g/day	3.1	3.0	2.80	3.1
N retention, %	10.0	9.8	9.20	9.8

[1]No significant difference between treatment means (P<.05).

of these lambs. All lambs that were fed aquatic plant-containing rations by Linn et al. (1975) lost weight, indicating that body protein breakdown occurred to meet energy needs.

Rumen fluid pH values, presented in Table 8, were not different significantly across treatment means. Values ranged from 7.82 for the 100% alfalfa ration to 7.97 for both the alfalfa-algae and the alfalfa-soybean meal mixtures. These values were all extremely high for rumen pH values evaluated when feeding both terrestial and aquatic plant forages. Linn et al. (1975) reported pH values of 7.1 to 7.5 for lambs consuming rations containing aquatic plants. The high values found in this study could be attributed to an error in sampling or a faulty pH meter.

Blood urea nitrogen values were also similar in value and were not significantly different at ($P<.05$). Values ranged from 24.47 mg% for the alfalfa-algae mixture to 24.48 mg% for the alfalfa-soybean mixture. Hentges et al. (1972) found values of 22.4 mg% for lambs when feeding ensiled aquatic plants.

Rumen NH_3 values were also not significantly different. Values ranged from 10.87 mg% for alfalfa-elodea to 12.12 mg% for the alfalfa-algae ration. These values are similar to those found by Linn et al. (1975b) in which both 100% alfalfa and aquatic plant forages were fed to growing lambs. Their values ranged from 11.45 mg% for an alfalfa-algae mixture (50:50) to 12.42 mg% for an 100% alfalfa ration.

TABLE 8

RUMEN pH, RUMEN NH_3, AND BLOOD UREA NITROGEN VALUES[a]

Item	100% Alfalfa	70% alf. 30% algae	70% alf. 30% elodea	95%alf. 5%SBM
Rumen pH	7.82	7.97	7.95	7.97
Blood urea Nitrogen mg %	25.20	24.47	24.79	25.48
Rumen NH_3 mg %	11.08	12.12	10.87	11.89

[a]No significant differences found between means ($P<.05$).

GENERAL CONCLUSIONS

The results of this study point to the following conclusions:

1. The chemical analyses indicate that aquatic plants may be useful forages for ruminant animals.
2. Both the algae and elodea were similar in crude protein to a conventional forage such as alfalfa and could be considered a potential alternative protein source for cattle and sheep.
3. Estimates of the hemicellulose, cellulose, and lignin contents suggested that both aquatic plants should be comparable in digestibility to terrestrial forages that are commonly consumed by ruminants.
4. Mineral contents of the aquatic plants were higher in both calcium and phosphorus than most land forages. Both algae and elodea should be adequate sources of macro and micro minerals.
5. Gross energy values for the aquatic plants were lower than alfalfa and an alfalfa-soybean mixture. This would indicate that the aquatic plants should be considered more as a protein source and would have to be supplemented with concentrates if used in growing rations for sheep and cattle.

6. Digestibility coefficients indicated that the alfalfa based ration containing 30% algae was just as digestible as 100% alfalfa or 95% alfalfa-5% soybean meal rations.
7. When comparing the two aquatic plants in both nutrient content and digestible nutrients, the algae was significantly greater in both parameters and would appear to have the greater potential as a livestock feed.
8. Further evaluations of aquatic plants need to be conducted before commercial livestock enterprises could use them in practice. Growth trials measuring average daily gains, feed efficiency, and carcass composition should be seriously considered. Cost of harvesting, pelleting costs, yield per acre, and potential toxicity problems are all practical parameters that should be investigated before aquatic plants can be adapted to commercial animal agriculture.

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