Order Number 8804195

Utilization of wheat straw in rations for lactating dairy cows

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The University of Arizona, 1987

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UTILIZATION OF WHEAT STRAW IN RATIONS
FOR LACTATING DAIRY COWS

by

Sadi Shalan Khalaf

A Dissertation Submitted to the Faculty of the

COMMITTEE ON NUTRITIONAL SCIENCES (GRADUATE)

In Partial Fulfillment of the Requirements
For the Degree of

DOCTOR OF PHILOSOPHY

In the Graduate College

THE UNIVERSITY OF ARIZONA

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THE UNIVERSITY OF ARIZONA
GRADUATE COLLEGE

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SIGNED Sadi Shalom Khalaf

ACKNOWLEDGMENTS

The author wishes to express his most sincere and deep gratitude to Dr. William H. Brown for all his counsel and guidance during the course of investigations and in preparation of this manuscript.

The author also is grateful to the financial support provided by the Department of Animal Science of the University of Arizona.

Special acknowledgments are extended to Dr. Frank M. Whiting for his assistance and encouragement during the graduate program, to Dr. R. Spencer Swingle for his most valuable suggestions in preparation and conducting of the experiment. Appreciations are also extended to the other members of the Committee: Dr. Thomas N. Wegner and Dr. William F. McCaughey for their invaluable help, suggestions, and reviewing of this manuscript.

The author also is grateful to Mrs. Kay Maddock for her friendship, help, endless patience, and skilled technical assistance during the entire undertaking.

A special note of appreciation is extended to the author's family for their love and support during the graduate program.

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ABSTRACT

An experiment involving three feeding trials was conducted to study the effect of substituting chopped wheat straw for alfalfa in diets for lactating dairy cows.

The results of these trials have shown that in complete mixed diets or diets containing long alfalfa hay, replacement of half of the alfalfa in rations containing 45% roughage for lactating dairy cows with chopped wheat straw does not adversely affect DM intake or milk yield and increase milk fat percentage. Replacing half of the long alfalfa with chopped alfalfa also apparently improved lactational performance although not as dramatically as that of chopped straw. Ammoniation of wheat straw did not improve the performance response by lactating cows. Inclusion of chopped straw in the diets seemed to enhance the efficiency of milk production. Higher ruminal acetate:propionate ratios and increased digestibility of ether extract resulted from feeding straw. Digestibility of other nutrients were generally either not affected or were depressed by straw feeding. Increasing the chopped wheat straw level to 75% of the roughage resulted in lower DM intake and milk yield and negative body weight gains but higher milk fat levels. It did not appear that maintenance of constant ADF level in a dairy ration regardless of roughage level was the solution to the maintenance of milk fat levels.

Thus it has been indicated that under the conditions of this experiment a combination of chopped alfalfa and wheat straw can be used

successfully in complete mixed rations for high producing dairy cows. For the most part all productive parameters measured were improved by the addition of straw and by the feeding of complete mixed diets. This was especially true for milk fat which, from a dairyman's viewpoint, is very important because of its impact on milk pricing. It would also have a direct bearing on management by reducing labor costs through elimination of labor intensive handling of long alfalfa. Mechanical handling of complete mixed rations is relatively easier and cheaper.

INTRODUCTION

World production of cereal grain straws has been estimated to be ca 1710 million metric tons per year (72). One kg of cereal crop residue could be available for each kg of grain produced even after leaving ample residue to prevent soil erosion and maintenance of soil quality (4). Millions of tons are being produced annually in North America and increased irrigation in the Southwest region of the United States dramatically increased grain production which in turn resulted in increased levels of cereal straw. This has provided one source of increased interest in the possible use of cereal grain straw in livestock feeding. The use of cereal grain straws and other crop aftermaths in animal feeding is somewhat limited in North America. However, in other parts of the world, particularly third world countries where livestock productive rates are much lower, cereal grain straw constitutes a major part of livestock diets (73).

Cereal grain straw contains more than 80% carbohydrate, mainly in the form of cell wall polysaccharides which potentially make up an excellent source of energy for ruminants. It has been suggested (36) that the inability of ruminants to avail themselves of the energy from the carbohydrate sources found in cereal grain straws can be explained by one or more of three factors: Lignin acts as an inert barrier between the carbohydrate and the digesting enzyme, the cellulose is too highly crystalline to be quickly available to enzyme action or silica inhibits carbohydrate digestibility. Lack of a readily available carbohydrate source to stimulate microbial growth may also be a factor.

In many developed countries high bulk residues, such as cereal grain straw, are disposed of by burning. This practice causes great palls of smoke for several weeks each year in many areas. New stringent environmental pollution laws prevent such burning and farmers are being forced to find other alternative methods of disposal. In most cases it is not desirable to leave straw on the ground because it can harbor harmful pests. Plowing the residue into the ground increases nitrogen requirements for fertilization and makes cultivation more expensive. In some cases there is too much bulk to allow effective incorporation into the soil. Plowing-in is an added expense with little or no compensating value. Furthermore, because cereal grain straws are generally cheaper than high quality roughages such as alfalfa there is an apparent increased interest in feeding them to ruminants if effective ways can be developed.

Straw has an overall poor nutritive value, being especially low in crude protein, minerals, and vitamins. In addition, because of the high fiber content, digestibility is low. It is used mainly for bedding and fed primarily to low performance animals. Nevertheless, straw can theoretically serve an essential role in diets for lactating dairy cows by supplying the fiber required for good rumen function and maintenance of milk fat. Chopped cereal straw has also been used along with fresh green chop such as alfalfa to prevent bloat. Also the use of straw as a major supplier of roughage would allow producers to potentially obtain higher profits from their land by growing less fodder crops and more cereal grain crops.

The objectives of this study were designed to determine the effectiveness of various means of including wheat straw in rations for lactating dairy cows. Several ideas were explored in an effort to overcome some of the well known disadvantages of inclusion of straw in ruminant diets: high fiber, and low protein, mineral, and vitamin contents. It was first decided that a ration containing 45% roughage would serve in all trials as a control, that alfalfa would serve as a roughage control, that a mixture of steam flaked milo, soybean meal, molasses, and animal fat would serve as the concentrate source, that all rations would be isonitrogenous and that all wheat straw would be chopped. It was then decided to use lactating dairy cows to test several theories concerning wheat straw's effect on various nutritional parameters including lactational response:

1) could chopped wheat straw substitute for half of the long alfalfa?
2) would ammoniation of the straw be effective?
3) what effect would chopping half of the alfalfa have?
4) what effect would chopping all of the roughage and consequently feeding the entire diet as a complete mix have?
5) could chopped straw substitute for 75% of the alfalfa?
6) would a diet containing a 50:50 mixture of chopped alfalfa and wheat straw that contained the same ADF level as one containing 45% chopped alfalfa produce the same results?

REVIEW OF LITERATURE

Influence of Roughage on Voluntary Feed Intake

Voluntary feed intake is a major factor in determining animal productivity with diets containing low quality roughages. Chemical composition (100), physical characteristics (10), rate and extent of digestion, and rate of passage of roughage through the alimentary tract (103) all influence voluntary feed intake.

Blaxter et al (15) have shown that the amount of dry matter (DM) present in the gut remains constant when sheep were fed different roughage diets ad libitum. They postulated that the rate of passage of food through the alimentary tract, and digestibility are the two factors controlling voluntary feed intake of roughage in ruminant animals. Campling et al (17, 18) also indicated that voluntary feed intake by cows fed hay, oat straw, or oat straw with urea was directly related to the rate at which digesta disappeared from the reticulo-rumen by digestion and absorption, and by the passage of feed through the alimentary tract. Coombe and Tribe (20) showed that addition of 3% urea too at straw diets fed to sheep resulted in increased ad libitum feed intake, rate of cellulose digestion and rate of passage through the alimentary tract. They also found that voluntary feed intake was positively correlated with rate of passage and when rate of passage was not considered, voluntary intake was not correlated with rate of cellulose digestion. Furthermore, Freer et al (32) indicated that rate of straw consumption was significantly increased by intraruminal infusion of urea. Since urea had been shown to enhance rate of digesta disappearance from the reticulo-rumen (18), they suggested that rate of feed consumption depended largely on the rate at which roughage is broken down and on the contribution mastication made to this breakdown. Freer et al (32) also listed two other factors that control rate of roughage consumption:daily time of access to roughage and amount of roughage offered.

Van Soest (100) reported that when forage cell- wall constituents were above 50% of the DM, voluntary feed intake was depressed. High correlations exist between intake, chemical composition, and digestibility of DM in forages with high cell wall contents. If nutritive value is defined as the product of consumption and digestibility then low protein, high cell-wall contents and high lignin levels of cereal residues have important implications in animal nutrition (4).

Several reports (60, 78, 79, 80, 81) indicate that increasing level of dietary straw tends to depress intake regardless of physical form. Lofgreen and Christensen (58) found that feeding barley straw as half of the roughage resulted in lowered feed intake with greater reticulo-rumen fill. Feeding long roughage to lactating dairy cows resulted in lower feed intake, smaller volume of rumen fluid, and lower rate of flow from the rumen while milled roughage resulted in normal levels of rumen fluid and flow rates (78). MacDearmid and Kay (60), feeding diets containing 5 to 45% chopped barley straw, showed highest DM intake on diets with 30% and lowest on diets with 45%. They also found that contents of the alimentary tract increased from 10% of liveweight for diets with 5% straw to 20% for diets with 45% straw. Owen et al (80) fed diets containing 20, 35, and 50% chopped barley straw to lactating dairy cows either as a loose mix or as cubes. They found that DM intake was depressed with the higher levels of straw when fed in a loose form, but was enhanced when cubed. However, diets with 20% cubed straw depressed feed intake compared to the diets with 20% loose straw. Forbes et al (31) reported a maximum DM intake at a level of 18.8% straw in diets for young beef cattle. Similar results were found by Bines and Davey (12) who reported lowest DM intake (7.5kg/d) on diets with no straw while inclusion of chopped barley straw at levels of 20, 40 and 60% increased DM intake to 10.7,11.3 and 10.7 kg/d, respectively. Contrary to others they found no depression in DM intake with straw levels up to 60%. Greatest digestible energy intake however was observed on diets containing either 20 or 40% straw. Lactating dairy cows showed depressed feed intake when the level of chopped straw increased to 45% (39).

Owen et al (77) found voluntary feed intake of lambs was uniformly depressed with increased dilution of the diet with coarse oat husks fed in the loose form. However, when oat husks were finely ground and pelleted, the response to increased levels was modified and in the case of older, heavier lambs intake initially increased. They concluded that ruminants may sometimes be able to respond to increased diet dilution by maintaining their maximum digestible energy intake through increased DM intake, even though the attempt is often thwarted in varying degrees by physical form of the feed. Others (55, 66) also reported that pelleting diets containing high levels of ground straw resulted in increased feed intake when compared to the same forage in the long or coarsely chopped form. In addition, the poorer the quality of the forage, the greater the difference in acceptability.

Supplementation with energy, nitrogen, and minerals have been shown to dramatically influence roughage digestibility and voluntary feed intake (5, 18, 19, 20, 29, 32, 59, 73, 87, 106). O'Donovan and Ghadaki (73) showed that supplementation with 400 g of concentrate per day increased DM intake of sheep from 645 to 1214 g/d. In another study (67) maximum DM intake with pelletedo at straw was achieved by the addition of 30% starch and while organic matter digestibility increased cellulose digestibility was depressed.

Improved voluntary feed intake of low quality roughages by addition of either protein or nonprotein nitrogen (NPN) has been shown (18, 20, 27, 32, 59, 106). Church and Santos (19) reported that consumption of chopped wheat straw was significantly increased by the addition of 1 g soybean protein per kg $BW^{0.75}$ while no increase was noticed with liquid urea supplement plus ammonium phosphate. Smith et al (87) indicated that a crude protein concentration of at least 85 g/kg DM was necessary to maximize digestibility of fiber) rich diets. Lyons et al (59) investigated the feeding of long barley straw diets to steers supplemented with 1.37 kg concentrate containing 8.9, 13.6, 19.1, or 29.2% crude protein. Voluntary straw intake on the treatment with 13.6% crude protein in the concentrate was 25% higher than on the diet containing only 8.9% crude protein. No improvement was noted in intake on the higher levels of supplementation. They suggested that voluntary straw intake was limited at the lowest level of supplementary protein by a deficiency of absorbed protein, while at higher levels of supplementary protein, intake was probably limited by the capacity of the alimentary tract.

Urea as a source of NPN also enhanced voluntary feed intake (18, 27, 32). In addition Fishwick et al (29) showed that oat straw intake increased by about 20% when supplemented with urea containing sugar beet pulp. However, another report (9) found no difference in intake with urea supplementation at 0, 0.75 and 1.5% of diets containing 45% pelleted wheat straw fed to Awasi lambs. Horton and Holmes (45) reported similar results. Kay et al (51) indicated that urea had little effect on straw intake unless it was available for frequent consumption.

Addition of crushed barley to diets of barley straw fed ad libitium to beef cows and sheep had no effect on DM intake or digestibility, but reduced live weight loss (51). Winter and Pigden (106) showed that sucrose addition to urea supplemented diets resulted in a small improvement in DM intake by beef cows fed chopped oat straw. Campling et al (18) indicated that infusion into the rumen of either 75 or 150 g of urea per day caused a 40% increase in voluntary feed intake of an oat straw diet fed to dry, nonpregnant cows. A daily infusion of 25 g urea caused only a 26% increase in intake. The addition of 500 g of sucrose to the daily infusion of either 75 or 150 g of urea caused no further increase in intake.

Nutritive Effect of Straw Processing

Low quality roughages can often be mechanically processed to improve palatability to livestock and to render them suitable for inclusion in complete mixes or pelleted diets. Owen et al (77) found that pelleting of finely ground oat husks resulted in higher intake compared to ground husks fed in the loose form. Pelleting of diets containing up to 50% barley straw increases feed intake as the percentage of straw increased above 20% (55). However, there was a linear depression in DM digestibility observed with increasing levels of straw in the diet. Pelleting of wheat straw diets of steers resulted in 8.4 and 16% increases in feed intake and average daily gain, respectively (47). Bines and Davey (12) reported highest digestible energy intake with diets containing 20 or 40% chopped wheat straw. However, DM digestibility was linearly reduced with increasing level of chopped straw in the diet. Raven et al (81) found highest DM intakes on diets containing 10 to 20% milled barley straw as compared to long straw and that 30% straw diets depressed organic matter digestibility. On the other hand, Mira et al (64) found that consumption of long straw was higher than shredded straw. White et al (105) found that steers receiving 20% ground rice straw consumed more DM and gained more weight than steers fed either pelleted or long rice straw at the same level or at the 5% level regardless of form. Coarsely ground barley straw can be successfully included in dairy rations at a level of 24 to 32%, however when fed at the 40% level both DM and digestible energy intakes were reduced (79). Reduction in DM digestibility was also found by Forbes et al (30) when particle size of coarsely ground straw was reduced.

Rodrigue and Allen (82) found that the grinding of hay in rations composed of a 2:1 ratio of hay to concentrate increased rate of passage of the hay as compared to unground hay. This increased rate of passage was associated with a reduction indigestibility of the main nutrients in the diet. They also reported that the finer the hay was ground, the greater was the depression in digestibility of the ration. Owen et al (78) also compared long and coarsely ground roughages in rations for lactating dairy cows and found that long roughage was consumed less and was associated with a lower rate of passage from the rumen.

Moore (66) reviewed some of the factors associated with processing of roughages. He found that pelleting, grinding, and chopping reduced the time spent to consume an equal amount of the same forage in the long form. Rumination time was reduced by fine grinding and pelleting while long hay stimulated saliva secretion. This was supported by the observation that pelleted hay reduced rumen pH from 6.9 to 6.0 when compared to long alfalfa hay. Also small amounts of straw raised rumen pH from 5.22 to 6.45 on all pelleted rations. This change was reported to be due to stimulation of rumination and saliva production. Moore (66) also indicated that grinding and pelleting the roughage increased the ratio of propionate to acetate in rumen fluid. Grinding also increased rate of passage, and DM and fiber digestibility.

Burt (16) reported that grinding and pelleting of barley straw improved its nutritive value. Feed intake and live-weight gain were improved and eating time was reduced from 4 h to 1 h/d. Rumination time was reduced by half. Even though grinding and pelleting of barley straw for dairy heifers resulted in lower digestibility of DM, the reduction in energy loss as methane and heat made straw similar in net energy value to long hay. Grinding and pelleting also resulted in lower saliva production, pH and rumen acetate, while rumen propionate was increased. Higher propionate and lower acetate would be beneficial for utilization of absorbed energy for lipogenesis but would have little effect for maintenance (7).

Effect of Supplementation on Nutritive Value of Roughage

Attempts to improve intake and utilization of low quality roughages such as cereal straw have dealt mainly with chemical (50, 91) and physical (16, 55, 79) treatments. An alternative approach is through proper supplementation. Low quality roughages are usually deficient in crude protein, readily fermentable carbohydrate, minerals, and vitamins. They are therefore unable to support rumen conditions necessary for optimum microbial activity. Addition of alfalfa hay, high protein feeds, and cereal grains to diets containing poor quality roughages generally increase the digestibility of the poor quality roughages (59, 70, 73). Supplementation of both long and chopped straw diets with either soybean meal or a molasses-urea mixture reversed a negative body weight gain in lambs to a positive gain (38). In another trial the same authors found that with nonlactating ewes supplementation of straw diets with barley-urea or barley alone resulted in positive weight gains, whereas a molasses-urea supplement resulted in a weight loss. Kay et al (51) found that while a crushed barley supplement did not affect intake or digestibility of straw, it did reduce weight loss. Increasing levels of barley supplement increased liveweight gain on both long and shredded barley straw diets when fed to steers (60, 64). Freer et al (32) found that intraruminal infusion of urea increased straw consumption. Coombe and Tribe (20) reported increased feed intake, rate of cellulose digestion and rate of passage with the addition of urea to sheep diets. However when the level of urea was increased from 16 to 32 g/d there was a significant reduction in rate of passage and intake. Intraruminal infusion of 150 g/d of urea into dry nonpregnant cows increased organic matter, fiber and nitrogen-free extract (NFE) digestibility of oat straw (18). Mean retention time of food residues in the digestive tract was also reduced. Fishwick et al (27, 29) also reported improvement in intake, and digestibilities of organic matter, DM, and crude fiber when oat straw was supplemented with urea. Contrary to others, Bhattacharya and Pervez (8) and Bhattacharya and Khan (9) found no improvement in feed intake, average daily gain (ADG) or nutrient digestibilities of diets containing up to 50% wheat straw when supplemented with urea.

Supplementation with urea and/or sucrose has also been investigated (18, 25, 106). Campling et al (18) showed that while infusion of urea caused an increase in voluntary feed intake of oat straw there was no further increase when sucrose was added to the same levels of urea infusion. Winter and Pigden (106) showed that whereas urea increased DM intake up to 23% on chopped oat straw diets, urea plus sucrose together only increased intake 14%. Digestibilities of DM and cellulose were increased with urea supplementation but not with the urea-sucrose supplement. Faichney (25) reported a similar reduction in intake of urea supplemented oat straw with increasing levels of sucrose in the diet. Additionally, sucrose tended to reduce crude fiber and nitrogen digestibility with no effect on rate of passage, cellulose digestion, or body weight gain.

Supplementation of straw with different levels of protein and energy for young cattle was investigated by Andrews et al (5). In comparing four protein and five energy levels, they found that at the lowest protein level (6.6%) intake of straw was low and live weight gains were low at all energy levels. Increased protein levels were necessary before intake and weight gains were improved. Lyons et al (59) showed somewhat similar results and suggested that voluntary intake of long barley straw was limited by low protein supplementation because of a deficiency of absorbed protein. They also indicated that increased protein content of the diets increased digestibility of organic matter, crude fiber, and protein of the whole diet. Others have also concluded that at least a certain minimum amount of supplementary protein is necessary to maximize digestibility of fiber rich diets with beef cattle (87) and to increase intake and liveweight gain with barley straw diets fed to lambs (1). Conversely, Mira et al (65) and Horton and Holmes (45) found no evidence that the crude protein content of the ration had any effect on straw intake.

Church and Santos (19) found that voluntary intake of wheat straw was increased by supplementation of soybean protein but was not affected by supplementation of urea plus ammonium polyphosphate. Fishwick et al (27) also studied phosphorus supplementation and found that while added urea increased straw intake, phosphorus gave no response either in the presence or absence of urea. In another paper Fishwick et al (28) found that severe reduction in phosphorus intake during pregnancy did not reduce birth weight, or the intake or digestibility of oat straw. They found that inadequate phosphorous levels during lactation resulted in depressed milk yield and loss of body weight. However, other work (11) found that liquid supplementation of chopped oat straw fed to beef cows with urea, calcium, phosphorus, sodium, trace minerals, and vitamins resulted in increased feed intake.

Both DM intake and digestibility increased linearly when sheep on straw diets were supplemented with concentrate (73). Mullholand et al (67) supplemented pelleted oat straw diets containing urea with 0, 5, 10, 15, 20, 30, and 40% starch. Maximum intake with sheep was achieved with 30% starch while 40% caused digestive disturbances. Daily gain and organic matter digestibility was increased by starch addition but cellulose digestion was depressed. Increasing starch levels had little effect on nitrogen digestibility but resulted in a substantial increase in nitrogen retention through reduction in urinary nitrogen excretion.

Bird (13) investigated the supplementation of both urea and sulphur to cattle and sheep. He confirmed the work of others in that urea added to wheat straw diets increased energy intake, efficiency of digestion, and live weight gain in both sheep and cattle. However, addition of sodium sulphate to rations already containing urea increased responses in sheep but not in cattle. It was concluded that cattle and sheep had similar capacities to digest straw but that cattle were more efficient than sheep when urea alone was included. The addition of sulphur decreased this disparity and allowed sheep to realize the full nutritional potential from the straw. Bird (13) concluded that cattle require less dietary sulfur and can cope with a wider nitrogen:sulfur ratio in feed than sheep, apparently, because sulfur is recycled more efficiently in cattle.

The possible complimentary effect of other feedstuffs on poor quality roughages has also been examined. Kromann et al (54) fed varying proportions of wheat straw and pea scalpings to sheep. They observed increased dietary intake, live weight gain, and digestibilities of organic matter, crude protein, ether extract, NFE, and total digestible nutrients as levels of pea scalpings rose. High pea scalping diets also resulted in lower reticulo-rumen fill.

Supplementation of barley straw, brome grass hay, and corncobs with alfalfa hay was studied by Ndlovu and Buchanan-Smith (70). They found that supplementation with 30% alfalfa increased ruminal ammonia nitrogen on all diets and increased the ruminal concentration of valerate and isobutyrate on corn cob diets and isobutyrate on barley straw diets. Supplemental alfalfa also increased rate of passage for the corn cob diets. They suggested that these results may help explain some of the associated effects previously observed between good and poor quality roughages.

Mir et al (63) found that branched chain fatty acids dramatically increased in vitro digestibility of barley straw while there was little effect on alfalfa digestibility. They felt that the high protein in the alfalfa hay probably contributed sufficient branched chain fatty acids to meet the needs of the rumen bacteria. Hungate and Dyer (48) supplemented diets containing 82% wheat straw with valeric and isovaleric acids but found that weight gains and rumen microbial activity did not change. They suggested that the negative results may have been due to insufficient digestible carbohydrate in the ration.

Influence of Straw on Nutrient Digestibility

Cereal grain straws generally contain more than 80% carbohydrates, which is mainly made up of cell wall polysaccharides that are potentially large sources of dietary energy for ruminant animals. Much of the cell wall polysaccharides are not utilized by rumen microorganisms due to covalent bonding between the polysaccharides and lignin which accounts for about 10% of the DM of the straws (40).

Digestibility of straw is affected by physical form (66), level of inclusion (55, 60, 81), and type and level of supplementation (18, 29, 59, 106). Lamming et al (55) reported a linear depression in DM digestibility with increasing levels of pelleted wheat straw. MacDearmid and Kay (60) and Kay et al (52) reported similar results with chopped straw. Others (12, 39, 53, 104) have also shown a linear decline in DM digestibility with increasing levels of straw. Swan and Lamming (92) suggested that there was a simple negative correlation between apparent digestibility and the crude fiber content of the DM. White et al (104) added that the decreased nutrient digestibilities were more pronounced in nutritionally unbalanced diets. As has been previously discussed in this dissertation, many researchers (18, 19, 20, 27, 29, 30, 50, 54, 87, 106) have shown that the addition of crude protein or an NPN source such as urea is necessary to maximize digestibility of fiber rich diets, while others have reported either mixed (51) or contrary results (8, 9).

Readily fermentable carbohydrate has been reported to significantly reduce cellulose and crude fiber digestibility of poor quality roughages (25, 45, 67) while organic matter digestibility was enhanced (67). El Shazly et al (21) attributed the reduction in cellulose digestibility to the preferential digestion of starch by rumen microorganisms. Topps et al (96) have shown that starch reduces rumen pH and thus provides a less favorable environment for cellulolytic and other bacteria that digest plant fiber. Reduction in cellulose digestibility could also be related to increased rate of passage due to reduction in particle size and increased feed intake (66).

Linear reduction in DM digestibility with increasing levels of dietary straw has not been associated with any reduction indigestibility of cell wall constituents. In fact, highest fiber digestion was observed at the highest level of straw inclusion (12, 39, 80, 81). Most of these reports show that increasing levels of straw result in a reduction in organic matter digestibility at the expense of crude protein and NFE, more than offsetting the increase in fiber digestion.

Processing (grinding, pelleting, etc.) tends to depress roughage digestibility (30, 66, 82). Reduction of digestibilities was associated with higher consumption and higher rates of passage. The finer the grind, the more rapid the rate of passage and the greater the depression in digestibility of DM and fiber.

<u>Influence of Straw on Animal Performance</u>

High proportions of straw are not normally included in diets for high performing animals such as lactating dairy cows and finishing beef cattle. Conversely high levels of straw are often included in rations of livestock with relatively low nutritional requirements such as slow growing cattle and dry mature cows. In general, high levels of straw in any form result in a reduction in growth rates (30, 31, 52, 53, 55, 58, 60, 73, 81, 92). Swingle et al (93) however, found that feed intake and average daily gain of growing and finishing steers were slightly increased when half of the alfalfa hay in diets containing either 20 or 40% roughage was replaced by chopped wheat straw.

Kay et al (51) indicated that live weight loss from straw feeding was reduced by the addition of crushed barley grain. This reduction in weight loss was also reported by Mira et al (64) by supplementation with barley grain, Mullholand et al (67) with starch, Hadjipanayiotou et al (38) with soybean meal or molasses-urea, and Kromann et al (54) with pea scalpings. Combining good and poor quality roughages was also found to be beneficial to animal performance (2, 37, 70).

Chemical Treatment of Straw

Chemical treatment of straw to improve its nutritive value dates back to the use of sodium hydroxide at the end of the 19th century (57). Since then several methods of treating straw with sodium hydroxide have been developed. These methods have been adequately reviewed by Jackson (49). In general, the process improves digestibility and palatability but has several disadvantages: a high requirement for labor, leaching of useful nutrients, the need to preserve the product by drying or ensiling, and a large requirement for water.

An alternative to sodium hydroxide treatment is ammoniation. Sundstol et al (91) reviewed ammonia NH_3 treatment as a means of improving the nutritive value of straw and other low quality roughages. In general the process of ammoniation simply involves the stacking of bales and covering them with polyethylene, followed by NH_3 injection through perforated pipe inserted into the stack. Treatment time can last from 1-8 wks depending on temperature. At the end of the treatment the stack is opened and free NH_3 is allowed to escape for a few days, after which it can be fed. There are several advantages to NH_3 treatment: it is simple and could easily be adapted by farmers, it is relatively inexpensive, the process creates no known pollution problem, the treated material is dry and easy to handle, treated material contains no compound such as NaOH that creates stress to the animal, NPN is added during treatment, treated material is reportedly more palatable, and, finally, studies have indicated that energy values may be raised as much as 70-80% by the process. The only two disadvantages listed by Sundstol et al (91) are: NH_3 is an unpleasant chemical to handle and some of the NH_3 is lost when the stack is opened.

The results of many studies (1, 33, 41, 46, 47, 56, 61, 65, 71, 75, 83, 99, 107) have indicated a general doubling of the nitrogen content of the treated material. Lawlor and O'Shea (56) and Oji et al (75) found that over half of the injected NH_3 was attached to the treated straw, while Herrera-Saldana et al (41) reported that only 18% was bound to the straw.

Al-Rabbat and Heany (3) found that ammoniation caused reductions in gross energy, ADF, cellulose, and lignin in mixed rations containing wheat straw. A reduction in cell wall constituents was also observed by others (1, 40, 44). Horton (44) suggested that the lower lignin in NH_3 treated wheat straw may indicate hydrolysis of the linkage between the uronic acid groups of hemicellulose and cellulose. Hartley and Jones (40), however showed that the lignin content of cell walls was increased by NH_3 treatment due at least in part to removal of other cell wall components. They indicated that NH_3 treatment caused the release of water soluble phenolic esters of carbohydrates from the cell walls. In contrast, several workers (46, 71, 90) found ammoniation had little effect on the crude fiber, cellulose, hemicellulose, NDF, or ADF content of straw. Arizona workers (99) did report a slight decrease in NDF and ADF values in ammoniated straw.

There is general agreement that ammoniation of straw results in higher feed intake (3, 33, 41, 43, 46, 47, 56, 65, 71, 76, 83, 90, 107), even though Swingle et al (93, 94) found that feed intake and ADG were not affected when ammoniated straw was fed to finishing steers. The work of Swingle et al (93, 94) may be explained by the finding of Horton (43) and Garrett et al (33) who reported that as concentrate supplementation increased, the increase in intake of NH_3 treated straw compared to untreated straw was negated. Mira et al (65) suggested that the marked inprovement in intake following ammoniation of straw appears to be associated with palatability. Improvement in intake could be due to the combined results of improved nutrient digestibilities (3, 42, 46, 47, 74, 76, 90) and reduced rumen retention time (75, 107). Ammoniation was also found to improve ADG (1, 3, 47, 65, 71) and efficiency of feed utilization (33, 71).

Many researchers have concluded that the improvement in the nutritive value of low quality roughages by ammoniation is a result of improvement in nutrient digestibilities. Ammoniation has been shown to increase digestibility of DM (1, 42, 43, 46, 56, 61, 74, 76, 90, 99, 107), organic matter (33, 40, 42, 46, 47, 56, 74, 76), energy (3, 33, 41, 46, 76), crude protein (3, 41, 42, 46), and cell wall components (3, 33, 41, 42, 43, 44, 46, 47, 74, 76, 83, 90, 107). In one case (3), nutrient digestibility of ammoniated straw exceeded that of alfalfa hay.

Improvement in digestibility has been reported to be related to increased availability of hemicellulose for degradation by the rumen bacteria as a result of solubilization of this fiber component by N_{H3} treatment (83). Horton (44) concluded that improvement in apparent digestibility of ammoniated straw diets was largely due to both solubilization by NH_3 and increased digestibility of the residual cellulose and hemicellulose. Lower lignin in ammoniated straw may indicate hydrolysis of linkages between uronic acid groups of hemicellulose and cellulose (26). Digestibility of cellulose may also be increased by swelling following treatment with N_{H3} since this would allow greater penetration by rumen bacteria (95).

Influence of Straw on Milk Production and Composition

Straw has an overall poor nutritive value. It is especially low in crude protein, energy, minerals and vitamins. In addition, because of the high level of cell wall constituents, digestibility of straw tends to be very low. For these reasons straw has not been extensively utilized in rations for lactating dairy cows. Nevertheless, it appears that straw, if used properly, could provide energy and fiber necessary for good rumen function and maintenance of normal milk fat levels. Several studies have been conducted with lactating dairy cows in attempts to better understand how straw may be more advantageously used in their diets.

Owen et al (78) fed 25% barley straw or rye grass diets in either the long or coarsely ground form to lactating dairy cows. They found restricted intake with the long form of both roughages that resulted in low milk fat and that the low intake of the long straw was associated with a smaller volume of rumen fluid, lower rate of flow from the rumen, and a lower proportion of acetic and butyric acids and a greater proportion of propionic acid in the rumen fluid. Milled roughage resulted in higher feed intakes, and normal milk fat levels, rumen volume, flow rate, and proportions of VFA.

Halevi et al (39), using wheat straw as the sole source of roughage for cows in midlactation, fed diets containing chopped straw and concentrate in the following proportions: 45:55, 30:70, and 15:85. They found feed intake depression with the high straw diet, but no significant differences between treatments in milk yield or composition, even though there was a trend towards higher milk fat percentage and body weight gains as straw increased in the diet. Despite the low straw diet producing lower levels of acetate and higher levels of valerate and isovalerate, the acetate:proportionate ratios on all diets were above 3:1. As the level of straw in the diet increased digestibility of DM and energy decreased while digestibility of fiber increased. Similar levels (17.5, 32.5 and 47.5%) of wheat straw were mixed and pelleted with the other feed ingredients and fed by Blair et al (14) to lactating dairy cows with somewhat similar results. DM intake was reduced by the highest level of straw. There were no differences in milk yield but body weight tended to be reduced with increasing levels of straw. Percentages of milk fat and total solids were increased by the high levels of dietary straw while SNF and protein declined. Milk energy/kg DM intake and gross feed efficiency were highest at the high level of dietary straw. As determined with steers, digestibility of DM, energy, protein, and ether extract declined with increasing levels of straw while that of fiber and cellulose increased.

In contrast to the previously discussed results (14, 39), Owen et al (79) found that high levels (40%) of coarsely milled barley straw decreased DM intake enough to cause a substantial reduction in digestible energy intake and a reduction in milk yield. Owen et al (79) also found milk fat severely depressed at the low level (16%) of straw inclusion while total solids and SNF were not affected. They concluded that maximum production could, however, be maintained with intermediate levels (24 and 32%) of straw in complete mixes for lactating dairy cows.

In another trial Owen et al (80) investigated the feeding of diets containing 20, 35, or 50% chopped barley straw fed either as a loose or cubed mix. Again they showed that DM intake, milk yield and SNF were reduced while milk fat increased with increasing levels of loose straw. Cubed diets containing either 35 or 50% straw, however, supported higher DM intake and milk yield with a lower milk fat percentage than their corresponding loose diets.

Sharma et al (85) compared untreated and steam treated wheat straw with other diets for Holstein cows. When 20 and 30% steam treated straw, 20% untreated straw, and 30% ground alfalfa diets were compared the 20% untreated straw diet resulted in a decrease in DM intake, milk production, milk protein and SNF percentage, and total milk protein. Milk fat was not affected. In another trial comparison of a 30% steam treated straw diet with a diet containing 60% corn silage showed that there was less DM intake, lower percent milk fat and SNF, and less 4% FCM produced on the straw diet. The diet containing 30% steam treated straw produced a lower molar percentage of acetate and a higher molar percentage of propionate both when compared to the 30% alfalfa diet and the 60% corn silage diet. This reduction in the acetate:propionate ratio was reflected in a reduction in milk fat percentage. Story and Rook (89) suggested that normal milk fat secretion may be maintained if the decline in molar proportions of acetic acid that usually accompanies the inclusion of low roughage diets or ground and pelleted diets is offset by an increase in butyric acid rather than propionic acid. When 20 and 30% steam treated straw diets were compared to alfalfa, it was found that butyric acid actually declined. In summing up both trials, Sharma et al (85) felt that steam treated wheat straw could be included at levels up to 20% in a total mixed diet for lactating dairy cows without affecting animal performance but above that level there may be depressions in DM intake and milk production.

EXPERIMENTAL PROCEDURE

Three feeding trials were conducted to study the nutritive value of wheat straw using lactating Holstein cows from the University of Arizona Dairy herd. Trials 1, 2, and 3 took place during the summer of 1985, fall of 1985, and spring of 1986, respectively. The trials were designed to investigate the effect of various levels of chopped untreated and NH_3-treated wheat straw as replacement for alfalfa hay (hereafter referred to as alfalfa) in rations for lactating dairy cows. Each trial consisted of four treatments of six cows each.

Roughage type and level for each treatment was as follows:

Trial 1: 1) 45% long alfalfa

2) 22.5% long alfalfa + 22.5% chopped alfalfa

3) 22.5% long alfalfa + 22.5% chopped wheat straw

4) 22.5% long alfalfa + 22.5% chopped NH=3 wheat straw

Trial 2: 1) 22.5% long alfalfa + 22.5% chopped alfalfa

2) 45% chopped alfalfa

3) 22.5% long alfalfa + 22.5% chopped wheat straw

4) 22.5% chopped alfalfa + 22.5% chopped wheat straw

Trial 3: 1) 45% chopped alfalfa

2) 22.5% chopped alfalfa + 22.5% chopped wheat straw

3) 11.25% chopped alfalfa + 33.75% chopped wheat straw

4) 15.5% chopped alfalfa + 15.5% chopped wheat straw

Wheat straw was ammoniated as previously described by Urias and Swingle (99). The concentrate portion of all rations was based on steam (processed) flaked (SPF) milo and soybean meal which were adjusted to make the diets isonitrogenous. The roughage portion of Ration 4 in Trial 3 was adjusted so that the ADF content was equal to that of Ration 1 in Trial 3. No attempt was made to make the rations isocaloric. Molasses, animal fat, dicalcium phosphate, salt, and vitamin A were added to each diet. Tables 1-9 present ration composition, chemical composition of ingredients and chemical composition of rations for all trials.

For those rations containing chopped alfalfa, the hay was processed through a slicer (H. L. Cross Co., Tulare, Ca.) to produce a particle size of ca 5 cm. In a previous trial at this station (35), alfalfa hay ground through a Miller hay mill had a small particle size that seemed to have an adverse effect on feed intake and lactational performance. Particle size of hay processed through the slicer was similar (ca 5 cm) to that of straw processed through the Miller mill (ca 3 cm). Ether extract of the straw was increased by the addition of ca 1% animal fat to reduce dustiness during processing. Throughout the remainder of the dissertation the processed alfalfa and straw are referred to as chopped alfalfa or chopped straw, respectively. Except for those rations containing long alfalfa, all ingredients were fed as complete mixes. The long alfalfa was fed on top of the other mixed ingredients for those rations containing it.

For each trial, 24 Holstein cows, selected for nearness to peak of lactation, were blocked on the basis of milk yield and six randomly

Table 1. Composition of Experimental Diets for Trial 1.

	Ration Number			
	1	2	3	4
Feed ingredient	45% long Alf.	22.5% long Alf. + 22.5% chop.Alf.	22.5% long Alf. + 22.5% WS	22.5% long Alf. + 22.5% NH_3-WS
Long alfalfa hay (%)	45	22.5	22.5	22.5
Chopped alfalfa hay (%)	--	22.5	--	--
Chopped WS (%)	--	--	22.5	--
Chopped NH_3WS (%)	--	--	--	22.5
SPF milo (%)	35.59	35.59	27.97	31.23
Soybean meal (%)	9.65	9.65	17.16	13.86
Molasses (%)	4.65	4.65	4.65	4.65
Animal fat (%)	3.87	3.87	3.87	3.87
Salt (%)	0.39	0.39	0.39	0.39
Dicalcium phosphate (%)	0.85	0.85	0.85	0.85

Vitamin A mix was added at 400 g/ton on top of each ration
WS = Wheat straw
SPF Milo = Steam processed and flaked milo

Table 2. Average Chemical Composition (DM basis) of Diet Ingredients for Trial 1.

	Feed Ingredient				
	Alfalfa hay	Wheat straw	NH_3-Wheat straw	SPF Milo	Soybean meal
Dry matter (%)	93.9	95.7	95.6	85.9	93.2
Organic matter (%)	83.3	83.7	82.5	84.2	86.2
Gross energy (kcal/g)	4.3	4.4	4.1	4.5	4.7
Crude protein (%)	20.13	3.3	7.7	10.6	50.8
Ether extract (%)	3.6	7.8	7.0	5.6	1.8
NDF (%)	38.5	75.7	75.3	30.3	13.2
ADF (%)	30.0	51.7	56.0	6.9	8.1
Cellulose (%)	21.7	35.9	37.3	3.4	5.0
Hemicellulose (%)	8.5	24.0	19.3	23.5	5.1
Lignin (%)	8.3	12.9	12.7	3.0	5.0
Total ash (%)	10.6	12.0	13.2	1.7	7.0

NDF = Neutral detergent fiber
ADF = Acid detergent fiber

Table 3. Chemical Composition of Rations for Trial 1.

	Ration Number			
	1	2	3	4
	45% long Alf.	22.5% long Alf. + 22.5% chop.Alf.	22.5% long Alf. + 22.5% WS	22.5% long Alf. + 22.5% NH_3-WS
Dry matter (%)	89.3	90.5	90.5	90.8
Organic matter (%)	81.5	82.7	81.5	81.6
Cell solubles (%)	74.2	71.5	69.7	70.0
Crude protein (%)	17.5	17.4	16.9	17.3
Gross energy (kcal/g)	4.6	4.7	4.6	4.5
NE1 (Mcal/kg)	1.8	1.8	1.7	1.7
Ether extract (%)	7.4	7.4	7.7	7.3
Total ash (%)	7.8	7.8	8.9	9.2
Insoluble ash (%)	0.1	0.2	1.5	1.3
NDF (%)	33.7	39.1	41.0	40.2
ADF (%)	17.4	20.2	23.4	20.9
Cellulose (%)	12.3	14.3	16.7	14.7
Hemicellulose (%)	16.3	18.8	17.5	19.3
Lignin (%)	5.1	5.8	5.2	4.8
Calcium (%)	1.1	1.1	0.9	0.8
Phosphorus (%)	0.5	0.5	0.6	0.5

NE1 = Net energy of lactation, NDF = Neutral detergent fiber, ADF = Acid detergent fiber.

Table 4. Composition of Experimental Diets for Trial 2.

Feed ingredient	Ration Number 1: 22.5% long Alf. + 22.5% chop.Alf.	2: 45% chop. Alf.	3: 22.5% long Alf. + 22.5% WS	4: 22.5% chop.Alf. + 22.5% WS
Long alfalfa hay (%)	22.5	--	22.5	--
Chopped alfalfa hay (%)	--	45.0	--	22.5
Chopped wheat straw (%)	--	--	22.5	22.5
SPF milo (%)	36.12	36.12	26.20	26.20
Soybean meal (%)	8.38	8.38	18.3	18.3
Molasses (%)	5.0	5.0	5.0	5.0
Animal fat (%)	4.0	4.0	4.0	4.0
Dicalcium phosphate (%)	1.0	1.0	1.0	1.0
Salt (%)	0.5	0.5	0.5	0.5

Vitamin A mix was added at 400 g/ton on top of each ration
WS = chopped wheat straw
SPF = steam processed and flaked milo

Table 5. Average Chemical Composition (DM basis) of Diet Ingredients for Trial 2.

	Feed Ingredient			
	Alfalfa hay	Wheat straw	SPF milo	Soybean meal
Dry matter (%)	88.2	90.1	85.8	90.1
Organic matter (%)	78.1	77.3	84.1	83.0
Gross energy (kcal/g)	4.4	4.1	4.5	4.7
Crude protein (%)	18.2	3.6	9.4	47.6
Ether extract (%)	1.5	4.1	3.3	1.2
NDF (%)	53.5	66.8	21.5	17.2
ADF (%)	35.6	51.6	5.3	8.0
Cellulose (%)	25.9	36.0	3.4	5.2
Hemicellulose (%)	17.8	15.2	16.2	9.2
Lignin (%)	9.5	11.2	1.8	3.0
Total ash (%)	10.0	12.8	1.7	7.2

NDF = Neutral detergent fiber
ADF = Acid detergent fiber

Table 6. Chemical Composition of Rations for Trial 2.

	Ration Number			
	1	2	3	4
	22.5% long Alf. + 22.5% chop.Alf.	45% chop. Alf.	22.5% long Alf. + 22.5% WS	22.5% long Alf. + 22.5% WS
Dry matter (%)	85.4	87.3	88.5	87.4
Organic matter (%)	78.1	79.7	79.1	78.7
Cell solubles (%)	79.1	77.7	72.3	65.1
Crude protein (%)	15.5	15.7	14.9	13.9
Gross energy (kcal/g)	4.6	4.5	4.6	4.5
NE1 (Mcal/kg)	1.8	1.8	1.7	1.7
Ether extract (%)	6.1	5.9	8.4	6.0
Total ash (%)	7.3	7.6	9.4	8.7
Insoluble ash (%)	0.4	0.4	1.8	1.5
NDF (%)	38.1	36.9	40.9	49.3
ADF (%)	22.6	21.3	26.4	33.9
Cellulose (%)	15.9	15.1	18.0	24.5
Hemicellulose (%)	15.6	15.6	14.4	15.4
Lignin (%)	5.3	5.2	5.3	5.3
Calcium (%)	0.9	1.1	0.8	0.8
Phosphorus (%)	0.4	0.4	0.4	0.4

NE1 = Net energy of lactation, NDF = Neutral detergent fiber, ADF = Acid detergent fiber.

Table 7. Composition of Experimental Diets for Trial 3.

	Ration Number			
	1	2	3	4
	45% long Alf.	22.5% chop. Alf. + 22.5% WS	11.5% chop. Alf. + 33.75% WS	15.5% chop. Alf. + 15.5% WS
Chopped alfalfa hay (%)	45.0	22.5	11.25	15.5
Chopped wheat straw (%)	--	22.5	33.75	15.5
SPF milo (%)	34.7	26.0	21.5	40.0
Soybean meal (%)	9.8	18.5	23.0	18.5
Molasses (%)	5.0	5.0	5.0	5.0
Animal fat (%)	4.0	4.0	4.0	4.0
Dicalcium phosphate (%)	1.0	1.0	1.0	1.0
Salt (%)	0.5	0.5	0.5	0.5

Vitamin A mix was added at 400 g/ton on top of each ration.
WS = chopped wheat straw.
SPF = steam process and flaked milo.

Table 8. Average Chemical Composition (DM basis) of Diet Ingredients for Trial 3.

	Feed Ingredient			
	Alfalfa hay	Wheat straw	SPF milo	Soybean meal
Dry matter (%)	93.6	92.9	86.6	93.8
Organic matter (%)	82.9	81.5	85.0	85.9
Gross energy (kcal/g)	4.3	4.2	4.5	4.7
Crude protein (%)	16.3	3.5	9.3	52.8
Ether extract (%)	2.6	6.0	2.3	1.5
NDF (%)	49.2	71.4	14.6	12.6
ADF (%)	37.0	51.7	4.5	11.9
Cellulose (%)	26.1	35.9	2.7	8.3
Hemicellulose (%)	12.2	19.7	10.1	0.8
Lignin (%)	10.7	12.1	1.7	3.3
Total ash (%)	10.7	11.4	1.7	7.9

NDF = Neutral detergent fiber
ADF = Acid detergent fiber

Table 9. Chemical Composition of Rations for Trial 3.

	Ration Number			
	1	2	3	4
	45% chop. Alf.	22.5% chop.Alf. + 22.5% WS	11.25% chop.Alf. + 33.75% WS	15.5% chop.Alf. + 15.5% WS
Dry matter (%)	92.1	93.1	92.3	92.1
Organic matter (%)	84.0	84.7	82.9	84.0
Cell solubles (%)	68.7	65.1	68.2	78.0
Crude protein (%)	15.4	15.5	16.4	15.1
Gross energy (kcal/g)	4.4	4.6	4.5	4.5
NE1 (Mcal/kg)	1.8	1.7	1.7	1.9
Ether extract (%)	6.5	7.3	7.7	7.1
Total ash (%)	8.1	8.5	9.4	8.1
Insoluble ash (%)	0.6	1.8	1.8	1.2
NDF (%)	39.9	42.3	40.2	30.6
ADF (%)	17.9	22.8	24.5	19.4
Cellulose (%)	12.8	15.5	17.3	13.6
Hemicellulose (%)	22.0	19.5	15.7	11.3
Lignin (%)	4.5	5.5	5.4	4.6
Calcium (%)	1.0	0.7	0.7	0.8
Phosphorus (%)	0.5	0.5	0.6	0.5

NE1 = Net energy of lactation, NDF = Neutral detergent fiber, ADF = Acid detergent fiber.

assigned from within blocks to each of the four treatments. Each trial consisted of one 8 wk. period. Animals were individually fed twice daily (0630 and 1830 h) through Calan (American Calan, Inc., Northwood, NH.) automatic headgates. Maximum feed intake was established by a daily adjustment of feeding level during the first 2 wks that allowed for ca 10% feed refusal. Feed refusals were weighed, recorded, and subtracted from feed offered to establish total feed intake. Fresh water was constantly available.

Body weights were measured at the beginning and end of each trial. Cows were milked twice daily (0500 and 1700 h). Milk samples collected during four consecutive milkings at the end of each week were composited by cow and analyzed within 48 h. Milk fat was determined by the standard Babcock method, protein by the Orange G method of Udy (98), and SNF by the method of Watson (101). All milk weights were recorded daily and averaged to determine average daily production for the entire experimental period. The results of the weekly analyses for percentages of fat, protein, and SNF were averaged to determine averages for each trial. Milk energy was calculated according to the formula of Tyrrell and Reid (97).

Feed samples were collected weekly and composited for each ration before analysis. Fecal samples were collected by rectal removal twice daily during six consecutive days at the end of each trial and composited for each cow. Dry composite feces (dried at 50^{o} C), feed ingredients and each ration mixture were analyzed for DM, ether extract, ash, crude protein, phosphorus, and calcium according to A.O.A.C. methods (6). Cell wall constituents were determined as described by

Goering and Van Soest (34). Gross energy was measured with an adiabatic oxygen bomb calorimeter (Parr Instrument Co., Moline Ill.). Apparent digestibilities were estimated using both lignin and insoluble ash ratios (68).

Rumen fluid samples were taken by stomach tube aspiration ca 3 h postfeeding on the morning of the last day of each trial. The samples were strained through 4 layers of cheese cloth and frozen at 10° C until analyzed for individual VFA by the method of Erwin et al (22).

Observation of eating, drinking, ruminating, and postural behavior was conducted for the third trial only. During a single 24 h period in the last week of the trial, the activity of each cow was monitored once every 5 min. Whatever the cow was doing at the time of observation was recorded for that 5 min. period. Thus there were a total of 288 observations made for each cow during the 24 h period. The percentage of time spent at each activity for the 24 h period was then calculated.

The data were subjected to analysis of variance procedures for randomized complete block design (88). When F-ratios were significant, differences among treatment means were located using least significant differences (88).

RESULTS AND DISCUSSION

Trial 1.

Condition and health of the cows remained satisfactory throughout the trial and no digestive disturbances were detected.

Ammoniated wheat straw produced for this trial had a light brown color as compared to the light yellow color of the untreated straw. Ammoniated straw also appeared to be more fragile resulting in a slightly smaller particle size when processed. Treating straw (62) or wood (84) with anhydrous or liquid ammonia has been shown to produce pronounced color changes. Shuerch and Davidson (84) postulated that this color change was the result of chemical reactions arising from either the oxidation of phenols or the condensation of aldehydic fractions in sugars with nitrogenous bases via the Millard reaction, thus forming a number of colored products.

Ammoniation produced several notable changes in the wheat straw. Crude protein was increased from 3.3 to 7.7%; ADF, cellulose, and total ash were slightly increased; hemicellulose was reduced from 24 to 19% and gross energy was slightly reduced. NDF and lignin were not affected. Reduction in gross energy and increased ash due to ammoniation has been previously reported (3). However, contrary to the results of this trial, others (1, 3, 40, 44) reported that ammoniation also caused a reduction in cell wall constituents such as ADF, cellulose and lignin.

Mean feed consumption, lactational performance and body weight changes are given in table 10. Contrary to other studies (33, 43, 65, 83, 107), ammoniated wheat straw did not improve any measure of feed intake compared to untreated straw. In fact, intake of the ammoniated straw diet (ration 4) tended to be lower (P>0.05) than that of the untreated straw diet (ration 3). This could be due to the treated straw diet having a lower palatability. Swingle et al (93) reported no differences in feed intake by growing-finishing steers when fed diets containing NH_3 treated or untreated straw. Horton's work (43) had shown that ammoniation increased both DM intake and digestibility only if it was not supplemented. Garrett et al (33) found somewhat similar results when they reported that a diet having 72% ammoniated straw was consumed in large quantities with a high feed efficiency, and high digestibility of organic matter, cellulose, and energy. However, when the straw content of the diet was reduced to 36%, ammoniated straw had no advantage over untreated straw. Garrett et al (33) surmised that alkali treatment of roughages may have little advantage when fed with high concentrate diets. This finding is in agreement with the current study where relatively high levels of concentrate were fed.

Daily milk yields were not different (P>0.05) among dietary treatments although milk yield was lowest on the 45% long alfalfa hay diet (ration 1) and highest on the diets containing 22.5% long alfalfa hay and either 22.5% chopped hay (ration 2) or untreated straw (ration 3). The only other known experiment that evaluated ammoniated wheat straw for lactating dairy cows was a previous one at this station (35) which also found treated straw had no advantage over untreated straw.

Table 10. Feed Consumption and Lactation Performance of Cows for Trial 1.

	Ration Number				
	1	2	3	4	
	45% long Alf.	22.5% longAlf. + 22.5% chop.Alf.	22.5% longAlf. + 22.5% WS	22.5% longAlf + 22.5% NH3-WS	SE
DM intake (kg/d)	16.6	17.3	18.2	17.4	1.2
DM intake(%of req)	126.0	119.0	110.0	110.0	7.1
NEl intake(mcal/d)	29.6	30.8	30.3	29.1	2.0
Milk yield (kg/d)	21.7	25.8	25.4	23.2	1.7
3.5% FCM (kg)	18.6[a]	23.2[b]	24.5[b]	22.8[ab]	1.8
Milk fat (%)	2.6[a]	2.9[ab]	3.3[bc]	3.4[c]	0.2
SNF (%)	8.5	8.2	8.2	8.1	0.2
Milk protein (%)	3.2[b]	2.9[a]	3.0[a]	3.0[a]	0.1
ADG (kg)	-0.3	-0.3	-0.2	-0.2	0.1
Milk energy(mcal/d)	13.1[a]	16.2[b]	17.0[b]	15.8[ab]	1.2
GE efficiency[d](%)	34.0[a]	44.0[ab]	50.0[b]	48.0[b]	4.6

[a,b,c] within a line with different superscrpts are significantly different ($p<0.05$)

[d] calculated as $= \dfrac{\text{milk energy + body weight change}}{\text{total NEl intake}} \times 100$

Rations 2 and 3 produced higher (P<0.05) yields of 3.5% FCM than ration 1. FCM yield on ration 4 was not different (P>0.05) from any of the other rations.

Even though mcal/d of calculated NE=l intake, or DM intake were not different (P>0.05), there was a trend resulting in higher total milk and total 3.5% FCM as total DM intake increased. Those cows on rations 1 and 2 where all the roughage was alfalfa consumed 126 and 119%, respectively, of their daily energy requirements (69). Cows on rations 3 and 4, where half the roughage was straw, consumed 110% of their requirements.

Substitution of untreated or ammoniated straw for 50% of the long alfalfa increased (P<0.05) milk fat percentage. It should be noted that milk fat percentage from ration 1 (2.6%) is considered quite low while that from rations 3 and 4 (3.3 and 3.4, respectively) is more nearly normal. Addition of straw to dairy rations has been previously reported to increase milk fat levels (14, 39, 74, 80).

There were no differences (P>0.05) in SNF content of milk from the various diets; however milk protein content was higher (P<0.05) on ration 1 than on the other diets. Perhaps there is a relationship between low milk yield and low fat percentage and the high concentration of protein and SNF.

Mean ADG was negative for all treatments (P>0.05). It is interesting to note that even though the cows were consuming from 10 to 26% more energy than was theoretically required to maintain body weight and produce at the levels reported, they did lose body weight. Further evidence is given by the gross energy efficiency ratios shown in table 10. Rations 3 and 4 were utilized more efficiently ($P<0.05$) than ration 1. It should also be pointed out that while the differences were not significant ($P>0.05$), the cows receiving the diets containing straw lost less body weight than did those receiving the diets containing no straw. The increase in gross energy efficiency found in this trial by replacement of half of the alfalfa hay with straw has been previously reported by others (14, 79); however, Halevi et al (39) found no differences in the efficiency of metabolizable energy utilization due to straw level in the diet.

Milk energy yield was higher ($P<0.05$) for rations 2 and 3 than for ration 1 while the yield from ration 4 fell in between the others and was not different ($P>0.05$) from any of them.

Mean molar percentages of rumen VFA for trial 1 are in table 11. Both rations containing straw had lower ($P<0.05$) propionate and valerate levels, higher acetate levels and higher acetate:propionate ratios compared to the rations containing alfalfa as the only roughage source. Butyric acid was not affected by diet. It has been known for many years that high acetate:propionate ratios are conducive to high levels of milk fat production (86), and that poor quality roughage enhances the high acetate level (39). The results of trial 1 are in complete agreement with these reports. Small differences ($P<0.05$) were detected among diets in concentrations of isobutyric, valeric, and isovaleric acids in rumen fluid, but it seems doubtful that differences of this magnitude would have biological significance.

Mean apparent digestibilities for trial 1 are given in table 12. An attempt was made to calculate apparent digestibilities by using both

Table 11. Mean Molar Percentages of Rumen Volatile Fatty Acids (VFA) for Trial 1.

	Ration Number				
	1	2	3	4	
VFA	45% long Alf.	22.5% longAlf. + 22.5% chop.Alf.	22.5% long Alf. + 22.5% WS	22.5% long Alf. + 22.55 NH3-WS	SE
Acetic acid	48.7^{a}	52.0^{a}	58.3^{b}	57.1^{b}	1.4
Propionic acid	28.2^{b}	27.1^{b}	20.9^{a}	22.5^{a}	1.6
Iso-Butyric acid	0.9^{ab}	0.8^{a}	1.0^{b}	1.0^{ab}	0.1
Butyric acid	16.9	16.2	16.1	15.9	1.2
Iso-Valeric acid	1.1^{b}	0.4^{a}	0.7^{ab}	0.8^{ab}	0.3
Valeric acid	2.8^{b}	2.9^{b}	1.9^{a}	1.7^{a}	0.3
A/P[c] ratio	1.8^{a}	2.0^{a}	2.8^{b}	2.6^{b}	0.2

[a,b] Values within a line with different superscripts are significantly different ($p<0.05$).
[c] acetate:propionate ratio

Table 12. Mean Apparent Digestibilities of Experimental Rations for Trial 1.

Nutrient	Ration Number 1: 45% long Alf.	2: 22.5% long Alf. + 22.5% chop. Alf.	3: 22.5% long Alf. + 22.5% WS	4: 22.5% long Alf. + 22.5% NH3-WS	SE
Organic matter	62.1^{b}	66.8^{c}	57.3^{a}	63.7^{cb}	1.6
Crude protein	61.5^{a}	66.8^{bc}	63.5^{ab}	68.4^{c}	1.7
Cell solubles	69.9^{ab}	73.4^{bc}	68.7^{a}	74.5^{c}	1.5
Ether extract	74.6^{a}	83.9^{b}	90.2^{c}	86.6^{cb}	1.8
Gross energy	59.2^{ab}	64.7^{c}	56.4^{a}	63.0^{bc}	1.9
NDF	35.2^{ab}	48.4^{c}	29.7^{a}	41.2^{b}	2.7
ADF	12.4^{a}	25.6^{b}	14.5^{a}	16.3^{a}	2.8
Cellulose	40.9^{b}	47.2^{c}	36.5^{ab}	35.0^{a}	2.4
Hemicellulose	59.6^{b}	72.8^{c}	50.0^{a}	68.0^{c}	3.0

a,b,c Values within a line with different superscripts are significantly different ($p<0.05$).

lignin and insoluble ash as internal markers. However, insoluble ash values for both feed and feces were extremely variable and resulted in highly variable and unrealistically high apparent digestibility values. Consequently, the values determined by insoluble ash were considered unreliable and are not presented. Digestibilities calculated by the lignin ratio technique were less variable and closer to normally accepted values (14, 39, 79, 80), although they were somewhat lower than expected. The low digestibilities calculated using lignin as an internal marker could be due to partial digestion of the lignin which would then result in lower digestion coefficients (23, 24). Replacing 50% of the long alfalfa in ration 1 with chopped alfalfa (ration 2) resulted in increased ($P<0.05$) digestibilities of all ration components. Use of chopped wheat straw (ration 3) in place of chopped alfalfa (ration 2) depressed ($P<0.05$) all digestibilities except crude protein and ether extract. It should be pointed out that a major portion of the protein in all diets (especially those containing straw) was furnished by soybean meal, and a major portion of the ether extract in all diets came from the animal fat that was included in all diets. Compared with the untreated straw diet, the diet with NH_3 straw had improved ($P<0.05$) digestibility of organic matter, crude protein, cell solubles, gross energy, NDF and hemicellulose. No differences ($P>0.05$) between treated and untreated straw in the digestibility of ether extract, ADF, oryyy cellulose were observed. Improvement of nutrient digestibilities by NH_3 treatment has been shown by others (3, 33, 42, 43, 83, 99, 107). Some of this improvement may be due to increased availability of hemicellulose for degradation by bacteria as a result of the solubilization of this fiber component by NH_3 (83). In this study, digestibility of hemicellulose increased from 50.0% in untreated straw to 68.0% in the ammoniated straw. Surprisingly, there was little difference (P>0.05) between the diet with chopped alfalfa and chopped NH_3 straw in digestibility of organic matter, crude protein, cell solubles, ether extract, gross energy and hemicellulose. The ammoniated diet had a lower digestibility of the major fiber components: NDF, ADF and cellulose.

The results of this trial indicate that half of the long alfalfa in 45% roughage rations for lactating dairy cows can be replaced with chopped roughage without decreasing milk yield and milk fat percentage and that chopped wheat straw was a satisfactory replacement for chopped alfalfa under the conditions of this trial. The diet containing ammoniated straw had higher digestibility of the major components than did the diet with untreated straw, but these differences were not reflected in lactational response. Chopped wheat straw fed with a high quality concentrate seems to enhance the efficiency of milk production.

Trial 2.

As was the case in trial 1 the condition and health of the cows remained satisfactory throughout the trial.

Mean values for feed consumption and lactational performance for trial 2 are given in table 13. Neither DM intake nor mcal NE_1/d were affected by diet (P>0.05) although cows receiving straw in the diets consumed slightly more DM than those that did not. However, when DM intake was calculated as percent of total requirement, the cows

Table 13. Feed Consumption and Lactation Performance of Cows for Trial 2.

	Ration Number 1	2	3	4	
	22.5% long Alf. + 22.5% chop.Alf.	45% chop. Alf.	22.5% long Alf. + 22.5% WS	22.55 chop.Alf. + 22.5% WS	SE
DM intake (kg/d)	19.6	19.8	20.0	20.4	1.2
DM intake(%of req)	138.0[b]	118.0[a]	119.0[ab]	120.0[ab]	8.2
NEl intake (mcal/d)	35.1	35.4	33.8	34.0	2.0
Milk yield (kg/d)	24.1[a]	28.1[b]	26.0[ab]	27.6[ab]	1.6
3.5% FCM (kg/d)	20.6[a]	27.1[b]	24.4[ab]	25.8[b]	1.6
Milk fat (%)	2.6[a]	3.3[b]	3.1[ab]	3.1[ab]	0.3
SNF (%)	8.2	8.5	8.4	8.4	0.1
Milk protein (%)	2.9	2.9	2.9	2.9	0.1
ADG (kg)	0.6	0.8	0.6	0.6	0.2
Milk energy(mcal/d)	14.5[a]	18.8[b]	17.0[ab]	17.9[b]	1.1
GE efficiency (%)	50.0[a]	65.0[b]	59.0[b]	61.0[b]	2.8

[a,b] Values within a line with different superscripts are significantly different ($p<0.05$).

receiving 22.5% long alfalfa hay + 22.5% chopped alfalfa hay consumed 138% of their theoretical requirement, a higher ($P<0.05$) amount than those where all the roughage was chopped alfalfa (118% of required). Consumption by the cows receiving 22.5% chopped wheat straw plus either 22.5% long alfalfa (119% of required) or 22.5% chopped alfalfa (120% of required) was not different ($P>0.05$) from either of the other two groups. These results are in agreement with those of trial 1.

ADG was not affected ($P>0.05$) by treatment. However in contrast to trial 1, ADG was positive for all diets. This difference was attributed to lower environmental stress as trial 2 was conducted in the fall whereas trial 1 had been conducted during the summer when environmental temperatures and humidity were much higher. It can perhaps be concluded that extra energy expenditure was necessary during trial 1 to overcome the extra burden of environmental stress while still maintaining normal body function and milk production.

Daily milk yield was increased ($P<0.05$) by chopping all the alfalfa hay (ration 2) as compared to chopping only 50% of it (ration 1). Replacement of half of the roughage with chopped wheat straw and fed with either long (ration 3) or chopped (ration 4) alfalfa resulted in a nonsignificant increase ($P>0.05$) in milk production when compared to ration 1 and a nonsignificant decrease ($P>0.05$) when compared to ration 2. Both rations containing only chopped roughage (rations 2 and 4) produced more ($P<0.05$) 3.5% FCM than did ration 1 that contained both long and chopped alfalfa hay. Production of 3.5% FCM by ration 3 was not different ($p>0.05$) than any of the other diets. As in trial 1, addition of straw to dairy rations enhanced milk production with the additional finding that chopping all of the roughage and feeding the ration as a complete mix produced an even greater enhancement of milk production. This could be attributed to improvement in digestibilities (table 15). These results are in agreement with Owen et al (79) who found that a level of between 24 and 32% coarsely ground barley straw resulted in higher milk production than either 16 or 40% straw. Also 40% straw reduced both DM intake and milk production. Others, however, (14, 39) found no differences in milk production with levels of from 15 to 47.5% wheat straw in the diet. Sharma et al (85) reported that unless straw was steam treated, milk production was decreased in comparison with alfalfa feeding.

Milk fat percentage was higher ($P<0.05$) on the diet (ration 2) containing 45% chopped alfalfa than on one where half of the alfalfa was long and half was chopped (ration 1). The two diets containing straw produced values between the other two and were not different ($p>0.05$) from either; they were higher than for ration 1. Thus the milk fat percentage findings are not in opposition to those found in trial 1. The higher milk fat content from ration 2 was attributed to its having the highest acetate:propionate ratio (table 14). Milk protein and SNF content were not affected by diet ($P>0.05$).

Total milk energy was higher ($P<0.05$) on the two diets with all roughage chopped (rations 2 and 4) than on ration 1. The gross energetic efficiency of ration 1, where half the alfalfa was long and the other half was chopped, was lower ($P<0.05$) than for the other three diets. This is in agreement with trial 1 and others (14, 79) who found improved feed efficiency by addition of straw to the diet. This is in contrast to ration 2 where with all chopped alfalfa there was a higher additional finding that chopping all of the roughage and feeding the (P>0.05) gross energy efficiency than ration 1 and a nonsignificant increase (P<0.05) compared to rations 3 and 4.

Mean molar percentages of VFA are shown in table 14. The all chopped diets (rations 2 and 4) resulted in higher (P<0.05) rumen acetic acid levels than ration 3, which produced higher (P<0.05) propionate levels than the other three diets. Consequently, the acetate:propionate ratio for ration 3 was lower (P<0.05) than the other three rations.

From these results it can be concluded that chopping all the roughage and feeding the ration as a complete mix improved the rumen production of acetate. It would appear that the result was due a more favorable rumen environment for the fermentation of fiber, perhaps because of a more uniform mixture and less layering of material in the rumen. The only other difference (P<0.05) noted in VFA concentrations was that ration 1 produced higher levels of butyrate than the other three. The direct relationship between acetate and propionate levels in the rumen fluid and milk fat percentage was not as positive as it had been in trial 1, even though ration 2 produced higher acetate and milk fat percentages and lower propionate percentages than any of the other rations.

Table 15 shows the mean apparent digestibility percentages of the experimental rations for trial 2. Comparison of rations 1 and 2 showed that the digestibility of all nutrients except cellulose were improved by chopping all the alfalfa. The improvement was however significant (P<0.05) only for crude protein, cell solubles and gross

Table 14. Mean Molar Percentages of Rumen Volatile Fatty Acids for Trial 2.

	Ration Number				
	1	2	3	4	
	22.5% long Alf. + 22.5% chop.Alf.	45% chop. Alf.	22.5% long Alf. + 22.5% WS	22.5% chop.Alf. + 22.5% WS	SE
Acetic acid	52.8^{ab}	55.5^{b}	51.1^{a}	55.4^{b}	1.4
Propionic acid	21.3^{a}	20.6^{a}	26.9^{b}	21.9^{a}	0.9
Iso-Butyric acid	1.0	1.1	1.1	0.9	0.2
Butyric acid	20.4^{b}	18.1^{a}	16.3^{a}	17.8^{a}	0.9
Iso-Valeric acid	0.9	1.0	1.0	0.9	0.3
Valeric acid	2.8	2.5	2.5	2.2	0.3
A/P ratio	2.5^{b}	2.8^{b}	1.9^{a}	2.6^{b}	0.2

^{a,b} Values within a line with different superscripts are significantly different ($p<0.05$).

Table 15. Mean Percentages of Apparent Digestibilities of Experimental Rations for Trial 2.

	Ration Number				
	1	2	3	4	
Nutrient	22.5% long Alf. + 22.5% chop.Alf.	45% chop. Alf. WS	22.5% long Alf. + 22.5% WS	22.5% chop.Alf. + 22.5% SE	
Organic matter	60.1^{bc}	66.3^{c}	51.0^{a}	57.4^{ab}	3.1
Crude protein	55.4^{a}	61.0^{bc}	58.5^{ab}	62.6^{c}	1.4
Cell solubles	72.4^{a}	75.6^{b}	70.2^{a}	72.6^{a}	1.1
Ether extract	77.5^{a}	79.3^{a}	85.7^{b}	84.8^{b}	1.3
Gross energy	57.1^{b}	62.0^{c}	53.2^{a}	59.5^{cb}	1.5
NDF	4.0^{b}	43.0^{cb}	26.8^{a}	47.8^{c}	2.0
ADF	26.0^{ab}	27.6^{b}	21.4^{a}	44.8^{c}	2.3
Cellulose	43.2^{b}	42.3^{b}	31.4^{a}	54.7^{c}	2.2
Hemicellulose	60.1^{cb}	64.0^{c}	36.8^{a}	54.4^{b}	2.7

[a,b,c] Values within a line with different superscripts are significantly different ($p<0.05$).

energy. None of the differences in digestibility of cell wall components (NDF, ADF, cellulose or hemicellulose) were significant. Comparisons of rations 3 and 4 where chopped straw was fed with either long or chopped alfalfa again showed digestibility improvement due to chopping of the alfalfa. While all components except ether extract were improved, only the digestibilities of crude protein, gross energy, NDF, ADF, cellulose, and hemicellulose were significantly improved ($P<0.05$). The combining of chopped alfalfa with chopped wheat straw in ration 4 produced the highest levels of digestibility for all of the cell wall components except hemicellulose when compared to the other 3 rations. The 2 rations containing only alfalfa as the roughage resulted in the highest digestibility of hemicellulose. Replacement of half of the roughage with wheat straw depressed most of digestibilities, particularly those of the cell wall components. However, the depressing effect seemed to be reduced by mixing chopped alfalfa with chopped wheat straw. The digestibility of ether extract was increased ($P<0.05$) by the addition of straw to the diet. Perhaps the inclusion of straw in ruminant diets might be one means of improving fat utilization. These findings are in agreement with the results of the first trial where the diet made up of 22.5% long alfalfa hay plus 22.5% chopped straw lowered the digestibility of all nutrients except protein and ether extract when compared to the diet consisting of 22.5% long alfalfa hay plus 22.5% chopped alfalfa hay. The digestibility of ether extract was raised in both trials when these 2 diets were compared.

The results of trial 2 seem to indicate that chopped wheat straw can replace half of the alfalfa in 45% roughage diets for lactating dairy cows. DM intake, milk yield and milk fat percentage were improved even though nutrient digestibilities for the most part were depressed when compared to a diet containing half long and half chopped alfalfa. A diet with all the alfalfa chopped produced much the same feed intake and milk production results as the diets containing straw but nutrient digestibility results were similar to the diet with half long and half chopped alfalfa.

Trial 3.

As was the case with trials 1 and 2, the condition and health of the cows remained satisfactory throughout the trial.
Mean values for feed consumption and lactational performance for trial 3 are given in table 16. Increasing the level of chopped wheat straw from 22.5% (ration 2) to 33.75% of the diet while reducing chopped alfalfa to 11.25% (ration 3) reduced ($P<0.05$) DM intake. This is in agreement with other studies (14, 79, 80). DM intake on rations 1 and 4 lay between the other two and was not different ($P>0.05$) from either. DM intake as a percent of total requirements was also lowest on ration 3 but was only significantly lower ($P<0.05$) when compared to ration 1 (45% chopped alfalfa) and ration 4 (15.5% chopped alfalfa plus 15.5% chopped straw). Feed intake when measured as Mcal/d of NE_1 was also lowest for the cows on ration 3; significantly so ($P<0.05$) when compared to rations 2 and 4. This reduction in dietary intake was reflected in ADG figures. The cows on ration 3 had lower ($P<0.05$) ADG values than the cows on the other three rations and were the only cows to have a negative ADG. Ration 4, the low roughage diet, produced the highest ADG even though it was not

Table 16. Feed Consumption and Lactation Performance of Cows for Trial 3.

	Ration Number				
	1	2	3	4	
	45% chop. Alf.	22.5% chop.Alf. + 22.5% WS	11.25% chop.Alf. + 33.75% WS	15.5% chop.Alf. + 15.5% WS	SE
DM intake (kg/d)	20.4^{ab}	23.0^{b}	20.0^{a}	21.9^{ab}	1.1
DM intake(%of req)	118.0^{b}	114.0^{ab}	96.0^{a}	128.0^{b}	8.2
NElintake (mcal/d)	36.3^{ab}	38.1^{b}	31.9^{a}	39.9^{b}	1.8
Milk yield (kg/d)	33.8	36.8	32.2	34.4	2.2
3.5% FCM (kg/d)	29.3	33.8	32.8	28.6	2.3
Milk fat (%)	2.7^{ab}	3.0^{b}	3.6^{c}	2.4^{a}	0.2
SNF (%)	8.3	8.3	8.3	8.1	0.1
Milk protein (%)	2.6	2.5	2.6	2.6	0.1
ADG (kg/d)	0.2^{b}	0.2^{b}	-0.3^{a}	0.5^{b}	0.2
Milk energy (mcal/d)	20.6	23.5	22.5	20.2	1.6
GE efficiency (%)	60.0	63.0	64.0	56.0	4.8

^{a,b} Values within a line with different superscripts are significantly different ($p<0.05$).

significantly higher (P>0.05) than diets 1 or 2. The reduction in ADG on ration 3 was probably related to lower DM intake while still maintaining a relatively high production of 3.5% FCM. The cows on ration 3 consumed only 96% of their daily DM requirements, while the other cows consumed from 114-128% of their requirements.

The cows on this trial produced considerably more milk than those on the previous two trials and consequently were probably more representative of the industry. There were no significant differences (P>0.05) in total milk yield among treatments, even though the diet with 22.5% chopped alfalfa plus 22.5% chopped straw (ration 2) produced ca 10% more milk than any of the other diets and ration 3 produced the least milk. Even though again the differences were not significant, (P>0.05) rations 2 and 3 produced ca 10% more 3.5% FCM than rations 1 and 4. These results agree with those of Owen et al (79) who concluded that diets containing 24-32% coarsely milled barley straw supported a higher milk yield than did diets containing either 16 or 40% straw. However, Halevi et al (39) had fed up to 45% chopped straw and Blair et al (14) 47.5% pelleted wheat straw without reducing milk yield. In both these studies (14, 39), milk yield was ca half of that in the current study.

Ration 3 with 33.75% chopped straw produced a higher (P<0.05) milk fat percentage (3.6%) than all the other rations. Ration 2 with 22.5% chopped straw produced a higher (P<0.05) milk fat percentage (3.0%) than ration 4 (2.4%) containing 31% total roughage. Diets with different levels of roughage but equal ADF content (rations 1 and 4) produced milk with milk fat percentages that were not different (P>0.05) from each other (2.7 vs 2.4%). Milk protein and milk SNF were not affected ($P>0.05$) by treatment in trial 3.

Milk energy yield and gross energetic efficiency were not different ($P>0.05$) among treatments. Ration 4 with only 31% roughage however produced the least number of mcal/d of milk and had the lowest gross energy efficiency.

Molar percentages of rumen VFA for trial 3 are shown in table 17. As the level of straw in the diet increased, there was an increase in molar percentage of rumen acetate ($P<0.05$) and a trend ($P>0.05$) towards a decrease in propionate. Concentration of VFA was similar for ration 1 and 4 which differed in total roughage content but had equal ADF levels. Acetate:propionate ratio tended to be highest ($P<0.05$) for ration 3 which had the highest content of straw. As acetate:propionate ratio increased, milk fat percentage increased which is in agreement with the previous two trials and earlier work (86). Butyrate and isobutyrate were not affected by diet ($P>0.05$). The small differences ($P<0.05$) among diets in valerate and isovalerate concentrations are probably not biologically significant.

Mean apparent digestibilities for trial 3 are given in table 18. Organic matter digestibility was depressed ($P<0.05$) by inclusion of straw in the diets, e.g., rations 2, 3, and 4 produced organic matter digestibilities varying from 57.0 to 59.9% compared to ration 1 with 65.0%. Inclusion of straw in the diet had the opposite effect on ether extract digestibility, with rations 2, 3, and 4 having higher ($P<0.05$) digestibilities than ration 1. Thus giving further credulence to the

Table 17. Mean Molar Percentages of Rumen Volatile Fatty Acids for Trial 3.

	Ration Number				
	1	2	3	4	
	45% chop. Alf.	22.5% chop.Alf. + 22.5% WS	11.25% chop.Alf. + 33.75 WS	15.5% chop.Alf. + 15.5% WS	SE
Acetic acid	50.6^{a}	52.3^{ab}	57.0^{b}	49.1^{a}	2.3
Propionic acid	29.3^{ab}	27.5^{ab}	25.3^{a}	31.6^{b}	1.9
Iso-Butyric acid	1.2	2.2	0.9	0.7	0.8
Butyric acid	13.4	15.2	14.6	15.0	1.2
Iso-Valeric acid	1.0^{b}	0.7^{ab}	0.5^{ab}	0.2^{a}	0.2
Valeric acid	3.2^{b}	2.6^{b}	1.3^{a}	3.0^{b}	0.5
A/P ratio	1.8^{ab}	1.9^{ab}	2.3^{b}	1.6^{a}	0.2

^{a,b} Values within a line with different superscripts are significantly different ($p<0.05$).

Table 18. Mean Percentages of Apparent Digestibilities of Experimental Rations for Trial 3.

	Ration Number				
	1	2	3	4	
	45% chop. Alf.	22.5% chop.Alf. + 22.5% WS	11.25% chop.Alf. + 33.75% WS	15.5% chop.Alf. + 15.5% WS	SE
Organic matter	65.0^{b}	57.0^{a}	58.0^{a}	59.9^{a}	1.6
Crude protein	61.2	62.4	65.0	61.6	1.7
Cell solubles	69.2	65.9	69.4	69.5	2.3
Ether extract	69.7^{a}	89.9^{c}	89.1^{c}	79.1^{b}	3.1
Gross energy	58.9	54.5	57.1	53.7	2.1
NDF	52.3^{b}	35.1^{a}	32.3^{a}	27.0^{a}	4.0
ADF	20.9^{b}	9.7^{a}	16.3^{ab}	17.0^{ab}	3.2
Cellulose	36.6^{b}	21.5^{a}	31.0^{b}	30.2^{ab}	3.7
Hemicellulose	77.8^{c}	64.7^{bc}	57.2^{ab}	44.3^{a}	6.4

^{a,b,c} Values within a line with different superscripts are significantly different ($p<0.05$).

findings in the first two trials that addition of straw may enhance fat utilization. The effect of straw inclusion on digestibility of both organic matter and ether extract in this trial are in complete agreement with those of trials 1 and 2. Digestibilities of crude protein, cell solubles, and gross energy were not different among diets ($P>0.05$). Digestibilities of cell wall constituents were lower on all straw-containing diets than on ration 1 which contained only alfalfa, even though not all the differences were significant ($P<0.05$). Similar results were obtained on trial 1 but trial 2 gave somewhat divergent results. In trial 2, mixing chopped wheat straw with chopped alfalfa hay improved digestibility of cell wall constituents compared to all chopped alfalfa hay ration.

Table 19 shows the percentage of time the cows spent on various activities during trial 3. Eating time was reduced ($P<0.05$) on ration 4, with the least amount of roughage in the diet, as compared to ration 3 with the most straw. Eating time of rations 1 and 2 was not different ($P>0.05$) from either ration 3 or 4. There were no other differences ($P>0.05$) noted in time spent at various activities due to diet, even though there appeared to be a trend towards increased rumination time as roughage and straw level increased in the diet. Eating and rumination times have been found to be proportional to total cell wall intake and could be a factor that limits voluntary feed intake when rumen-fill is a limiting factor (102).

The results of trial 3 indicate that replacement of half of the chopped alfalfa in a 45% roughage diet for lactating cows with chopped straw improves DM intake, milk yield and milk fat percentage.

Table 19. Mean Percentage of Time Cows spent on Various Activities.

	Ration Number				
	1	2	3	4	
	45% chop. Alf.	22.5% chop.Alf. + 22.5% WS	11.25% chop.Alf. + 33.75% WS	15.5% chop.Alf. + 15.5% WS	SE
Eating	12.2^{ab}	11.0^{ab}	13.2^{b}	9.5^{a}	1.5
Drinking	4.3	2.5	2.7	2.7	0.8
Ruminating	19.5	20.7	23.2	18.8	2.8
Idling	64.0	65.0	61.5	68.8	3.9

^{a,b} Values within a line with different superscripts are significantly different ($p<0.05$).

Replacement of 75% of the chopped alfalfa with wheat straw however, resulted in higher milk fat levels, lower DM intake and milk yield, and negative body weight gains. It did not appear that maintenance of a constant ADF level in a dairy ration regardless of roughage level was the solution to maintenance of normal milk fat levels.

CONCLUSIONS

The results of these trials have shown that in complete mixed diets or diets containing long alfalfa hay, replacement of half of the alfalfa in rations containing 45% roughage for lactating dairy cows with chopped wheat straw does not adversely affect DM intake or milk yield and increases milk fat percentage. Replacing half of the long alfalfa with chopped alfalfa also apparently improved lactational performance although not as dramatically as that of chopped straw. Ammoniation of wheat straw did not improve the performance response by lactating cows. Inclusion of chopped straw in the diets seemed to enhance the efficiency of milk production. Higher ruminal acetate:propionate ratios and increased digestibility of ether extract resulted from feeding straw. Digestibility of other nutrients were generally either not affected or were depressed by straw feeding. Increasing the chopped wheat straw level to 75% of the roughage resulted in lower DM intake and milk yield, and negative body weight gains, but higher milk fat levels. It did not appear that maintenance of constant ADF level in a dairy ration regardless of roughage level was the solution to the maintenance of milk fat levels. Further study in this area is needed.

Thus it has been indicated that under the conditions of this experiment a combination of chopped alfalfa and wheat straw can be used successfully in complete mixed rations for high producing dairy cows. For the most part, all productive parameters measured were improved by the addition of straw and by the feeding of complete mixed diets. This was especially true for milk fat which, from a dairyman's viewpoint, is very important because of its impact on milk pricing. It would also have a direct bearing on management by reducing labor costs through elimination of labor intensive handling of long alfalfa. Mechanical handling of complete mixed rations is relatively easier and cheaper. In addition, straw is an inexpensive source of roughage as compared to alfalfa hay.

Seldom does one study provide all the answers to a particular problem or fail to raise other questions. This experiment was no exception. Further study needs to be conducted with the same rations over an entire lactation. Perhaps higher levels of straw can be used in rations for lower producing cows. Type of supplementation, environmental influences, particle size and concentrate used as the basic energy source could alter responses found in the current study. Other cereal grain straws and other poor quality roughages need to be evaluated. One of the earliest and perhaps still the major concern is the improvement in poor quality roughage digestibility. After all, that's the main reason they are poor quality.

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