LUPIN SILAGE AND LUPIN SEEDS IN BEEF CATTLE RATIONS

A Thesis

Submitted to the Graduate Faculty

in Partial Fulfillment of the Requirements

for the Degree of

Master of Science

in the Department of Health Management

Faculty of Veterinary Medicine

University of Prince Edward Island

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CHARLOTTETOWN, P.E.I.

July, 1993

ISBN 0-315-88450-9

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ABSTRACT

This study was undertaken to evaluate various aspects of feeding lupin silage and lupin seeds to beef cattle. The effects of harvest date on ensiling characteristics and nutrient yield per hectare were evaluated for lupin (Lupinus albus), lupin-oat and oat (Avena sativa) crops. Growth performance, carcass merits and feed intakes were evaluated for both lupin silage and raw and roasted lupin seeds in two steer feeding trials.

To evaluate the effect of harvest date on chemical composition and nutrient yield, lupin, lupin-oat and oat herbage were harvested, after wilting, on July 30 (J30), August 16 (A16) and August 27 (A27), when the lupin crop was at the second pod, third pod and senescence stages and the oat was at milk, dough, and mature stages, respectively. The forages were ensiled in laboratory-scale silos for 175 days. The lupin silages had a lactate-type fermentation with low pH and high lactic acid contents. Crude protein (CP) content decreased from 19.1 % at the second pod stage to 16.7 % at senescence. Lupin-oat silages had higher dry matter (DM) content 28.9, 29.7 and 65.5 % compared to lupin 20.5, 20.8 and 47.0 % at each harvest date, with shorter drying times. Lupin and lupin-oat had significantly higher yields per hectare of dry matter and metabolizable energy compared to oat. Lupin had the highest yield of CP and protein N per hectare at each harvest date.

Twenty-eight Simmental-cross steers weighing 200 ($\pm$ 20.5) kg were used to evaluate grass (Phleum pratense and Poa pratensis) and whole plant lupin silages in terms of growth rate, DM intake and carcass characteristics. The steers were randomly assigned to pen and one of four treatments: steers were fed grass or lupin silage supplemented with either rolled barley or crushed potato. The chemical composition of the silages was determined and Dacron bag procedures were used to estimate DM and CP degradability. The lupin silage had a lactic acid fermentation with lower DM, neutral detergent fiber (NDF) and protein nitrogen content than the grass silage but higher CP. There were no statistically significant differences in gain, carcass weight, dressing percentage or backfat levels between steers fed lupin or grass silage. Dry matter intake of the silages was not significantly different but there was a tendency for lower DM intake of lupin silage when supplemented with potatoes. Lupin CP degraded at a significantly faster rate (24.5% h^{-1}) compared with the grass (10.4 % h^{-1}). The effective degradation of CP was 63.8 % and 79.1 % for grass and lupin silage, respectively.

Twenty eight Charolais-cross steers (235 $\pm$ 35 kg) were fed grass silage only (SIL, n=7) or silage plus supplements fed to supply CP at 6.5 % of the silage DM intake from raw lupin (RL, n=7), roasted lupin (ROL, n=7) or soybean meal (SBM, n=6). When the steers reached 330 kg liveweight they were placed on a finishing diet of chopped hay, barley and protein supplements at a rate of 4.5 % of barley DM intake. The effect of roasting on the solubility and rumen degradability of lupin was evaluated by chemical and dacron bag procedures. Effective degradability of CP and rate of CP degradation predicted by the dacron bag procedure were lower for roasted lupin (82.3 %, 9.2 %/h) compared to raw lupin (86.7%, 11.9 %/h). In the growing phase, steers fed RL, ROL or SBM had daily gains significantly higher ($P < 0.05$) than steers fed SIL. Steers fed the SBM diet had significantly higher daily gains than RL, with steers fed ROL being intermediate. Silage DM intake was significantly lower on RL and ROL supplemented diets compared to SIL. In the finishing phase, there were no significant differences in daily gain, carcass weight, dressing percentage, loin eye area or dry matter intake among diets.

Lupin can be successfully ensiled with a lactate fermentation at various growth stages from second pod stage to senescence. Lupin silage is readily consumed by beef steers and will result in similar growth performance to beef steers fed grass silage. Roasting lupin seeds will decrease CP solubility and rumen degradability. Roasted lupin could replace soybean meal in rations for growing beef steers. Lupin is a versatile crop which can be harvested either as whole plant silage or as a high protein seed, both of which can be utilized in beef cattle diets.

ACKNOWLEDGEMENTS

I have been very fortunate to have assistance in the completion of this study from a great number of people to whom I extend my deepest appreciation. First, thanks to my supervisor, Dr. Mary McNiven, who encouraged me to undertake this study initially and then provided the guidance and attention, particularly in editing, necessary to complete the work.

Thanks to Dr. Peter Robinson for his valued constructive criticisms. In addition, his encouragement throughout this project were greatly appreciated.

To the other members of my Supervisory Committee; Dr. John MacLeod, Dr. Gavin Richardson, Dr. Peter Nijjar and Dr. Tim Ogilivie, I thank them for their time and valued opinions.

I extend a very special expression of appreciation to Dr. Les Halliday of the PEI Cattlemen's Assoc. who graciously allowed the use of his research facilities. More importantly, his keen interest and support throughout this study, made this an enjoyable learning experience.

I wish to express my gratitude to the many people in Agriculture Canada and at AVC who provided technical assistance: Christine Coles, Harry Younie, Wilfred Moase, Dave Grimmett, Lloyd [illegible], John Keough, Dunning Bulman, Chris McQuaid and Brian Grimmelt.

In addition, I wish to thank the staff of the Livestock Section of the PEI Dept. of Agriculture, in particular [illegible] Deelstra, for their patience and understanding throughout this project.

This study was funded in part by financial assistance from the Canada/Prince Edward Island Subsidiary Agreement on Livestock Feed Development.

Finally, the successful completion of this study was made possible because of the loving support provided by my family; my wife Debi and children Katrina, Mitchell and Steven.

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1. INTRODUCTION

The North American cattle feeding industry is structured around two main types of finishing systems. In grain growing regions, rations for growing and finishing animals consist primarily of small grains or corn. Elsewhere, heavy reliance is placed on forages to maintain efficient and cost effective beef production.

In Maritime Canada, beef feeder calves that are weaned at 225 kg are fed diets with high proportions of forages until they reach 320 to 360 kg. This period of growth corresponds to a phase in which the feeder is depositing a greater proportion of lean meat (Forest et al., 1975), which means the animal has a higher requirement for crude protein (CP) relative to later stages of growth (NRC, 1984). The feeder animal's requirements gradually shift towards fat deposition during the finishing phase and as a result, a higher concentration of energy and less protein is required in the diet.

Until recently in Maritime Canada, much of the requirement for protein supplements for livestock has been met by importing soybean meal. It would be advantageous to grow protein crops locally. This would provide better crop rotations, stabilize the cost of feed ingredients and allow beef producers to be more self-sufficient in feed resources.

Lupin is a legume seed crop that can tolerate the cool, moist local climate (MacLeod et al., 1987) and is a substitute for soybean meal. Lupin may benefit animals in the growth phase to meet the higher CP requirements.

Forage preservation in northeastern North America has largely shifted from hay to silage production. This is the best method available to harvest and store large volumes of forage in areas which experience high summer rainfall. Lupin is grown for

its seed. However, if climatic or growing conditions are not favourable for successful harvesting of lupin seed then the alternative is for the whole lupin plant to be ensiled for use in ruminant diets.

1.1. LUPIN FORAGE AS A SILAGE CROP

Sweet white lupin (Lupinus albus) grain production in cool temperature regions has been limited as a result of the variable length of the maturation period for the pods and seeds. Lupins are indeterminate, which means the length of its growing season is not fixed. Lupins, seeded in the spring, normally require 100 - 140 days to reach seed maturity (Putnam et al., 1991), with up to five orders of inflorescence being produced during a season (Clapham and Elbert-May, 1989). Most varieties of Lupinus albus are thermosensitive with pod dessication triggered by drought or high air temperatures (> 26 °C). If appropriate conditions for pod dessication do not occur then the plant will continue to flourish late into the fall, as lupins can tolerate moderate frosts. Clapham and Elbert-May (1989) conducted research in Maine, USA, where weather conditions were similar to Maritime Canada with cool moist conditions. These workers demonstrated that under their cool moist climate the lupin plant remained in a vegetative stage in which the plant continued to produce inflorescence. The continued production of inflorescence can delay pod dessication. Delayed pod dessication results in the seed retaining moisture. This prevents the crop being harvested as seed, which could lead to crop failure unless an alternative harvesting method is available. An alternative harvesting method would be to ensile the whole lupin plant.

Offutt and Davis (1973) demonstrated that lupin forage CP did not vary substantially when harvested at pre-bloom, medium bloom and seed formation, whereas alfalfa CP decreased with advancing growth stages. The metabolizable energy (ME)

content of the alfalfa was higher at the first harvest date compared to lupin but there were no differences at the final two harvest dates. Digestibility of lupin forage was also higher than that of alfalfa. Offutt and Davis (1973) suggested that to obtain maximum value from sweet white lupin, the crop could be harvested as green chop or silage.

Several workers (Aksland, 1991; Andrieu et al. 1982; Tisserand and Faurie, 1982) have evaluated lupin silage quality. In a California trial, Aksland harvested lupin at one week intervals for a total of six weeks beginning with the first pod formation and ending with all pods at the dough stage. He concluded that, based on its higher CP content and comparable dry matter (DM) yield ha^{-1}, lupin silage would make an excellent replacement for winter cereal silage. Andrieu et al. (1982) conducted research in southern France on lupin silage and concluded that the quality of lupin silage was good, based on its chemical profile, yield and digestibility in sheep. They suggested that the best stage of harvest was when the seeds were well formed and contributed 25 - 30 % of the DM, however this optimum stage of harvest is short, particularly in hot dry summers. Lupin forage has been shown to maintain its quality over an extended period of time under southern United States growing conditions but there appears to be a shorter optimum harvest date for lupin silage in Mediterannean conditions. The effect of harvest date on silage quality and yield of nutrients per hectare, when lupin is grown under Maritime climatic conditions, needs to be evaluated.

Ensiling herbage permits more rapid harvesting than for hay production and may reduce field nutrient losses. Silage is the material produced by the controlled anaerobic fermentation of a high moisture crop. Achieving anaerobic conditions, by storing the forage in a sealed container, will allow the preservation of the crop by natural fermentation. Undesirable microorganisms such as clostridia and enterobacteria

are present in the forage. They degrade amino acids and carbohydrates, producing end products which may reduce the nutritional value of the silage (McDonald et al., 1991). Lactic acid bacteria can prevent the increase in numbers of clostridia and enterobacteria by rapidly producing lactic acid. The lactic acid concentration in silage is normally 8 - 12 % of the DM (McDonald et al., 1991) which contributes to a decrease in pH in the silage. A low pH inhibits the undesirable bacteria from multiplying. Inhibition of undesirable bacteria can also be accomplished by increasing the DM content (> 30 % DM) of the harvested forage. Clostridia require very wet conditions for growth. Successful preservation of low dry matter (< 30 % DM) silage results from a rapid decline of pH to less than 4.2 with an optimal range of 3.7 to 4.2. The pH decline inhibits plant protease activity and results in a chemically stable silage.

Crude protein has been used as one of the main indicators of feedstuff quality. However, silages made from grasses and legumes require a more complete profile of the nitrogen (N) fractions to define their feeding value (Fisher and Shelford, 1984). The nitrogen in fresh herbage is usually 75 to 90 % protein N. Nitrogen in silages can be analyzed for true protein N and ammonia N. The proportion of total nitrogen (TN) as protein N provides an indication of the level of proteolysis which occurred during wilting and ensiling. Levels of protein N greater than 50 % of total N (Demarquilly, 1990), indicate that proteolysis was not extensive and that protein was preserved. Ammonia is used as a negative quality indicator, with concentrations greater than 10% of TN indicative of excessive degradation of forage protein (McDonald et al., 1991).

Inhibition of proteolysis can be accomplished by wilting to increase the DM content of the forage and/or ensiling the forage (McDonald et al., 1991). Tisserand and Faurie (1982) observed storage losses of 29 % of the DM and N with lupin silage harvested at a low DM content of 17 %. Sheldrick et al. (1980) noted that the pod shells of Lupinus albus were particularly thick and fleshy in comparison to Lupinus

augustifolius. Thick pod shells could increase wilting times thereby increasing the potential for nutrient losses in the field or the necessity to harvest low DM silages, with the potential of storage losses. Daniel and Romer (1988) observed that silage mixtures consisting of a companion crop of maize and 12.5 - 50 % Andean lupin (Lupinus mutabilis), harvested at 20 - 28 % DM, produced good quality silage with low pH, high lactic acid content and low ammonia concentrations. Seeding lupin with a companion crop such as oat, which is an earlier maturing crop compared to lupin could have the effect of increasing the DM content of the silage and reduce the wilting times. The effect of a combination of lupin and oat on chemical composition, yield of nutrients ha^{-1} and wilting times has not been examined.

1.2. EFFECT OF LUPIN SILAGE CHEMICAL COMPOSITION ON ANIMAL PERFORMANCE

Evaluation of a new feedstuff, such as lupin silage, can be accomplished by chemical analysis but the feedstuff also needs to be evaluated in a controlled feeding experiment utilizing the target group of ruminants. Measuring silage quality by chemical methods can provide an estimate of the nutrient value for the ruminant which is useful in ration balancing. Offering the silage to growing steers provides a complementary assessment of silage quality in addition to its chemical parameters. Silage quality and palatability are reflected in animal responses, such as average daily gain, dry matter intake and carcass traits. Tisserand and Faurie (1982) fed lupin silage to sheep and found that they consumed 70 g of silage DM per kilogram of metabolic body weight, or 2.21 % of liveweight, which is similar to the DM intake observed when sheep are fed other legumes (Van Soest, 1982). Andrieu et al. (1982) observed

that DM intake of lupin silage by sheep was similar to corn silage. No references were found in the literature for research on dry matter intake or rate of gain of beef cattle fed lupin silage nor the rate of lupin silage N or DM degradability in the rumen.

The rate at which lupin silage CP degrades in the rumen will influence the rate at which N is available for incorporation into rumen microbes. Under most conditions nitrogen delivered to the small intestine will consist of 60 to 80 % microbial N with ruminally undegraded protein supplying 15 to 35 %, and endogenous protein up to 10 % (Robinson and Tamminga, 1984). Therefore, optimizing microbial synthesis of protein is of major significance to the ruminant. The rumen microbial population has specific energy requirements for maintenance and growth. Microbes require adenosine triphosphate (ATP) for the synthesis of amino acids, peptides, protein (enzymes) and nucleic acids. Microbial protein production is heavily dependent on available energy. Legume silages such as alfalfa have a highly soluble CP fraction and a rapid rate of CP degradability (Makoni et al., 1991). Legume and grass silages are sources of ME for rumen microbes but much of the ME may be in the form of lactic and volatile fatty acids which are poor energy sources, resulting in an energy shortage for the rumen microbes (AFRC, 1992). If lupin silage has the same CP degradability characteristics, as other legume silages, then it will need to be supplemented with feeds rich in energy yielding nutrients.

Barley and cull potatoes are the primary energy sources available on Prince Edward Island for ration supplementation. Data from NRC (1984) indicates a metabolizable energy (ME) value for raw potatoes and barley of 12.26 and 12.72 MJ kg^{-1} DM, respectively. Robinson (1992) indicated that 65 % of the DM in potatoes is in the form of starch which has a rate of degradation in the rumen ranging from 3 to 10 % h^{-1}. This rate of starch degradation is similar to corn grain but is less soluble and degradable than starch from small grains such as wheat, oats or barley. Robinson

(1992) indicated that barley starch is ruminally degraded at a rate of 25 to 30 % h^{-1}. The rate of energy release from these sources can influence the balance of N and energy available to rumen microbes.

1.3. EFFECT OF ROASTING LUPIN SEED ON ANIMAL PERFORMANCE

Raw lupins seeds have been utilized widely throughout the world as a source of supplemental protein in ruminant and monogastric diets including humans (Hill, 1986). Lupinus albus seed has an average concentration of 36.6 % CP (Hill, 1977). The high protein content of the lupin seed allows it to be classified as a protein supplement. The principal reasons for supplementing ruminant diets with protein sources are to (1) ensure an adequate supply of dietary protein to meet animals requirements for maintenance and gain, (2) provide a source of peptides and/or protein N to increase microbial protein synthesis, and (3) provide a rumen undegradable N source containing a better supply of amino acids for delivery to the small intestine (Veira et al., 1985). Protein supplemention of ruminant diets has been extensively studied in recent years, both in terms of improving the quality of protein delivered to the microbes and evaluating production responses to rumen undegraded protein.

Lupin proteins are similar to soybean proteins in that they consist primarily of globulins with lesser amounts of albumin (Oomah and Bushuk, 1983). The high proportion of globulins and albumins in lupin contributes to its high protein solubility (Van Soest, 1982). The elevated solubility and rumen degradability of the N in the raw lupin bean (Erasmus, 1988; Freer and Dove, 1984; Aufrere et al., 1991) may restrict its use in diets containing grass or legume silage which also contains high levels of soluble N. The N from either source would be rapidly soluble potentially reducing the efficiency of microbial incorporation of the N.

Robinson and Tamminga (1984) outlined a number of methods for reducing protein degradability in the rumen by treating the protein source with formaldehyde, alcohol, acetic acid, or heat. These workers indicated that heating the protein source resulted in protein structure stabilization in which peptide chains form cross-linkages both within and among chains. Cross-linkages are also formed with carbohydrates (Van Soest, 1982). The cross-linkages decrease the protein solubility and rumen degradability. Commercial grain roasters are available in the Maritimes, and if the temperature and duration of roasting are adequate, the protein structure of the lupin seed will be cross-linked reducing protein degradability in the rumen.

During the roasting process, there is potential for overheating the protein causing the Maillard reaction, which results in an undegradable residue composed of protein bound to carbohydrates (Van Soest, 1982). This heat damage to protein is commonly measured using acid detergent insoluble nitrogen (ADIN) to estimate the amount of nitrogen which is unavailable to the animal (Fisher and Shelford, 1984). Kung et al. (1991) observed that ADIN increased to 11.3 % of total N in high heat roasted lupin compared to 3.3% and 4.8% for raw and medium roasted lupins.

Hoover and Stokes (1991) indicated that the major determinants of microbial yield are ruminally available carbohydrate and protein. The rapid degradation of feedstuffs can result in ammonia concentrations in the rumen higher than optimal, 2 - 5 mg dl^{-1} (Clark et al., 1992), for microbial growth. Roasting lupins may reduce the rumen degradability of its nitrogen, decreasing the potential for excess ammonia production and providing a more sustained release of nitrogen in the rumen. This sustained release of N may closely complement the rate of energy release from silage to optimize microbial growth.

Freer and Dove (1984) demonstrated that rumen degradability of raw lupin seed CP was reduced as particle size increased. The accepted procedures for chemical (AOAC, 1990) and dacron bag (Orskov and McDonald, 1979) analysis of CP solubility and degradability has been to grind the feedstuff through a 1 mm screen. Evaluating the lupin seed by the dacron bag method or by chemical methods using the particle size as it is offered to the animal, may offer a better description of the CP degradability of lupin seeds in that the larger particle size would reduce the rate of CP degradation. Coarsely ground roasted lupin seeds could be a complementary N source for grass silage.

McKinnon et al. (1993) demonstrated that beef steers fed barley silage based diets supplemented to provide varying protein and energy levels, had increased daily gains with protein supplementation of low energy diets (11.17 MJ ME kg^{-1} DM). They concluded that the steers were not protein deficient but that growth rate was restricted by energy intake. The ME values for Maritime grown forages tend to be lower than 11.17 MJ ME kg^{-1} DM (McQueen and Martin, 1981). Lupin seeds may have beneficial attributes in addition to its higher protein content in that it has an ME value of 13.1 MJ ME kg^{-1} DM, which would have the effect of increasing dietary energy density in grass silage based diets.

Hill (1990) cited a large number of trials which measured growth performance of beef animals fed raw lupin seeds. Raw lupin seed supplementation of high grain diets generally produced improved performance. However several workers reported that the high level of CP degradation in the rumen may have decreased performance. Only a limited number of papers examined the effect of heat processing of lupin seeds on the performance of ruminants. Cros et al. (1992) demonstrated significant decreases in ruminal CP degradability in lupin after extrusion at 120°C or 150°C, with decreases of 11.6 and 25.2 %, respectively. Kung et al. (1991) roasted lupins with exit

temperatures of moderate (130-145°C) or high heat (150-175°C). Roasting decreased ruminal degradability but did not improve feed intake, daily gains or feed efficiency of lambs compared to raw lupin or soybean meal (SBM). This trial was only 5 weeks in duration, which may have been insufficient time to delineate differences in performance due to protein supplementation. Johnson et al. (1986) fed Jersey heifers a corn and oat grain diet supplemented with either extruded lupin or soybean meal. Daily gain, feed efficiency and digestibility were not different between the two diets. They concluded that extruded lupin seed was utilized well by dairy heifers. Robinson and McNiven (1992) found that early lactation dairy cows consumed more DM when alfalfa silage was supplemented with SBM than those supplemented with either raw or roasted lupin. However, milk yield was not different among treatments. Singh et al. (1992) observed that roasting lupins reduced the soluble N fraction in the rumen compared to raw lupin. The rate of ruminal N degradation was also decreased as a result of roasting. They demonstrated a significant increase in milk yield of mid-lactation dairy cows when diets were supplemented with roasted lupin compared to raw lupin or SBM. These results suggest that roasting lupin seeds may yield a protein supplement for beef animals which could produce similar growth performance to SBM supplemented animals.

1.4. OBJECTIVES

The purpose of this study was to examine the potential uses for whole plant lupin silage and lupin beans in beef cattle diets.

(1) Lupin silage was evaluated to:

(a) determine the chemical composition and nutrient yield per hectare of lupin, and lupin-oat silages at three harvest dates.

(b) determine if incorporation of oats in a lupin forage stand would improve field wilting times or nutrient yields in silage.

(c) determine the ruminal N solubility and rumen degradability of DM and CP in lupin and grass silage

(d) determine the growth performance and carcass merits of beef steers fed lupin versus grass silage supplemented with barley or potatoes as energy sources.

(2) Lupin seeds were evaluated to:

(a) determine the chemical composition of raw and roasted lupin seeds

(b) determine the effect of roasting on the dry matter and nitrogen fractions by dacron bag and in vitro methods.

(c) compare the performance of growing beef steers fed a diet of grass silage only, or supplemented with raw lupin, roasted lupin or soybean meal, in terms of growth rate and dry matter intake.

(d) determine the influence of supplementing a grass silage diet with raw lupin, roasted lupin or soybean meal on rumen fermentation characteristics.

2. CHEMICAL COMPOSITION AND YIELDS OF LUPIN, LUPIN-OAT AND OAT SILAGE HARVESTED AT THREE DIFFERENT HARVEST DATES

2.1 ABSTRACT

The effect of harvest date on ensiling characteristics and nutrient yield per hectare was evaluated for lupin (Lupinus albus), lupin-oat and oat (Avena sativa) crops. Forages were harvested on July 30 (J30), August 16 (A16) and August 27 (A27), when the lupin crop was at the second pod, third pod and senescence stages and the oat was at milk, dough, and mature stages, respectively. The forages were ensiled in laboratory scale silos for 175 days.

The lupin silage had a lactate type fermentation with low pH and a high lactic acid content. Crude protein (CP) content decreased from 19.1% at the second pod stage to 16.7 % at senescence. Protein N content was high for the J30 and A27 harvest dates but the A16 silage appeared to have undergone an altered fermentation resulting in degradation of the protein nitrogen (N) and higher ammonia N levels. Lupin-oat silages had higher dry matter contents (28.9 , 29.7 and 65.5 %) compared to lupin silages (20.5, 20.8 and 47.0 %), with shorter drying times at the J30 and A16 harvest dates. At the first two harvest dates, the lupin-oat crop had lower CP and protein N content than lupin. Lupin and lupin-oat had significantly higher yields per hectare of dry matter and metabolizable energy compared to oat. Yield of CP per hectare was significantly different among the three crops, with lupin having the highest yield and oat the lowest yield. Protein N yield was lower for lupin and lupin-oat on the A16 harvest date compared to J30 and A27. Lupin had the highest yield of protein N per hectare at each harvest date.

2.2 INTRODUCTION

Sweet white lupin acreage has increased since 1986 due to its ability to fix soil nitrogen, tolerate acid soils and produce a seed with a high protein content. Harvesting lupin for grain has met with variable success due to the indeterminate nature of lupin plant growth (Clapham and Elbert-May, 1989) which results in different parts of the plant being at various stages of growth, such as vegetative and reproductive, simultaneously. As a result of this growth pattern, some lupin beans may be immature at harvest.

Ensiling the whole lupin plant may offer an alternate harvesting method in regions where successful harvesting of the beans is difficult. The entire lupin plant contains levels of crude protein similar to other legumes such as alfalfa or red clover. Aksland et al. (1991) demonstrated lupin forage yields in California of 12,000 kg DM ha^{-1} with 18% crude protein . These yields were comparable to that of small grain silages but with higher protein levels. The nutritive value of lupins for forage has been examined at various growth stages and compares favourably to alfalfa (Offutt and Davis, 1973).

Sheldrick et al. (1980) noted that the pod shells of Lupinus albus were particularly thick and fleshy in comparison to Lupinus augustifolious. The thick pod shells may resist drying which could extend the time necessary for wilting.

Small grains have the potential to produce good yields and high quality silage when harvested at the appropriate growth stage (Helsel and Thomas, 1987; Cherney and Marten, 1982; Burgess et al., 1973; Bergen et al., 1991). Legume forages have been used to increase the crude protein content of small grain silage (DePeters et al., 1989; Jaster et al., 1985). Alternatively, small grains can be mixed with lupin to contribute bulk to the forage windrow and enhance drying.

The objectives of this study were to (1) determine if drying times could be decreased with an oat-lupin forage crop compared to a pure lupin crop, (2) determine the chemical composition and ensiling characteristics of lupin, oat and lupin-oat at 3 harvest dates and (3) determine the maximum yields of nutrients and optimum harvest dates of these silages.

2.3 MATERIALS AND METHODS

Plots (4.2 x 6.0 m) were seeded on May 3 with lupin, Lupinus albus (cv. Ultra) seeded at a rate of 140 kg ha^{-1}, oat, Avena sativa (cv. Garry) at 140 kg ha^{-1} and lupin-oat at 105 kg lupin and 35 kg oat per hectare. No herbicides were used.

Four plots from each crop were harvested per time period. Plots were harvested using a sickle bar mower on July 30 (J30), August 16 (A16) and August 27 (A27), and the forage was wilted to approximately 30% DM. Wilting times, defined as the number of hours between cutting the standing forage and collection of the forage for chopping, varied depending on the crop and harvest date. After wilting, the plant material from each plot was weighed and chopped with a single row corn harvester to a theoretical length of 20 - 25 mm. The dimensions of the area harvested were measured to determine forage yield.

Three to five kg of chopped material from each plot were pressed into individual experimental silos by a hydraulic press, with 3.52 kg cm^{-2} pressure applied on the silage. The silos measured 0.62 m by 10 cm and were made of ABS (acetyl-butyl- styrene) pipe. Each silo had a screw cap with a Bunsen valve to allow gases to escape during fermentation.

Fresh chopped forage, 100 g, were dried at 70°C for 48 hours prior to determination of acid detergent fiber (ADF) and neutral detergent fiber (NDF) according to the sequential method described by Van Soest (1982). Forty grams of fresh material were mixed with 300 grams of distilled water and blended at high speed for one minute. This material was strained through 3 layers of cheese cloth and the liquid was used to determine pH. Following overnight refrigerated storage, the strained liquid was centrifuged at 4,000 x *g* for 10 minutes and 30 ml of supernatant was retained for NH_3 analysis.

After 175 days the experimental silos were opened. Water extracts of each silage were obtained as described above. A 20 ml sample of supernatant was combined with 20 ml of trichloroacetic acid for non-protein nitrogen (NPN) determination. The NH_3 samples of the fresh forage and the silage were centrifuged at 27,000 x *g* for 10 minutes. Total N, NPN and NH_3 were determined using a Technicon Traacs 800 autoanalyzer (AOAC, 1990).

Silage ethanol, volatile fatty acid (VFA) and lactic acid content were determined by mixing 50 grams of silage with 200 ml of 0.03 M oxalic acid. The mixture was then shaken and let stand for 48 hours at 4°C, strained through cheese cloth, and centrifuged at 27,000 x *g* for 10 minutes. The ethanol and organic acid profile were measured[1] using a Hewlett Packard gas chromatograph (model # 5890A, Hewlett - Packard Co., Avondale, PA) fitted with a glass column packed with 80/120 carbopack B-DA/4% carbowax 20M / 1% trimesic acid (Supelco Separation Technologies, Supelco Inc., Bellefonte, PA).

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1. analysis conducted by Dr. L. Halliday

Silage dry matter was determined by drying at 100°C for 48 hours and correcting for VFA loss (Dulphy and Demarquilly, 1981). Determination of ADF and NDF on silage samples were completed as described above.

Metabolizable energy (ME) was calculated using the method described by McQueen and Martin (1981) for digestible energy (DE) subsequently corrected as described in NRC (1984).

Statistical analysis

The treatments were a factorial combination of crops and harvest dates. The experimental design was a split-block with 4 replications (Steel and Torrie, 1980). Data were analyzed using analysis of variance techniques (Genstat 5, 1990). The harvest date sums of squares were partitioned into linear and quadratic components. Crop sums of squares were segregated using orthogonal comparisons. When the crop x harvest date interaction was not significant ($P > 0.05$) differences between means were determined by a protected t test ($P < 0.05$).

2.4 RESULTS

Stage of Maturity

On the J30 harvest date, the lupin crop had completed its third flowering with the second set of pods established. The lupin pods were very thick and fleshy which made it difficult to attain a dry matter content of 30% for the lupin and lupin-oat crops. Oats were at the milk stage. On the second harvest date (A16) the third pod set was established on the lupin plants and the oats were at the dough stage. Due to very hot and dry weather conditions between the A16 and A27 harvest dates, both lupin and oats

matured rapidly. On the third harvest date (A27), the lupin plants had lost most of their leaves which is consistent with the onset of senescence. The pods were brown in colour and brittle. The oats at this date were mature.

Drying Times

Drying times were 4.5 hours less for lupin-oat compared to lupins on the J30 and A16 harvest dates (Table I). The DM concentration of lupin-oat was higher than lupin even though there was a shorter drying period. Each crop was harvested within minutes of each other as a result there are not enough observations per crop to conduct a statistical analysis of drying times.

Chemical Composition

The DM content of oats increased linearly with each subsequent harvest date. In contrast, lupin and lupin-oat DM contents were similar between J30 and A16 but increased substantially by A27 (Table I). The silage pH increased linearly with each subsequent harvest date, for each crop.

There was a significant crop x harvest date interaction for CP, protein N, NPN, and ammonia (Table I). The CP of the oats increased linearly with each subsequent harvest date. For lupin and lupin-oat silages, crude protein decreased linearly with time. For lupin, ammonia decreased linearly with each subsequent harvest date. There was a linear and quadratic effect for protein N. Protein N was lower on A16 compared to the other two harvest dates. There were no significant crop x harvest date interactions for ammonia in the fresh material, which decreased with time for each crop.

There was a crop x harvest date interaction for cell contents, hemicellulose, and ADF in both fresh and ensiled forages (Table II). The ADF tended to be higher in the silage compared to the fresh material and hemicellulose tended to be lower.

Cell contents, hemicellulose and ADF for oats remained virtually unchanged among harvest dates. In lupin silage there was a linear increase in ADF and hemicellulose with time and a corresponding linear decrease in cell contents. Lupin-oats hemicellulose responded quadratically with a small increase between J30 and A16 followed by a substantial increase on A27. There was a corresponding quadratic decrease in cell contents. There was a significant crop x harvest date interaction for ME. Lupin ME decreased linearly with time. There was a significant crop x harvest date interaction ($P < 0.05$) for ethanol, butyric acid and lactic acid (Table III), and a linear decrease in lactic acid with each subsequent harvest date. Butyric acid responded linearly and quadratically. Oat had higher butyric acid on A16 whereas lupin and lupin-oat had substantial decreases in butyric acid on A27. Acetic acid decreased linearly with each subsequent harvest date.

Nutrient Yield per Hectare

There was no significant difference ($P > 0.05$) in dry matter yield between lupin-oat (4197 kg ha^{-1}) and lupin (4020 kg ha^{-1}); however, both were higher ($P < 0.05$) than oat (3271 kg ha^{-1}). Crude protein yields of the silages were significantly different ($P < 0.05$), with the mean yield of lupin being significantly higher than those of lupin-oat and oat. Lupin-oat had a significantly higher yield of CP than oat. There were no significant ($P > 0.05$) crop x harvest date interactions for dry matter, crude protein or metabolizable energy yield per hectare (Table IV). There was a significant crop x harvest date interaction for protein N, and a linear and quadratic response for yield of protein N, which was lower on A16 for lupin and lupin-oat than

at other harvest dates. Oat protein N increased linearly with time. The mean ME yield of the lupin and lupin-oat did not differ ($P > 0.05$) but both were significantly higher than oat.

2.5. DISCUSSION

Drying Time

The first objective of this study was to determine if field drying times would be reduced with lupin-oat forage compared to a pure lupin forage. For harvest dates J30 and A16, time to harvest was reduced by 4.5 hours (18 % reduction in drying time) for lupin-oat compared to the lupin forage. This improvement in drying time was accompanied by a higher DM content in the lupin-oat forage. The DM content of the lupin-oat was in the range of 28-34% DM, suggested by Bolsen (1978) to be ideal for fermentation. The lupin-oat may have attained a higher DM content due to the oat plants supporting the lupin forage in the windrow and improving air flow through the windrow. However, the improvement seems more likely to have been due to the incorporation of oat which had a high DM content at each harvest date, as the lupin pods did not appear to dry faster in the lupin-oat windrow compared to the pure lupin.

Chemical Composition

McDonald et al. (1991) suggested that a typical composition for a well preserved unwilted silage would include low pH values, usually between 3.7 and 4.2, and high lactic acid concentrations (8.0 - 12.0 % of DM). In general, the silages in this study fitted the typical values for pH, with the main fermentation acid being lactic acid for all silages.

Higher levels of lactic acid are to be expected in wet silages rich in soluble carbohydrates (McDonald et al., 1991). The low DM silages tended to have the highest concentrations of fermentation acids which decreased with crop maturation and increasing DM content. The high level of lactic acid (20.7 %) in J30 lupin silage contributed to the very low pH of 3.5. Vetter and Von Glan (1978) suggested that low pH or high free acid content could be associated with reduced intake, which indicates that the low pH silages may limit silage intake when offered to animals. The high total concentration of fermentation acids and low pH of the J30 lupin silage could potentially limit dry matter intake of this silage. Wilting with the resulting increases in DM content tended to restrict fermentation resulting in higher pH values and lower levels of fermentation acids. The lactic acid levels of A27 lupin-oat and oat were quite low which undoubtedly contributed to the higher pH of these silages.

Andrieu et al. (1982) found that the organic acid profile of lupin silage (whole plant harvested when seeds contributed 25 % of DM) was 4.62 % lactic, 1.04 % acetic, 0.04 % propionic, 0.01 % butyric and 0.47 % ethanol. This profile was similar to the A27 lupin silage in this study. Although the A27 lupin silage in this trial had a DM content of 47 %, all of the fermentation characteristics were very good. McDonald et al. (1991) observed that badly preserved silages had high pH values (5.0 - 7.0), high ammonia N (up to 20 % of TN), and fermentation acids consisting primarily of acetic and butyric acid. The A27 oat silage had a DM and pH of 70.0 % and 5.0, respectively, indicating a restricted but adequate fermentation. Vetter and Von Glan (1978) indicated that ensiling materials with greater than 50 % DM, such as the A27 oat silage, can result in undesirable fermentations due to the lower density material trapping oxygen.

Tamminga et al. (1991) indicated that plants accumulate N in chloroplasts, mitochondria, membranes, and in association with cell walls. The proportion of N associated with cell walls varies with cell wall content. Furthermore, they suggested the amount of N associated with cell wall increases as total N content decreases, due to an inverse relationship between NDF and N content (Tamminga et al., 1991). This suggests that the low CP content of oat silage would lead to more N being associated with cell walls. Lupin silage N would tend to be associated with chloroplasts and mitochondria, which are more soluble, and potentially more degradable, in the rumen.

In previous studies, CP content of oat silage declined with maturity (Helsel and Thomas, 1986; Cherney and Martin, 1982). However, in this trial CP content increased slightly with maturity, presumably due to the maturation of the oat grain kernels, which could increase CP concentration. The CP of lupin silage decreased with maturity, which is consistent with observations of Burtt and Hill (1990a) using Lupinus augustifolious.

About 75-90 % of the total nitrogen (TN) in fresh herbage is present as protein N. The protein N in the fresh forage can be degraded by plant proteases during wilting or by microbes during the ensiling process. During wilting, plant proteases are particularly active in solubilizing protein N from cell organelles such as chloroplasts and mitochondria (Tamminga et al., 1991) where much of the lupin forage N is expected to be located. Microbes in the silage mass reduce protein N to NPN. McDonald et al. (1991) suggested that protein N could be reduced by 50 to 60 % of TN and the extent varies with plant species, rate and extent of pH change, DM content, and temperature. The protein N content in the silages in the current study indicates that very little protein N degradation occurred for most silages except A16 lupin and lupin-oat silage which appeared to have undergone extensive degradation of protein N.

Demarquilly (1990) indicated that silages with protein N values less than 50% of TN could be considered poor quality. The protein N contents of A16 lupin and lupin-oat were lower than the suggested minimum, indicating more extensive proteolysis in the silo. Petit and Flipot (1992) found that the average daily gain in beef steers fed grass silage only or with supplements was highly correlated with intake of protein N. This suggests that the concentrations of protein N and NPN in silage may be as important as total N in evaluating silage quality and potential for intake.

One of the main indicators used to evaluate silage quality is ammonia N; if ammonia N is greater than 10 % of TN, it is an indication of extensive proteolysis (Edwards and McDonald, 1978). With the exception of the A16 lupin, lupin-oat and J30 oat, the ammonia N values in our silages were lower than 10 % indicating satisfactory fermentation. Andrieu et al. (1982) using a low DM lupin silage had an ammonia N of 15.1 % which was reduced to 9.8 % by addition of formic acid. MacPherson and Slater (1959) found that extending the wilting period increased NPN and ammonia N due to more extensive proteolysis. In the present study, ammonia N levels of silage were higher than that found in the wilted material as would be expected. The lower ammonia levels in the fresh material for A16 supports the possibility that the protein N was extensively degraded after ensiling.

Cherney and Martin (1982) found that in small grain silage, cell wall contents and ADF increased until about 1 week after the appearance of awns and then stabilized at about 55 % NDF. Helsel and Thomas (1987) found that NDF declined at the later stages of harvest of oat silage due to new tillering and new leaf growth, but ADF increased. In the present study, oat silage NDF and ADF remained virtually unchanged with time. This could be attributed to the late stage of harvesting of the oats and the resulting plateau of fiber levels also observed by Cherney and Martin or to increased proportions of DM as starch. Oat ADF content was lower than that reported

by Burgess et al. (1973), and fiber levels of lupin and lupin-oat increased with maturity, which is in agreement with work on lupins by Tisserand and Faurie (1982) and Offutt and Davis (1973).

In general, all nine silages could be considered well preserved lactic acid silages, with only the pH of the A27 oat silage and ammonia of the A16 lupin, A16 lupin-oats and J30 oat as potential indicators of reduced silage quality.

The ME values for all silages were low in comparison to European wilted grass silages reported by McDonald et al. (1991) which had ME values ranging from 10.21 to 10.96 MJ kg^{-1} DM. In our study, lupin silage had the highest ME concentration at each harvest date. However, Baumgardt (1970) suggested that DM intake was maximized with diets containing ME concentrations of 10.5 MJ kg^{-1}DM. All silages evaluated here would therefore require supplementation with higher energy feedstuffs to maximize DM intake, including the J30 lupin silage. The J30 lupin silage had high levels of lactic acid which as suggested by Vetter and Von Glan (1978) would lower DM intake and have lower ME values.

Nutrient Yield per Hectare

The DM yield for lupin in this trial was consistent with that observed in other trials with similar seeding rates (MacLeod et al., 1987; Clapham and Elbert-May,1989). Andrieu et al. (1982), however, reported a lower DM yield of 2.1 tonnes ha^{-1}.

Sweet white lupin is an indeterminant crop. The main stem is the primary source of pods with lateral branching a function of length of the growing season and plant density. Yield of DM has been shown to increase with plant maturity, with yields

at preflowering of 5220 kg ha^{-1} (Burtt and Hill, 1990b) and at the green pod stage of 10,000 to 11,000 kg ha^{-1} (Sheldrick et al., 1980; Clapham and Elbert-May, 421989 and Aksland et al., 1991).

Helsel and Thomas (1986) evaluated wheat, barley, rye and oats for silage and found that oats provided the best silage, compared to the other crops evaluated, late in the growing season. Yields of DM of oat silage in this trial were consistent with Burgess et al. (1973) who had yields ranging from 2.5 to 3.8 tonnes ha^{-1} but lower than those reported by Cherney and Martin (1982), which ranged from 4.9 to 5.9 tonnes ha^{-1}.

Evaluation of these three crops from DM yield alone suggests that lupin-oat would be the optimum crop. However, critical factors such as yield of CP, protein N and ME per hectare must also be considered. If crop yields were evaluated using these three parameters, then lupin silage maximized nutrient yield $hectare^{-1}$ at each harvest date. Burtt and Hill (1990b) evaluated Lupinus augustifolius and observed a ME yield of 40,080 to 85,200 MJ ha^{-1}, which increased with stage of growth. The ME yield per hectare observed in this trial for lupin silage was at the lower end of this range but substantially higher than for the oat. Protein N yield for lupin was considerably higher than for oat or lupin-oat, which is consistent for legumes. Yield of nutrients per hectare is important when comparing different crops, however, nutrient density of the ration is the most critical factor for high performance animals such as fast gaining steers.

Ruminant Dietary Usage

The lupin silage at all three harvest dates had adequate CP levels for maintaining rapid growth in young ruminants; however there was a concern that the energy levels at these stages would be lower than optimum. If maximum growth in

young ruminants is desired, lupin forage harvested at the J30 (second pod) stage would provide optimum concentrations of crude protein and metabolizable energy, with the recognition that CP is highly soluble at this stage and may require supplementation with a rapidly available energy source to maximize nitrogen utilization. High concentrations of fermentation acids in immature lupin could also limit dry matter intake.

2.6 CONCLUSIONS

Whole plant lupin can be successfully ensiled at various stages from second pod stage to senescence. The nutrient content of lupin silage indicates lupin will produce a high quality silage, comparable in quality to other legume silages. Lupin-oat herbage tended to wilt to 30 % DM more rapidly than lupin silage. However, the nutrient concentration and yield per hectare of lupin-oat silage will be inferior to lupin silage.

Table I. Chemical composition and drying times for oat (O), lupin (L) and lupin-oat (LO) silages.

	Oat			Lupin			Lupin-oat				Significance[y]						
											Crop		Harv	C x H	Harv date within		
Parameter[z]	J30	A16	A27	J30	A16	A27	J30	A16	A27	SEM	A	B			O	L	LO
Dry matter	32.2	51.7	70.0	20.5	20.8	47.0	28.9	29.7	65.5	1.35	-	-	-	*	L	LQ	LQ
pH	3.8	4.2	5.0	3.5	3.8	4.1	3.7	3.9	4.5	0.18	*	NS	L	NS	-	-	-
Silage																	
CP (% of DM)	6.1	6.4	7.3	19.1	18.3	16.7	12.0	9.5	9.9	0.44	-	-	-	*	L	L	L
Protein N (% of TN)	61.6	74.2	91.6	74.3	50.7	79.7	60.9	29.5	83.5	2.67	-	-	-	*	LQ	LQ	LQ
NPN (% of TN)	38.4	25.8	8.1	25.7	49.3	20.3	39.1	70.5	16.5	2.67	-	-	-	*	L	LQ	LQ
Ammonia (% of TN)	11.0	6.7	2.7	7.9	13.2	6.6	9.9	18.5	4.4	0.62	-	-	-	*	LQ	L	LQ
Wilted herbage																	
Ammonia (% of TN)	5.45	3.49	2.85	5.11	6.33	4.36	6.79	5.84	4.69	0.51	-	-	-	*	L	L	L
Drying time (hr)	0.5	0.5	1.5	24.5	24.0	1.5	20.0	19.5	1.5								

[z] CP = crude protein, NPN = non protein nitrogen; TN = total nitrogen.

[y] * = $P < 0.05$; NS = not significant ($P > 0.05$); L = linear; Q = quadratic response; SEM = standard error of mean. Crop SS were segregated into orthogonal comparisons A = oat vs lupin and lupin-oat; B = lupin vs lupin-oat; Harv = harvest date; C x H = crop x harvest date interaction ($P < 0.05$);

J30 = July 30; A16 = August 16; A27 = August 27. Four observations per crop per time period.

Table II. Chemical constituents (% of DM) of oat (O), lupin (L) and lupin-oat(LO) silages.

												Significance[y]				
	Oat			Lupin			Lupin-oat				Crop		Harv	C x H	Harvest Date within		
Parameters	J30	A16	A27	J30	A16	A27	J30	A16	A27	SEM	A	B			O	L	LO
Wilted herbage (% of DM)																	
Cell contents	35.1	36.0	36.1	64.0	49.6	47.2	49.1	43.3	39.7	1.14	-	-	-	*	L	Q	L
Hemicellulose	28.3	28.6	27.6	12.2	20.9	18.2	20.8	24.5	24.6	0.67	-	-	-	*	L	Q	L
ADF[z]	33.9	32.8	34.6	20.8	27.8	32.2	27.4	30.1	33.6	0.92	-	-	-	*	LQ	L	LQ
Silage (% of DM)																	
Cell contents	35.7	35.5	34.9	60.7	52.6	47.2	46.3	45.5	36.2	1.16	-	-	-	*	L	L	Q
Hemicellulose	26.5	26.6	27.1	11.5	14.3	17.8	21.1	20.9	25.4	0.71	-	-	-	*	L	L	L
ADF	35.2	35.8	35.8	25.2	30.7	33.5	30.6	31.7	37.8	0.64	-	-	-	*	L	L	LQ
ME[z]	8.9	8.8	8.8	10.3	9.5	9.1	9.6	9.4	8.3	0.18	-	-	-	*	L	L	LQ

[z] ADF = acid detergent fiber; ME = metabolizable energy (MJ kg^{-1}DM).

[y] L = significant linear response ($P < 0.05$); Q = significant quadratic response ($P < 0.05$); * = $P < 0.05$; NS = not significant; SEM = standard error of mean; crop SS were segregated into orthogonal comparisons; A = oat vs lupin and lupin-oat; B = lupin vs lupin-oat. Harv = harvest date; C x H = crop x harvest date interaction ($P < 0.05$)

J30 = July 30; A16 = August 16; A27 = August 27.

Table III. Chemical constituents (% of DM) of oat (O), lupin (L) and lupin-oats (LO) silages.

										Significance[z]						
	Oat			Lupin			Lupin-oat				Crop		Harv	C x H	Harvest date within		
Parameters	J30	A16	A27	J30	A16	A27	J30	A16	A27	SEM	A	B			O	L	LO
Ethanol	0.75	0.09	0.02	2.99	0.57	0.57	1.78	0.56	0.24	0.26	-	-	-	*	LQ	LQ	LQ
Acetic acid	0.74	0.18	0.15	2.51	1.53	0.72	1.72	1.17	0.29	0.21	*	NS	L	NS	-	-	-
Propionic	0.01	0.02	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	NS	NS	Q	NS	-	-	-
Lactic acid	5.7	2.4	1.4	20.8	10.8	5.2	13.9	6.4	0.9	1.40	-	-	-	*	L	L	L
Butyric acid	0.11	0.23	0.03	0.09	0.11	0.04	0.11	0.12	0.04	0.02	-	-	-	*	LQ	LQ	LQ

[z] * = $P < 0.05$; NS = not significant ($P > 0.05$); SEM = standard error of mean; L = linear and Q = quadratic orthogonal contrasts; crop sums of squares were segregated into orthogonal contrasts; A = oat vs lupin and lupin-oat; B = lupin vs lupin-oat. Harv = harvest date; C x H = crop x harvest date interaction ($P < 0.05$).

J30 = July 30; A16 = August 16; A27 = August 27.

Table IV. Yield of chemical constituents (kg ha^{-1}).

	Oat			Lupin			Lupin-oat				Significance[y]						
											Crop		Harv	C x H	Harvest date within		
Parameters	J30	A16	A27	J30	A16	A27	J30	A16	A27	SEM	A	B			O	L	LO
Dry matter	2832	3638	3344	3335	4277	4447	3953	3963	4675	327.9	*	NS	L	NS	-	-	-
Crude protein	172	231	245	641	781	737	475	406	464	34.7	*	*	Q	NS	-	-	-
Protein N	106	172	240	476	393	586	293	146	386	32.4	-	-	-	*	L	LQ	LQ
ME[z]	25.3	31.8	29.4	34.3	40.5	40.2	37.8	37.1	38.5	2.7	*	NS	NS	NS	-	-	-

[z] ME = metabolizable energy (KJ ha^{-1}).

[y] Crop SS were segregated into orthogonal contrasts; A = oat vs lupin and lupin-oat;
B = lupin vs lupin-oat. Q = quadratic; L = linear; * = $P < 0.05$; NS = not significant.
Harv = harvest date; C x H = crop x harvest date interaction ($P < 0.05$); O = oat; L = lupin;
LO = lupin-oat.

J30 = July 30; A16 = August 16; A27 = August 27.

3. GRASS AND LUPIN SILAGE IN RATIONS FOR BEEF STEERS SUPPLEMENTED WITH BARLEY OR POTATOES

3.1 ABSTRACT

Twenty eight Simmental-cross steers weighing 200 (± 20.5) kg were used to evaluate grass (Phleum pratense and Poa pratensis) and whole plant sweet white lupin silages in terms of growth rate, dry matter intake (DMI) and carcass characteristics. The chemical composition of the silages was determined and dacron bag procedures were used to estimate dry matter and protein degradability. The steers were randomly assigned to pen and diet: lupin or grass silages were supplemented with either rolled barley or crushed potatoes. The lupin silage had a lactic acid fermentation with lower dry matter (DM), neutral detergent fiber (NDF) and protein nitrogen (N) than the grass silage but higher crude protein. There were no statistically significant differences in gain, carcass weight, dressing percentage or backfat levels between steers fed lupin or grass silage. Dry matter intake of the silages was not significantly different but there was a tendency for lower DMI of lupin silage when supplemented with potatoes. There was no difference in DM degradability between lupin and grass silages. Lupin N degraded at a significantly faster rate (24.5 % h^{-1}) compared to the grass (10.4% h^{-1}). The effective degradation of N at a ruminal fractional outflow rate of 0.05 h^{-1} was 63.8% and 79.1% for grass and lupin silage, respectively. Ensiling whole plant lupin can produce a high quality silage for use in beef rations.

3.2 INTRODUCTION

Sweet white lupins are grown throughout the world, primarily for the lupin seed which has a high protein and oil content. Lupins are adapted to cooler climates and acidic soil conditions (Williams, 1986; Gladstones, 1970). Lupin is a legume, and its ability to fix nitrogen in the soil (MacLeod et al., 1987) allows it to be utilized in rotations with crops such as potatoes and small grains which require substantial nitrogen (Putnam et al., 1991). Sheldrick et al. (1980) demonstrated that whole plant lupin could yield 11 tonnes of dry matter per hectare. This suggests that during years of difficult harvesting conditions for the lupin seed crop or as a part of the crop rotation, the whole plant could be harvested and ensiled for use in beef or dairy cattle rations.

Trials have been conducted to evaluate the digestibility of lupin silage DM, total N, crude fiber and nitrogen free extract (NFE) resulting in values of 56.0 to 62.4 %; 75.7 %; 44.3 to 58.3 % and 58.4 %, respectively (Tisserand and Faurie, 1982; Saric and Ramosevac, 1981). The digestibility of DM, crude fiber, and NFE, but not crude protein were increased significantly by the addition of 20 % barley grain to a lupin silage diet (Saric and Ramosevac, 1981).

Barley and cull potatoes are the two major energy feeds used in Maritime Canada for supplementing silage based rations. There is a lack of published information on the performance of beef animals fed lupin silage.

The first objective of this study was to determine the quality of whole plant lupin silage from its chemical composition, dacron bag degradation rates, and growth rates, blood composition and carcass traits of beef steers fed lupin or grass silage. The second objective was to determine the performance of the steers when the silages were supplemented with rolled barley or potatoes.

3.3 MATERIALS AND METHODS

Silage

Two silages were compared in this study, a control silage made from a grass-legume mixture and whole plant sweet white lupin silage. The grass-legume silage, consisting primarily of grass (Phleum pratense and Poa pratensis) with some legume, was harvested with a mower conditioner at the mid-bloom stage. Lupin plants were at the 2nd to 3rd pod set at the time of harvesting, which is considered a relatively immature stage. Lupin (Lupinus albus) was harvested from a pure stand with a disc mower and wilted for 48 hours. The silages were chopped to a length of 3.5 cm and packed into polyethylene tubes (Ag Bag Corp., Warrenton, Oregon) measuring 2.4 m by 30 m. At the beginning of the feeding trial, the lupin and grass had been ensiled for 3 and 4 months, respectively.

Feeding Trial

Twenty eight Simmental crossbred steers were trained to a Calan gate system over a 3 week period. During this period the steers were dehorned, vaccinated for clostridial diseases and offered a mixture of grass and lupin silages. At the end of the 3 week adjustment period, the steers, weighing approximately 200 ($\pm$20.5) kg, were randomly assigned to one of four treatment groups: grass-barley (GB), grass-potato (GP), lupin-barley (LB) and lupin-potato (LP). The steers were then randomly assigned to one of four pens, with seven steers per pen. The steers were housed in a cold

housing facility equipped with mechanical ventilation. Temperatures during the trial ranged between +10°C and -20°C. Steers were weighed every 28 days after feed was withdrawn for 16 hours.

Steers were fed twice daily with one of the silages plus a supplementary energy source, either rolled barley or potatoes. The potatoes, which were frozen, were cleaned of soil and they were crushed by mechanical rollers. Dry matter intake from silage was calculated as a percentage of body weight as follows: 2% for Days 1 to 112, 1.5% for Days 113 to 140, and 1.0% for Days 141 to 230. Each diet was formulated to contain approximately 10.86 MJ kg^{-1} DM, which was suggested by the NRC (1984) for large frame steers gaining 1.4 kg d^{-1}. Barley or potatoes were added to balance energy levels. Crude protein levels varied between diets. Samples of silages were taken biweekly and frozen for analysis. Feed refusals were measured weekly. The steers had free access to a mineral-vitamin mix (containing Ca, P, Na, Mg, Mn, Zn, Co, Vitamins A, D and E) and cobalt iodized salt (99.0% NaCl; 70 mg/kg I; 40 mg/kg Co). Samples of blood were taken in serum tubes from the coccygeal vein of each steer on Day 112 between 1000 to 1200 h and delivered to the laboratory for immediate analysis. A Discrete Analyzer with Continous Optical Scanning (Coulter Electronics, Hialeah, Florida) was used to determine urea, total protein and albumin in the blood samples[2]. On Day 230 all steers were slaughtered and carcass data, including carcass weight, backfat, dressing percentage and loin eye area were assessed at a federally graded slaughter plant.

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2. analysis conducted by R. MacKinnon, Atlantic Veterinary College.

Dacron Bag Trial

Two nonlactating ruminally cannulated Jersey cows were used to determine ruminal dry matter and nitrogen degradation of the grass and lupin silages. The cows had been fitted with the ruminal cannula several years prior to the start of this experiment. The cows were fed alfalfa and grass hay ad libitum plus 1 kg of barley mixed with a protein supplement containing raw lupin, roasted lupin and fishmeal. The barley and supplement were fed at 800 and 1600 hours each day. The biweekly samples of silage taken during the feeding trial were composited and chopped through a Hobart slicer (model # PD-70, Hobart Canada, Don Mills Ont.). Approximately 5 grams of silage dry matter were placed in each Dacron bag (42 μm pore size, B&SH Thompson, Scarborough, Ontario) measuring 9 cm by 14 cm. Two replicates were placed in the rumen of each cow per incubation period. The silages were incubated for 2, 4, 7, 16, 24 and 48 hours. The complete exchange method as described by Paine et al.(1982) was used. Upon removal, bags were hand washed until the effluent was clear. Zero hour bags were washed using the same procedure. The bags were then dried at 90°C for 48 hours and weighed to determine dry matter loss. The contents of each bag were analyzed for nitrogen by the Kjeldahl method with auto-titration using a Technicon Traacs 800 autoanalyzer (AOAC, 1990). Degradation rates were determined as described by Orskov and McDonald (1979).

Chemical Analysis

Dry matter contents of silages were derived by drying at 90°C for 48 hours and correcting for VFA loss (Dulphy and Demarquilly, 1981). Acid detergent fiber (ADF) and NDF were determined[3] as described by Van Soest et al. (1991). Crude protein

was determined by the Kjeldahl method (AOAC, 1990). Water extracts of each silage were obtained by adding 250 ml of distilled water to 40 grams of silage, blending at high speed for 1 minute and straining the extract through cheese cloth. pH was determined immediately and the extract was then centrifuged at 4,000 x *g* for 10 minutes. Two 30 ml samples of the supernatant were retained for soluble N and NH_3 analysis. A 20 ml sample of supernatant was combined with 20 ml of trichloroacetic acid for non-protein nitrogen (NPN) determination. The soluble N and NH_3 samples were centrifuged at 27,000 x *g* for 10 minutes. The total nitrogen and NPN were determined by the Kjeldahl method (AOAC, 1990). Ethanol, VFA and lactic acid were determined by mixing 50 grams of silage with 200 ml of 0.03M oxalic acid, the mixture was then shaken and let stand for 48 hours at 4°C, strained through cheese cloth, and centrifuged at 27,000 x *g* for 10 minutes. The ethanol and organic acid profile were measured[4] using a Hewlett Packard gas chromatograph (model # 5890A, Hewlett-Packard Co., Avondale, PA) fitted with a glass column packed with 80/120 carbopack B-DA / 4% carbowax 20M /1% trimesic acid (Supelco Separation Technologies, Supelco Inc., Bellefonte, PA). Gross energy was measured using an isoperibolic oxygen combustion bomb calorimeter (Parr Instrument Co., Moline, Ill., model # 1261). Metabolizable energy was calculated using the method described by McQueen and Martin (1981) for digestible energy (DE) and the DE value was corrected as described by the NRC (1984).

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3. analysis conducted by J. Keough, Agriculture Canada, Fredricton.

4. analysis conducted by Dr. L. Halliday, Charlottetown Research Station

Statistical Analysis

The experimental design was a two by two fully fixed factorial with silage and concentrate source as factors and initial weight as a covariate. All production parameters were subjected to analysis of variance but numbers within cells were unequal (number of animals per treatment were not equal among pens) and the data were analyzed by fitting constraints using SAS (1988). Significant treatment effects were determined at $P < 0.05$, and differences among means were tested using the PDIFF option of SAS. The Maximum Likelihood Program (Ross, 1987) was used to evaluate differences in position of degradation curves of N and DM in nylon bags.

3.4 RESULTS

Chemical Composition

The chemical composition of the silages differed with the grass silage having a higher DM and NDF ($P < 0.05$) compared to the lupin silage (Table V). However, the lupin silage had higher CP ($P < 0.05$) than the grass silage. The fermentation of both silages produced primarily lactic acid with low pH, low ammonia and negligible levels of butyric acid. Analysis of the water soluble fraction revealed that the water soluble N and NPN levels in the lupin silage were significantly higher ($P < 0.05$) than in the grass silage. Both NPN and water soluble N values were similar which indicated that most of the water soluble N was NPN.

Steer Feeding Trial

There were no significant differences in daily gain, carcass weight, dressing percentage or fat cover between steers fed the two silages. There was a significant silage x concentrate interaction for loin eye area (Table VI), with the loin eye of the LP treatment being significantly smaller than the other 3 treatments. Concentrate intake ($P < 0.01$) and total dry matter intake ($P < 0.05$) were higher for barley supplemented steers compared to potato fed steers. There was no significant difference in dry matter intake between the silages but there was a tendency for steers on the LP treatment to have lower dry matter intakes of silage (Table VI). There were no significant differences in feed efficiency.

Three steers fed LP and two steers fed GP in one pen experienced respiratory infections caused during the second month of the trial.

The blood analysis revealed that albumin and total protein were not significantly different among treatments (Table VII). However, potato supplemented steers had significantly lower blood urea levels ($P < 0.05$) than barley supplemented steers.

Dacron Bag Trial

There was no significant difference in DM degradation between grass and lupin silage (Table VIII). The rapidly soluble N (fraction 'a') was higher for the lupin silage. Fraction 'b', the more slowly degradable N fraction of both silages was similar. However, the rate of N degradation was significantly more rapid ($P < 0.05$) in the lupin ($0.245\ h^{-1}$) compared to the grass silage ($0.104\ h^{-1}$). The rumen undegradable fraction was higher in the grass silage compared to the lupin silage.

The Agricultural Research Council (1984) suggested that for growing beef cattle, a fractional outflow rate of 0.05 h^{-1} is appropriate. The effective degradation of the grass silage N was markedly less than that for the lupin silage at this ruminal fractional outflow rate.

3.5 DISCUSSION

Our first objective in this trial was to determine the quality of whole plant lupin silage from its chemical composition. Mertens (1989) indicated that NDF content can be a reliable predictor of forage intake because it is associated with cell wall content, rate of fibre digestion and passage, as well as rumen fill. The lupin silage had a similar ADF but lower NDF than the grass silage indicating that the lupin silage had a lower hemicellulose fraction compared to the grass silage which would lead to potentially higher intake. Both the lupin and grass silages were characterized by lactic acid fermentation with low pH, low ammonia N and high lactic acid content.

The nitrogen in the lupin silage consisted of 48.4% true protein with the remainder of the nitrogen as NPN. This is in contrast to the grass silage which had 65.4% true protein. Castle et al (1984) described an excellent quality white clover silage with 24.3 % crude protein and 37.4 % protein N. Thomas & Chamberlain (1982) suggested that well preserved lactate silages should have a protein N proportion of 35 to 60%. Thus the lupin silage is well within the satisfactory range for protein N. Thomas & Gill (1988) suggested that high levels of soluble N and the consequent high concentration of rumen ammonia are two of the main factors associated with the low microbial efficiencies frequently observed with silage diets.

Dacron bag trial results concur with observations of Thomas & Gill (1988) as the lupin silage, with a higher NPN level, had a significantly ($P < 0.05$) faster rate of N degradation compared to the grass silage. Disappearance of N from nylon bags at 48 hours were 78% and 87% for the grass and lupin silage, respectively. The ARC (1984) indicated a range for silage N degradability of 75 to 85 percent. Hvelplund & Madsen (1990) presented average values for sweet lupin silage as 20 % DM and 18.1 % CP with a ruminal protein degradability of 0.75. These results indicate that lupin silage N is rapidly and extensively degraded in the rumen. Buttery (1977) suggested that for an efficient fermentation to occur in the rumen, energy and nitrogen supply must be balanced. Too little nitrogen would induce uncoupled fermentation (i.e. fermentation without useful ATP production), while too much nitrogen and not enough available energy would result in an inefficient use of nitrogen. The higher solubility and rapid degradability of the lupin silage N (Table VIII) indicated that rumen microorganisms would require a source of available energy to efficiently utilize the released ammonia.

The undegradable nitrogen fraction calculated for the grass silage was higher than that of the lupin silage. Makoni et al. (1991) found that wilting of a grass-legume silage reduced the soluble N fraction and significantly increased the amount of undegraded protein leaving the rumen. The higher DM content of the grass silage may have contributed to the higher rumen undegradable N value compared to the lower DM lupin silage.

Spicer et al. (1986) observed that 87.7% of barley starch was digested in the rumen, and they stated that in grains, maximum total tract starch digestibility appeared to be positively related to the extent of digestion in the rumen. This suggests that barley is a good potential source of rapidly available energy to complement the rapidly degradable N of the lupin silage.

Cull potatoes have been assessed by several authors (De Boever et al., 1983; DeBrabander et al., 1982) as having 19.9 to 21.6% DM, 10.4 to 11.8% CP, and 76.5 to 78.3% NFE. The digestibility values of these fractions in dairy cows were on average 86%, 73% and 97%.

Cone (1991) determined barley and potato starch degradability by incubation in rumen fluid for 6 hours. Starch degradabilities were 37.5 % for barley and 31.2 % for potato, which implies that barley should provide more rapidly available energy for efficient capture of the lupin silage N than supplementation with potatoes. Slower release of energy from the potatoes along with the lower DM intake may have contributed to the lowered performance of the LP treatment.

The differences in the lupin and grass silages observed in the chemical composition and the dacron bag trial did not translate into significant differences in animal performance. Daily gains were lower than predicted by the NRC (1984) which may have been a result of the cold temperatures experienced throughout most of the trial. This may have contributed to a significant pen effect for feed to gain ratio, due to lower dry matter intake and daily gain during this period. Although there were lower DM intakes on the potato treatments, some caution must be exercised in interpreting this result. Due to the low DM content of potatoes, a 1 to 2 % increase in DM content could negate the significant differences in concentrate DM intake.

The low DM content of the LP diet may have contributed to its low DM intake. The quantity of water in the feeds consumed per day differed among diets; 5.2, 17.0, 9.5 and 19.4 kg d^{-1} for GB, GP, LB and LP, respectively. Using sheep that were fed diets of potatoes or swedes, Orskov et al. (1969) suggested that moisture content and rate of rumen degradation would determine the extent to which animals can compensate for the increased bulk and achieve equal intakes of digestible dry matter with such feeds. The higher moisture content of the potato diets in conjunction with the lower

dry matter of the lupin silage may have limited the LP steers' ability to achieve similar dry matter intakes to the barley fed steers. Van Soest (1982) indicated that fermentation rates changed during or after consumption of cold water or feed. The consumption of frozen potatoes may alter rumen fermentation, especially with high moisture silages. Frozen potato consumption may also increase the energy required to maintain body temperature.

Chou and Walker (1964) found that rumen concentrations of total N, protein N and total VFA's were lower for sheep that were fed potatoes than for sheep that were fed cereals. Blood urea levels in this trial were significantly lower for steers that were fed potato diets than for steers that were fed barley diets. The lower blood urea levels of the potato fed steers suggests that performance may have been limited by the lower intake of nitrogen.

3.6 CONCLUSIONS

In conclusion, silage made from whole plant lupin had a chemical profile indicating that it was well preserved and had higher crude protein and lower NDF than a grass legume silage. However, the nitrogen in the lupin silage was rapidly degraded in the rumen, which may have implications for efficient microbial utilization of the nitrogen. When fed to beef steers, lupin silage resulted in growth rates, carcass merits and dry matter intake similar to that of a grass-legume silage. These results suggest that lupin silage could replace grass-legume silages in growing and finishing beef cattle rations with the expectation of similar animal performance.

TABLE V. Chemical composition of grass and lupin silages, barley and potatoes.

Parameters[z]	Silage				Barley	Potato
	Grass	SEM	Lupin	SEM		
Dry Matter[y] (%)	43.2	3.28	28.0	0.88	90.0	20.0
NDF[y](% of DM)	54.7	0.48	47.8	0.72	19.4	6.5
ADF (% of DM)	37.5	0.41	37.5	0.60	7.7	3.7
pH	4.5	0.07	3.9	0.02	nd	nd
Crude protein[y] (% of DM)	13.8	0.38	16.0	0.24	13.5[x]	9.5[x]
Gross energy (MJ kg^{-1}DM)	18.6	0.09	18.4	0.16	nd	nd
ME (MJ kg^{-1}DM)	8.4		8.5		12.72[x]	12.26[x]
	------% of total N ---------					
Ammonia	7.7	0.53	9.0	0.47		
Water soluble N[y]	34.3	2.61	50.9	2.54		
Non protein N[y]	34.6	1.18	51.6	1.81		
Protein N[y]	65.4	1.18	48.4	1.81		
	--------- % of DM ----------					
Ethanol	0.87	0.25	1.24	0.15		
Acetic acid	1.41	0.17	1.40	0.09		
i & n Butyric acid	0.06	0.01	0.05	0.00		
Lactic acid[y]	8.31	1.20	11.85	0.54		

[x] NRC (1984) feed composition table values , nd = not determined, SEM = standard error of mean.

[y] significant difference between lupin and grass silage parameter ($P < 0.05$) seven samples per silage (t-test, df = 12).

[z] NDF = neutral detergent fiber; ADF = acid detergent fiber; ME = metabolizable energy.

TABLE VI. Growth and carcass characteristics for beef steers fed either grass or lupin silage supplemented with barley or potatoes.

Silage	Grass		Lupin		
Concentrate	Barley	Potato	Barley	Potato	sem
Total gain (kg)	252	246	255	217	12.3
Carcass wt (kg)	248	242	248	232	8.61
Daily gain (kg d^{-1})	1.10	1.07	1.11	0.94	0.05
Dressing percentage (%)	55.2	54.6	54.9	56.2	1.06
Backfat (mm)	3.8	3.3	3.3	3.6	0.35
Loin eye area[z] (cm^2)	70.2[a]	70.7[a]	76.5[a]	61.4[b]	2.02
Dry matter intake (kg d^{-1})					
Silage	3.7	3.7	3.7	2.9	0.21
Concentrate[y]	3.4	3.0	3.6	2.7	0.12
Total[x]	7.1	6.7	7.3	5.6	0.32
Feed:Gain	6.6	6.3	6.6	6.0	0.17
CP intake (kg d^{-1})[y]	0.97	0.80	1.05	0.76	0.05
ME intake (MJ d^{-1})	73.5	68.6	74.5	58.7	4.19

[z] means within a row not sharing a common superscript differ ($P < .05$).

[y] significant effect due to concentrate ($P < 0.01$)

[x] significant effect due to concentrate ($P < 0.05$)

Table VII. Blood composition of beef steers fed lupin or grass silage supplemented with barley or potato.

	Treatment				
	Grass		Lupin		
Item (mg $100ml^{-1}$)	Barley	Potato	Barley	Potato	SEM
Urea[a]	11.9	7.0	11 6	6.9	1.1
Albumin	3607.0	3182.0	3791.0	3923.0	238.0
Total protein	7177.0	6950.0	7615.0	6597.0	451.0

[a]significant effect due to concentrate ($P < 0.05$).

TABLE VIII. Ruminal degradation of nitrogen and dry matter in grass and lupin silage.

Silage	Grass	SE[z]	Lupin	SE
Nitrogen fractions (% of total N)				
soluble	31.8	(2.30)	39.8	(1.38)
potentially degradable	47.3	(3.39)	47.2	(1.67)
undegradable	20.9		13.0	
Dry matter fractions (% of total DM)				
soluble	16.3	(1.81)	16.2	(1.99)
potentially degradable	53.8	(3.37)	50.4	(2.92)
undegradable	29.9		33.4	
Fractional rate constants (h^{-1})				
nitrogen	0.10	(0.016)	0.24	(0.019)
dry matter	0.06	(0.009)	0.09	(0.013)
Effective degradation[y]				
nitrogen	63.8		79.1	
dry matter	45.2		49.2	

[z] SE = standard error, four samples per feed per incubation period.

[y] Effective degradation (% of total N or DM) at 0.05 h^{-1} ruminal fractional outflow rate (k) in equation $P = a + (bc)/(c + k)$; (Orskov and McDonald, 1979).

4. RAW AND ROASTED LUPIN SUPPLEMENTATION OF GRASS SILAGE DIETS FOR BEEF STEERS

4.1 ABSTRACT

Raw or roasted lupins were evaluated as protein supplements in rations for growing and finishing beef steers. Lupins were roasted in a flame roaster with an exit temperature of 105°C. The effect of heating on protein solubility and rumen degradability of lupin was evaluated by chemical and dacron bag procedures. Nitrogen soluble in borate phosphate buffer was reduced from 69.8 % in raw lupin to 35.8 % with roasted lupin. Effective degradability values of crude protein (CP) and rate of CP degradation predicted by the dacron bag procedure were lower for roasted lupin (82.3 %, 9.2 % h^{-1}) compared to raw lupin (86.7 %, 11.9%). Heat damage measured by acid detergent insoluble N was not different for raw lupin (3.31% of total N) or roasted lupin (3.46%). Twenty seven Charolais cross steers with an average weight of 235 (± 35) kg were randomly assigned to pen and one of four diets: grass silage only (SIL, n = 7) or silage plus supplements to supply crude protein at 6.5 % of the silage dry matter intake (DMI) with raw lupin (RL, n = 7), roasted lupin (ROL, n = 7) or soybean meal (SBM, n = 6) as the sources of supplemental protein. When the steers reached 330 kg liveweight they were placed on a finishing diet of chopped hay, barley and the same protein supplements at a rate of 4.5% of barley DMI. In the growing phase, steers fed RL, ROL or SBM had daily gains significantly higher ($P < 0.05$) than steers fed SIL. Steers fed the SBM diet had significantly higher daily gains than those fed RL, with steers fed ROL being intermediate. Silage DMI was significantly lower on RL and ROL supplemented diets compared to SIL. In the finishing phase, there were no significant differences in daily gain, carcass weight, dressing percentage,

loin eye area or dry matter intake among diets. Heat treatment of lupins decreased solubility and ruminal degradability of N and increased performance of steers on the grower ration. Roasted lupin can replace soybean meal as a protein supplement in beef cattle rations.

4.2 INTRODUCTION

Grass silage is used extensively in rations for growing beef steers. However, proteolytic activity during wilting and ensiling can result in degradation of 50 to 60 % of protein nitrogen (N) to non-protein nitrogen (NPN) (McDonald et al., 1991). Much of the NPN is soluble and will be rapidly degraded in the rumen to ammonia, decreasing the efficiency of microbial synthesis. Veira et al. (1990) and Steen (1989) demonstrated that steers fed grass silage, even with high crude protein (CP) content, can benefit from protein supplementation. McDonald et al. (1991) suggested that supplementation with protein may have a positive effect on microbial protein synthesis and animal performance by providing more intact amino acids and peptides, by serving as a source of gluconeogenic substrates or from rumen undegraded protein which may provide the animal with essential amino acids for tissue synthesis.

Anderson et al. (1989) observed that a corn grain and corn silage diet supplemented with either fat extracted lupin meal or soybean meal produced similar daily gains and feed conversions in growing steers. A number of authors have established that the protein in lupin is rapidly solubilized in the rumen (Freer and Dove, 1984; Valentine and Bartsch, 1988; Erasmus et al., 1988). This rapidly soluble N can be a concern in grass silage based diets since both silage and lupin contain a large portion of soluble N. Solubility and ruminal degradability of proteins can be reduced by heating (Van Soest, 1982). Cros et al. (1991) demonstrated that extrusion

of lupins decreased rumen degradability of the crude protein. The reduced degradability appeared to be primarily due to lower solubility of N. Kung et al. (1991) demonstrated that roasting lupins reduced ruminal in situ N disappearance by 40 % after a 12 hour incubation. Although daily gains of lambs fed a hay and cracked corn basal diet were not different than for lambs fed the basal diet supplemented with roasted lupin, they suggested that roasting increased the supply of absorbable amino acids and improved nitrogen retention.

The objectives of this experiment were to: (1) determine the chemical composition of raw and roasted lupin seeds, (2) determine the effect of roasting on the dry matter and crude protein fractions of raw lupin as compared to roasted lupin, soybean meal and grass silage by dacron bag and in vitro procedures, (3) evaluate the response in daily gain and feed intake when beef steers are fed a grass silage-based diet alone or supplemented with raw lupin, roasted lupin or soybean meal, (4) evaluate each diet, in vitro, for rumen fermentation characteristics and (5) determine growth and carcass traits for steers fed hay and barley alone or supplemented with raw lupin, roasted lupin or soybean meal, during the subsequent finishing phase.

4.3 MATERIALS AND METHODS

Twenty eight Charolais crossbred steers, average weight 235 $\pm$ 35 kg, were fed grass hay for a 10 day adjustment period during which time they were castrated, dehorned, dewormed and vaccinated for respiratory and clostridial diseases. After the adjustment period, the steers were offered grass silage and trained to use gates for individual feeding over a 14 day period.

At the beginning of the experiment, the steers were weighed, blocked according to liveweight and randomly assigned to treatment (seven steers per treatment). The steers were randomly assigned to one of four pens, with seven steers per pen. The steers were housed in a cold housing facility with temperatures during the trial ranging between +10°C and -20°C. During the growth phase, the treatments consisted of silage only (SIL) or silage supplemented with raw lupin (RL), roasted lupin (ROL) or soybean meal (SBM). Silage was fed ad libitum in all treatments. Supplements were fed to supply crude protein at the rate of 6.5% of the silage dry matter intake. The steers were weighed every 28 days and when they reached approximately 330 kg, they were changed to a finishing diet.

The soybean meal was a commercially prepared solvent extracted meal. Half of the lupin beans were roasted in a flame roaster (Roast-a-matic, Lebanon, PA) with an exit temperature of 105°C and a residence time of about 1 minute. Raw and roasted lupins were coarsely rolled in a commercial roller mill. The silage was harvested on June 30, three months prior to the start of the feeding trial, from a mid-bloom grass-legume (Phleum pratense, Trifolium pratense) stand using a mower conditioner. It was chopped to a theoretical length of 3.5 cm and packed into 2 polyethylene tubes (Ag Bag Corp., Warrenton, Oregon) measuring 2.4 m x 30 m.

The steers were allowed a 14 day transition period to the finishing diet which consisted of 2.5 kg d^{-1} of chopped timothy hay, ad libitum barley plus the same protein supplement as in the growth phase, fed at a rate calculated to deliver 4.5 % of the barley dry matter intake as CP.

The steers were fed twice daily. A sample of each feed was taken biweekly; silage samples were frozen for analysis and feed refusals were measured weekly. The steers had free access to a mineral-vitamin mix (containing Ca, P, Na, Mg, Fe, I, Mn, Zn, Co, Vitamins A, D, and E) and cobalt iodized salt (99.0% NaCl; 70 mg/kg I; 40

mg/kg Co). Steers were slaughtered when they were visually appraised by a representative of the abbatoir to have at least 4 mm of backfat. Carcass data collected were carcass weight, backfat thickness, dressing percentage and loin eye area.

Biweekly samples of diet components were composited before analysis. Dry matter (DM) content of lupins, soybean meal, barley and hay were determined by drying at 90°C for 24 hours. Silage DM was determined after drying at 60°C for 48 hours and correction for volatile fatty acid (VFA) loss (Dulphy and Demarquilly, 1981). Acid detergent fiber (ADF) and neutral detergent fiber (NDF) were determined[5] as described by Van Soest et al. (1991). Crude protein was determined by a macro Kjeldahl method (AOAC, 1990). Protein N, water soluble N, NPN, ammonia and VFA were determined as described previously by Murphy et al. (1992). Gross energy was measured using an isoperibolic oxygen combustion bomb calorimeter (Parr Instrument Co., Moline, Ill., model # 1261). Metabolizable energy (ME) of the silage was calculated using the method described by McQueen and Martin (1981) for digestible energy (DE) and the DE value was corrected for urinary and methane energy losses as described in (National Research Council (NRC) 1984). Buffer insoluble nitrogen (BIN) was determined by the method of Krishnamoorthy et al. (1982) and acid detergent insoluble nitrogen (ADIN) was determined as described by Van Soest et al. (1991). BIN and ADIN were conducted on ground samples (1 mm) and on the samples with particle sizes as presented to the steers. Alkaloid levels (lupanine and 13-hydroxylupanine) were determined[6] by the method described by Harris and Wilson (1988). Ether extract was determined by (Tecator Soxtec System HT6, Hoganas,

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5. analysis conducted by J. Keough, Agriculture Canada, Fredricton.

6. analysis conducted by B. Grimmelt, Atlantic Veterinary Col-

Sweden). Samples were ashed at 450 °C for 4.5 hours. Non-structural carbohydrate (% of DM) was calculated for each supplement by the equation; 100 - (CP % + ether extract % + NDF% + ash%)

Two nonlactating Shorthorn heifers with rumen cannulas were used to determine ruminal dry matter and nitrogen degradation of the raw lupin, roasted lupin, soybean meal and grass silage. Cannulation was completed 2 months prior to the start of the trial.

The heifers were fed 8 kg of grass silage twice daily (800 and 1600 hours) plus equal portions of raw lupin, roasted lupin and soybean meal. Approximately 5 g of each supplement (as-fed particle size) or 15 g of grass silage were placed in dacron bags (42 μm pore size, B&SH Thompson, Scarborough, Ontario) measuring 9 cm by 14 cm. The silage was chopped through a Hobart slicer (model # PD-70, Hobart Canada, Don Mills, Ont.). Each dacron bag was heat sealed and clamped at the top with a plastic clip. The bags were randomly attached at one of four sites on a 38 cm nylon line (91 kg test weight). The nylon line and dacron bags were attached to a pulley which was suspended in the rumen on a 53 cm nylon line. The samples were incubated in the rumen for 0.1, 1, 2, 4, 8, 18, 24 or 48 hours. One bag per test feed was placed in the rumen of each heifer for each incubation period. The bags were inserted in reverse order, beginning with the 48 hour incubation, so that all bags were removed at t = 0 and immediately immersed in an ice bath. The bags were washed for 2 cycles (including the rinse cycle) in a washing machine (Whirlpool, model # 39080), dried at 55°C for 48 hours and DM disappearance was determined. Samples were then ground by mortar and pestle prior to N determination by macro Kjeldahl. Degradation rates for N and DM were determined as described by Orskov and McDonald (1979).

Rumen fluid ammonia, pH, VFA and gas production were measured in vitro. Four samples of each diet (0.44 g DM grass silage plus supplements supplying CP at 6.5 % of silage DM) were placed in Nalgene tubes. The grass silage was chopped through the Hobart slicer but the supplements were the particle sizes as fed. Rumen fluid was obtained prior to the morning feeding from a heifer fed twice daily, for 12 days, a diet of red clover silage plus 1 kg d^{-1} of a mixture of raw and roasted lupin. Rumen fluid was strained through 3 layers of cheese cloth into a glass bottle filled with CO_2 and placed in a 39 °C water bath. Rumen fluid was immediately mixed in a 1:1 ratio with a buffer solution (39.2 g $NaHCO_3$, 28.0 g $Na_2HPO_4.H_2O$, 1.88 g NaCl, 2.28 g KCl, 0.48 g $MgSO_4.H_2O$, 0.16 g $CaCl_2$ dissolved in 4 liters of distilled water infused with CO_2), and CO_2 was added to the mixture. After addition of 25 ml of rumen fluid:buffer mixture to each Nalgene tube, the tubes were sealed with rubber stoppers that were pierced by an 18 gauge needle attached to a 60 cc syringe, for measurement of gas production. The tubes were placed in a water bath maintained at 39°C and were removed from the bath after 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 and 4.0 hours, plus four tubes per feed which were not incubated in the water bath. Four tubes containing rumen fluid buffer mixture only (control) were incubated and removed at each time period to allow correction for ammonia production from rumen fluid. Immediately after removal of the tubes from the bath, pH and gas production were measured. Gas volume was determined as the number of ml displaced in the syringe. Fermentation was arrested by addition of 1 ml of 5 % mercuric chloride. Tubes were centrifuged (3,000 x *g* for 15 minutes) and supernatant was collected for ammonia determination. A 5 ml sample of supernatant was treated with 1 ml of 25 % metaphosphoric acid (HPO_3) and centrifuged (15,000 x *g* for 15 minutes) for VFA analysis. Ammonia N was measured by autoanalyzer as described above. Volatile fatty acids were measured by gas chromatograph (model # 5890A, Hewlett-Packard Co.,

Avondale, PA) using a column packed with 80/120 chromosorb W-Acid Washed coated with 10% SP 1200 and 1% H_3PO_4. The 2 m coiled column was 0.635 cm in outer diameter with a flow rate of 20 ml min^{-1} of hydrogen gas (Supelco Separation Technologies, Supelco Inc., Bellefonte, PA).

All data from the feeding trial, randomized incomplete block design, were subjected to analysis of variance using the General Linear Model (GLM) procedure (Statistical Analysis Systems Institute (SAS), 1988). Data from the growth and finishing phases of the feeding trial were analyzed separately and then combined to determine overall performance. The model included treatment and pen as factors with initial weight as a covariate. The numbers within cells were unequal (number of animals per treatment varied among pens) and the data were analyzed by fitting constraints. Significant treatment effects were determined at $P < 0.05$ and differences among means were tested, with the residual error term, using the PDIFF option of SAS (1988). Rumen fluid parameters were subjected to analysis of variance with a completely randomized design using Genstat 5 (1990). Factors used were feed, time and their interaction. Time and feed x time were analyzed for linear, quadratic and cubic effects. The Maximum Likelihood Program (Ross, 1987) was used to evaluate differences in position of degradation curves of N and DM in dacron bags.

4.4 RESULTS

The CP content of the lupins was lower than that of the SBM. Lupins were higher in NDF and ADF compared to the SBM (Table IX). Percentages of ether extract and gross energy were higher for lupin than for SBM. Lupin had a higher non-structural carbohydrate content than for SBM. Total alkaloid levels in the raw and

roasted lupin were low. The silage had a lactic acid fermentation with low pH and ammonia content, and a moderate CP percentage. Silage protein N of 74.3 % of total N was high with all of the water soluble nitrogen consisting of NPN.

Buffer soluble nitrogen (100 - BIN) was highest for raw lupin followed by roasted lupin and SBM (Table X). The reduction in solubility due to roasting was 33.9 % with the as-fed particle size. There was a substantial increase in BSN when raw lupin was ground through a 1 mm screen. Roasted lupin and SBM showed only a small increase in buffer soluble nitrogen (BSN) after grinding. Acid detergent insoluble nitrogen in the as-fed particle size, was highest for raw lupin followed by roasted lupin and SBM. Grinding to 1 mm particle size reduced the ADIN values of raw and roasted lupin to 3.31 and 3.46 compared to 2.82 for SBM. Particle sizes of the three supplements (Table XI) varied, with the raw lupin having the largest mean particle size.

The soluble DM fraction and the more slowly degradable fraction of raw and roasted lupin were similar (Table XII). The rate of degradation of DM was slower ($P < 0.05$) for roasted lupin than for raw lupin. Soybean meal and grass silage had lower ($P < 0.05$) soluble DM fractions than did the lupin treatments.

There were no significant differences ($P > 0.05$) in N degradation rates among RL, ROL or SBM (Figure 1 and Table XI). The degradation curve for roasted lupin was significantly lower than for raw lupin ($P < 0.05$). The soluble N fractions of the raw and roasted lupin were not significantly different. The soluble CP fraction and degradation curve for soybean meal were significantly lower than for raw and roasted lupin. The effective degradability of CP (fractional outflow rate of 0.05 h^{-1}) was highest for raw lupin (86.7%) with roasted lupin (82.3 %) being slightly lower.

In vitro rumen fluid pH of all diets declined linearly with time (Fig. 2). The SBM diet had a significantly higher ($P > 0.05$) gas production than ROL and SIL diets. All diets had significant increases in gas production over time with significant ($P < 0.05$) linear, quadratic and cubic effects (Fig. 3). There was a significant feed x time interaction ($P < 0.001$) for ammonia production (Fig. 4) with linear, quadratic and cubic effects ($P < 0.001$). Total VFA concentration was significantly higher ($P < 0.001$) for the supplemented diets compared to the grass silage only diet (Table XV). Total VFA and molar percentages of individual VFA's had a significant effect due to time ($P < 0.001$) with significant linear, quadratic and cubic effects. There were no significant differences in molar percentages for propionate among the four diets. A significant feed x time interaction ($P < 0.001$) for acetate, butyrate and valerate was detected.

During the growth phase, steers fed RL, ROL and SBM had significantly ($P<0.05$) higher daily gains compared with those fed the SIL diet (Table XIII). Steers on the SBM diet had daily gains which were significantly higher than for the steers fed RL. Steers fed the ROL diet had daily gains that were not different from the steers fed RL or SBM. The number of days to reach final weight for the growth phase was significantly lower ($P < 0.05$) for steers on the supplemented diets compared to steers on the SIL diet. One animal on the SBM diet was removed from the trial due to reasons unrelated to the experiment. Steers on the SIL diet consumed significantly ($P < 0.05$) more silage DM than did the raw and roasted lupin supplemented steers. There were no significant differences in total dry matter intake (DMI) among the steers on the four diets.

Estimated metabolizable energy intake was significantly higher for steers on the RL, ROL and SBM diets compared to those on the SIL diet. There were no significant differences in ME intake among steers on the supplemented diets. Steers fed ROL and

SBM consumed similar amounts of total CP but they consumed significantly ($P < 0.05$) more CP than steers fed SIL and RL diets. Steers fed RL consumed significantly more CP than those fed SIL. Crude protein intake calculated as a percentage of silage DMI for RL, ROL and SBM diets were 6.14, 6.42 and 6.33 %, respectively.

In the finishing phase, there were no significant differences due to treatment on daily gain, carcass weight, dressing percentage or loin eye area (Table XIV). There were no significant differences for DMI or metabolizable energy intake among steers on the four diets. There was a significant difference ($P < 0.05$) in CP intake with steers fed RL and SBM consuming more CP than did the steers on the SIL diet. Crude protein intakes of steers fed roasted lupin were not different from those fed the SIL, RL or SBM diets.

In the overall experiment there were no significant differences in daily gain, dry matter intake or days to slaughter among steers on the four treatments. However, there was a tendency for SBM-fed steers to have lighter slaughter weights and require fewer days to attain adequate fat cover.

4.5 DISCUSSION

During the growth phase of this study, steers fed only silage consumed less DM than predicted by the NRC (1984) for large frame steers. The steers consumed more silage DM but had similar CP intake to that recorded by Petit and Flipot (1992) who fed a timothy silage to steers that resulted in a daily gain of 0.68 kg d^{-1}, which is identical to the daily gains observed in this trial. Dry matter intake of silage is generally lower than that of hay which may partially explain lower than predicted intakes (Rook and Gill, 1990; Petit and Flipot, 1992). McDonald et al. (1991) suggest that with silage diets containing high concentrations of CP and NPN, significant

reductions in DMI can result from excessive absorption of ammonia from the rumen. They also indicated that DMI of silages can be decreased by an average of about 30 % compared to fresh grass and that reductions are greater with grass than with legumes. Even though this silage had relatively low levels of NPN, the rumen fluid ammonia concentrations observed in vitro appear to broadly support the theory that ammonia production from the silage diet would be higher than the optimum suggested by Clark et al. (1992) for microbial incorporation. Potentially high in vivo rumen NH_3 may have resulted in silage DMI being limited.

Supplementing silage with RL and ROL significantly depressed silage DMI by 12.0 and 8.7 %, respectively. This depression in silage DMI was not consistent with reports from other authors such as Veira et al. (1990) who found increases in silage DMI with protein supplements such as fishmeal and soybean meal. The NRC (1984) suggested that the daily crude protein intake from supplemented diets is sufficient to support daily gains of 1.36 kg, but daily gains observed here were much lower.

Thomas and Gill (1988) suggested that the rapidly degradable N and the lower energy values in silage, when it is the sole feed, can result in lower microbial synthesis. Veira (1985) indicated that this lower microbial efficiency results in reduced quantities of amino acids being supplied to the animal than the CP percentage of the diet would suggest, which could limit daily gains.

Lupin protein, like soybean, contains relatively high level of globulins and lesser amounts of albumins (Oomah and Bushuk, 1983), which are highly soluble in vitro and in situ (Aufrere et al., 1991). Freer and Dove (1984) found in an in situ study that particle size of lupin affected the rate of N degradation more than the rate of non-nitrogenous dry matter disappearance. They observed that lupin with finer particle sizes had a higher rate of disappearance of N than medium or coarsely ground lupin. Roasted lupin appeared to shatter more readily than raw lupin and as a result ROL had

the largest percentage of particles under 1 mm, with SBM intermediate. The reduced solubility with the larger particle sizes of the raw lupin (Table X) observed in this study supports the results of Freer and Dove (1984) and suggests that the reduction of N solubility and the potential decrease in rumen degradability could partially be accomplished with minimal processing of the lupin seed. The in vitro ammonia concentrations (Fig. 4) did not display the characteristic peak observed in vivo by other workers (Aronen, 1991; Nicholson et al., 1992; Robinson et al., 1992). The gradual increase in ammonia concentration may be partially due to particle size, as microbes would not have access to the nitrogen at the same rate as feedstuffs ground to 1 mm.

Van Soest (1982) indicated that globulins and albumins are more sensitive to heat denaturation than are prolamines or glutelins. Heating lupin, in which globulins represent the largest protein fraction, should result in decreased solubility and rumen degradability. However, Kung et al. (1991) observed that higher temperatures and longer heating times appeared to be required to decrease ruminal degradation of lupin, relative to SBM or cottonseeds. They suggested that lupin protein may have a reduced susceptibility to denaturing with heat or interactions with carbohydrates.

The roasted lupin used in this study had a lower N solubility than raw lupin in vitro and a nonsignificant decrease ($P > 0.05$) with the dacron bag procedure. Equally as important, the fractional rate constant for the potentially degradable N fraction was lower than for raw lupin. This suggests that there would be a more sustained release of N from roasted lupin (CP degradation was 9.9 % lower for roasted lupin than for raw lupin for incubation times 0.1 through 4.0 hours), decreasing the potential for excessive amounts of N being rapidly released in the rumen. The effective degradation of nitrogen of roasted lupin was only slightly less than that for raw lupin which indicates that the animals did not necessarily benefit from rumen escape of roasted lupin N.

Roasting lupin at a higher temperature than that used in this study may further reduce N solubility and degradability, particularly since there was no heat damage detected at this temperature (105 °C exit temperature).

Rooke and Armstrong (1989) suggested that the rumen bacteria of cattle on silage diets may respond to additional protein N. Rooke et al. (1986) and Veira et al. (1990) demonstrated that protein N supplied by soybean meal stimulated microbial N synthesis and this may have contributed to the increased daily gains of the SBM fed steers in this study. If gas production is assumed to be a measure of microbial activity, the significantly higher concentration of gas produced by the SBM diet suggests that microbial activity was enhanced by the SBM relative to the response of ROL and SIL diets. However, higher gas production suggests that more of the energy from the SBM diet may have been diverted to methane production in the rumen (Czerkawski, 1969).

The silage fed in this trial had a lower concentration of ME compared to values for grass silages reported by McDonald et al. (1991). According to the NRC (1984), the ME concentration of the supplemented diets were adequate to support a daily gain of 0.91 kg. The observed daily gains of RL and ROL were lower and the daily gains for SBM were higher than this predicted value. Raw lupin contained the most soluble N of the three supplements and it resulted in the lowest daily gains. Soybean meal contained the least soluble N and it resulted in the highest daily gains. Energy content appeared to be the most limiting factor in daily gain but nitrogen degradability may have influenced the microbial efficiency and ultimately the performance of the steers.

For maximum nitrogen utilization in the rumen, energy and protein availabilities need to be synchronized. The grass silage had a large portion of rapidly available N which would have required a readily available source of energy (Chamberlain et al., 1985). Lupin contributed 20 % of the ME in the ROL and RL diets. The higher NSC content of the lupin compared to SBM should provide slightly more rapidly available

energy for the microbes but the low inclusion rates of the supplements and the decreased silage DM intake for the lupin diets resulted in similar intakes of NSC. Valentine and Bartsch (1987) indicated that lupin has a starch content of less than 10 % and that the major carbohydrate in the lupin kernel is ß(1-4) galactan. They suggested that the ß(1-4) galactan in lupin grain may ferment more slowly in the rumen than does barley starch. Total VFA concentration of the supplemented diets was higher than SIL which indicates that lupin will increase VFA production similar to soybean meal without affecting the acetate:propionate ratio. The low level of energy available from the silage plus the potentially slower rate of energy availability from lupin may have limited the ability of the microbes to utilize the N in the grass silage and raw lupin diet. The slower rate of N availability from roasted lupin may have matched the slower rate of energy availability from silage and lupin to yield more efficient microbial synthesis.

Baumgardt (1970) suggested that DMI would peak with a diet ME concentration of 10.5 MJ kg^{-1}DM and that intake decreased with lower and higher ME concentrations. Metabolizable energy concentrations on all four growing diets were lower than this optimal level. Holzer et al. (1986) fed steers a diet containing 9.6 MJ kg^{-1}DM which, due to reduced fermentable energy, resulted in an increased loss of ammonia from the rumen and may have reduced microbial protein synthesis. Their study indicated that with low ME diets, as observed in the growth phase of this study, protein which is slowly degraded would be preferable and that sources of rapidly degradable N such as that found in raw lupin are more suited to high energy diets (> 10.5 MJ kg^{-1} DM).

In the finishing phase, there were no differences in average daily gain ($P > 0.05$) among steers in the four treatments even though the steers previously fed SIL consumed significantly less CP. This suggests that protein was not a limiting factor. Estimated ME concentration was approximately 11.6 MJ kg^{-1}DM for all four

diets which is higher than that suggested by Baumgardt (1970) for maximum DMI. Using steers with lighter starting and finishing weights than the steers in this study, Barker et al. (1985) obtained an increased gain of about 0.2 kg d^{-1} with lupin supplementation of a barley and hay diet compared to the gain with barley and hay alone (minimum ME concentration of 11 MJ kg^{-1}DM). However, Steen (1989) observed that in most experiments with steers on finishing rations of grass silage and barley, only cattle implanted with growth promotants showed positive response to protein supplementation.

It has been demonstrated that following a period of growth restriction and a sufficient period of realimentation, cattle can exhibit compensatory gain (Fox et al., 1972; Wright and Russel, 1991) and eventually reach the same body composition as unrestricted controls. Steers fed silage-based growing rations supplemented with various protein sources (Steen, 1989; Gibb and Baker, 1991; Petit and Flipot, 1992) have exhibited compensatory gain in a subsequent finishing phase. In the current study, steers fed raw lupin diets appeared to have exhibited compensatory gain. Steers previously fed the SIL diet had similar daily gains but body composition did not appear to recover as they tended to have a lower dressing percentage, backfat and loin eye area.

When the results of the growing and finishing phases are combined, the net result was no difference in overall body weight gain or carcass traits for the experiment. Daily gains were approximately 0.08 kg d^{-1} higher for the supplemented diets; however, the small number of animals per treatment reduced our capability to detect small differences among treatments.

4.6 CONCLUSIONS

Results of this trial indicate that roasting will decrease the solubility and rumen degradability of lupin seed protein. In growing beef cattle rations, roasted lupin supplementation of grass silage diets can produce similar performance to soybean meal supplemented diets. One area of further research would be to determine the roasting temperature and time for lupin which would yield the optimum percentage of undegraded protein without incurring excessive heat damage and evaluate the cost effectiveness of roasting versus feeding raw lupin seeds. Raw lupin crude protein is rapidly degradable and as a result, raw lupin may be most beneficial in a protein supplement with a rapidly degradable energy source or in diets with low protein or at least more slowly degradable protein than that normally found in grass or legume silages. Minimal processing (e.g. coarse rolling) of the lupin seed would be useful in decreasing crude protein degradability.

Table IX. Chemical composition of feed ingredients.

Parameter[y]	Raw Lupin	Roast Lupin	Soybean Meal	Grass Silage	Barley	Timothy Hay
Dry Matter (%)	93.8	92.6	92.8	31.0	91.8	94.6
Crude protein (% of DM)	35.5	35.7	50.6	14.8	11.8	8.5
Neutral detergent fiber (% of DM)	17.5	17.7	10.4	50.3	19.4	57.1
Acid detergent fiber (% of DM)	13.9	13.4	6.1	33.5	7.7	35.4
Gross energy (MJ kg^{-1}DM)	20.9	21.1	16.8	19.6	19.9	18.0
Metabolizable energy (MJ kg^{-1}DM)	13.1	13.1	12.7	9.1	12.7	8.8
Ether extract (% of DM)	10.1	9.8	2.2	-	-	-
Alkaloid (% of DM)	.019	.011	-	-	-	-
NSC (% of DM)	32.7	32.8	28.3	24.6[z]	-	-
Ash (% of DM)	4.2	4.0	8.5	-	-	-
pH	-	-	-	4.1	-	-
Protein N (% of total N)				74.3		
Water soluble N (% of total N)				25.7		
Non protein N (% of total N)				25.7		
Ammonia (% of total N)				5.9		
Ethanol (% of DM)				0.26		
Acetic acid (% of DM)				0.93		
Lactic acid (% of DM)				3.33		

[z] calculated assuming ether extract = 2.6 and ash = 7.2 (Sniffen et al.1992)

[y] NSC = nonsturctural carbohydrates
biweekly samples were composited, two subsamples of composite were used for analysis.

Table X. Buffer soluble nitrogen and acid detergent insoluble nitrogen with particle sizes of supplements, as fed and 1 mm grind.

	Raw Lupin	Roasted Lupin	Soybean Meal	Grass Silage
	------% of total nitrogen ---------			
BSN[z] (as fed)	46.0	30.4	12.9	50.7
BSN (1 mm)	69.8	35.8	15.5	nd
ADIN[y] (as fed)	9.67	7.42	4.48	12.11
ADIN (1 mm)	3.31	3.46	2.82	nd

[z]Buffer soluble nitrogen
[y]acid detergent insoluble nitrogen

nd = not determined.

biweekly samples of feeds were composited, three subsamples of composite were used for each analysis.

Table XI. Particle size of supplements (% of total weight).

	Raw Lupin	Roasted Lupin	Soybean Meal
< 1 mm	28.3	57.9	39.6
1 - 2 mm	31.9	29.8	55.2
2 - 4 mm	35.4	11.5	5.2
> 4 mm	4.5	0.8	0.0

Table XII. Dry matter and nitrogen disappearance in the rumen as predicted by the dacron bag procedure.

Fraction	Raw Lupin	(SE)	Roasted Lupin	(SE)	Soybean Meal	(SE)	Grass Silage	(SE)
Dry matter fractions (% of total)								
soluble	35.3	(2.11)	36.7	(2.83)	30.4	(1.94)	29.2	(0.76)
potentially degradable	66.6	(2.99)	66.9	(4.50)	72.2	(2.62)	54.5	(1.74)
undegradable	20.4		21.2		20.2		41.4	
Nitrogen fractions (% of total)								
soluble	51.2	(2.25)	43.8	(3.44)	10.4	(2.29)	57.0	(1.96)
potentially degradable	50.4	(2.91)	56.6	(5.15)	93.3	(3.00)	31.0	(2.71)
undegradable	13.3		17.7		24.6		20.2	
Fractional rate constant (h^{-1})								
dry matter	0.100	(0.01)	0.085	(0.02)	0.109	(0.01)	0.059	(0.01)
nitrogen	0.119	(0.02)	0.092	(0.02)	0.115	(0.01)	0.138	(0.04)
Effective degradation[z]								
dry matter	79.6		78.8		79.8		58.6	
nitrogen	86.7		82.3		75.4		79.8	

[z] Effective degradation at .05 h^{-1} ruminal fractional outflow rate (k) in equation $P = a + (bc)/(c + k)$; (Orskov and McDonald, 1979).

SE = standard error, n = two observations per feed per incubation period.

Table XIII. Growth performance and feed intake of steers in the growth phase.

Diet[x]	SIL	RL	ROL	SBM	sem[y]
Start wt. (kg)	234.3	231.3	237.7	237.6	9.99
Final wt.[z] (kg)	335.4[a]	339.8[a]	346.7[ab]	353.1[b]	4.03
Daily gain[z] (kg d^{-1})	0.68[a]	0.80[b]	0.87[bc]	0.95[c]	0.04
Days on feed[z]	146[a]	130[b]	128[b]	123[b]	6.91
Dry matter intake (kg d^{-1})					
silage[z]	5.26[a]	4.63[b]	4.80[bc]	5.00[ac]	0.12
protein supplement[z]	0.00	0.80[a]	0.87[b]	0.62[c]	0.01
total	5.26	5.43	5.67	5.62	0.13
Crude protein intake (kg d^{-1})					
silage[z]	0.78[a]	0.68[b]	0.71[bc]	0.74[ac]	0.02
protein supplement[z]	0.00	0.27[a]	0.31[b]	0.34[c]	0.01
total[z]	0.78[a]	0.95[b]	1.02[c]	1.08[c]	0.02
ME intake[z] (MJ kg^{-1}DM)	47.6[a]	52.4[b]	54.9[b]	53.2[b]	1.21
NDF intake (kg d^{-1})	2.67	2.49	2.58	2.61	0.06
NDF intake (% of BW)	0.94	0.87	0.88	0.87	0.00

[z] means within a row not sharing a common superscript differ ($P < 0.05$).

[y] sem = standard error of mean; SIL, RL and ROL n= 7; SBM n = 6.

[x] SIL=silage only, RL=raw lupin, ROL=roasted lupin,SBM=soybean meal.

Table XIV. Performance of steers in the finishing phase and the overall experiment.

Diet[x]	SIL	RL	ROL	SBM	sem[y]
Finishing Phase					
Final wt. (kg)	502.5	511.1	514.6	485.4	12.08
Daily gain (kg d^{-1})	1.39	1.45	1.35	1.25	0.09
Days on feed	100	103	115	100	8.61
DMI (kg d^{-1})	8.26	8.39	8.01	8.33	0.29
CP intake[z] (kg d^{-1})	0.89[a]	1.07[b]	1.01[ab]	1.08[b]	0.04
ME intake (MJ d^{-1})	95.0	97.3	93.3	96.6	3.61
Overall Performance					
Carcass wt. (kg)	272.8	289.0	287.9	276.2	9.61
Dressing percentage	54.3	56.5	56.0	56.9	1.12
Backfat (mm)	4.1	8.6	4.8	7.2	1.09
Loin eye area (cm^2)	70.5	82.6	84.4	81.1	4.17
Daily gain (kg d^{-1})	1.00	1.08	1.08	1.09	0.03
Days on feed[w]	256	236	244	2	2 1 6.00
DMI (kg d^{-1})	6.42	6.70	6.78	6.79	0.10

[z] means within a row not sharing a common superscript differ ($P < 0.05$).

[y] sem = standard error of mean; n = 7 for SIL,RL and ROL, N = 6 for SBM.

[x] SIL=silage only, RL=raw lupin, ROL=roasted lupin, SBM=soybean meal, DMI = dry matter intake.

[w] P value for days on feed = .1383

Table XV. Least square means for rumen fluid volatile fatty acids measured in vitro in response to protein supplementation of grass silage.

						Significance[z]								
							Feed			Time	Interaction			
Volatile fatty acids	RL	ROL	SBM	SIL	SEM	Sign.	D	E	F		F x T	D	E	F
Total VFA	64.34	64.31	64.81	61.24	0.546	*	NS	NS	NS	LQC	NS	-	-	-
Molar concentration of VFA's (%)														
Acetate	66.60	66.60	66.53	66.62	0.041	-	-	-	-	-	*	NS	QC	Q
Propionate	20.20	20.21	20.21	20.19	0.027	NS	NS	NS	NS	LQC	NS	-	-	-
Butyrate	11.00	10.98	11.08	11.04	0.019	-	-	-	-	-	*	NS	QC	QC
Valerate	2.21	2.15	2.18	2.15	0.009	-	-	-	-	-	*	NS	C	C
Acetate:propionate	3.32	3.32	3.32	3.33	0.006	-	-	-	-	-	*	NS	NS	NS

[z] significance levels: * = $P < 0.05$, NS = not significant ($P > 0.05$), L = linear, Q = quadratic, C = cubic; Sign. = significance of main effect of feed; feed SS were segregated into orthogonal comparisons, D = RL vs ROL; E = RL vs SBM; F = ROL vs SBM; F x T = feed x time interaction, SEM = standard error of mean.

RL = raw lupin; ROL = roasted lupin; SBM = soybean meal; SIL = silage only.

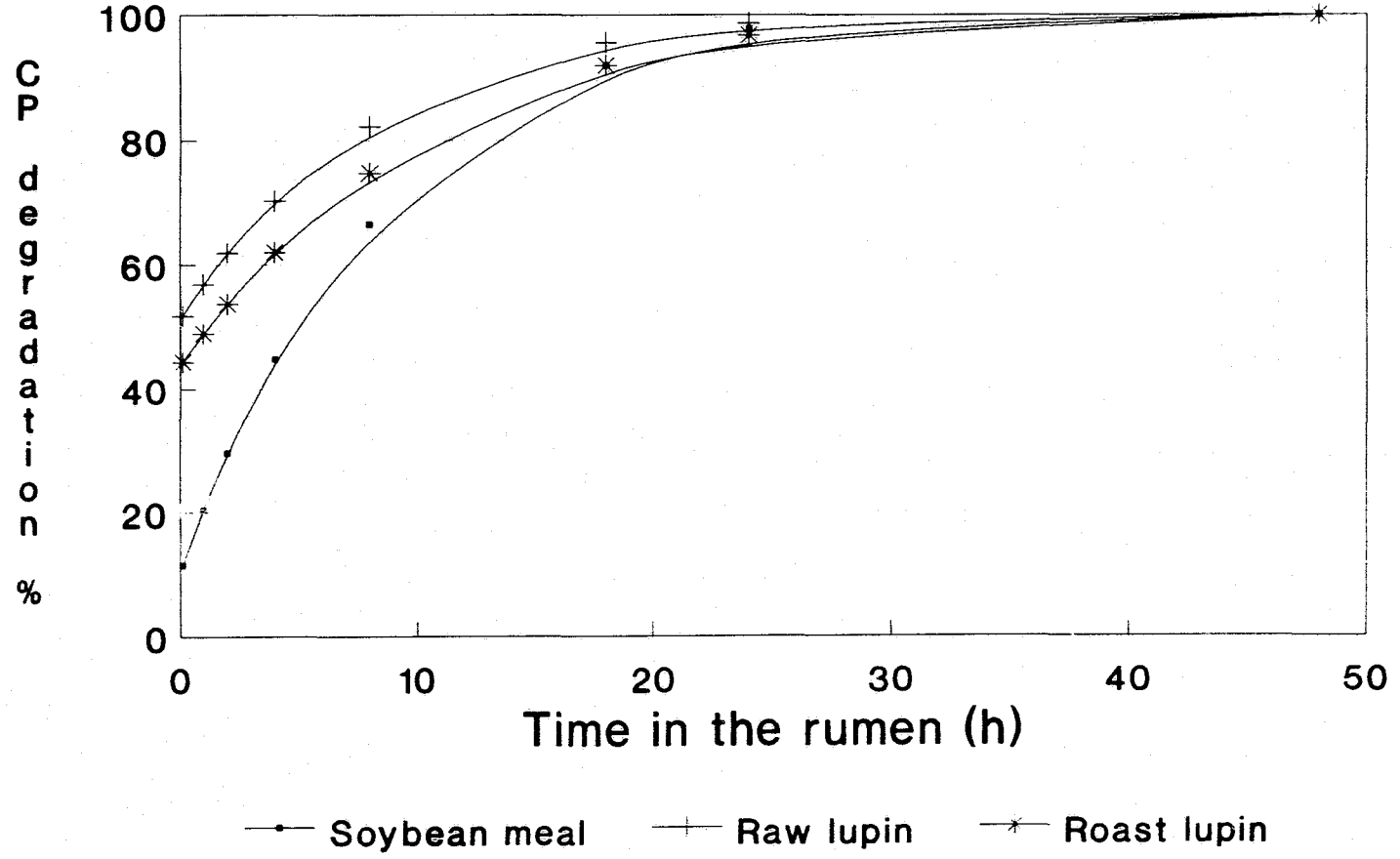

Fig 1. Crude protein disappearance of supplements predicted by dacron bag procedure.

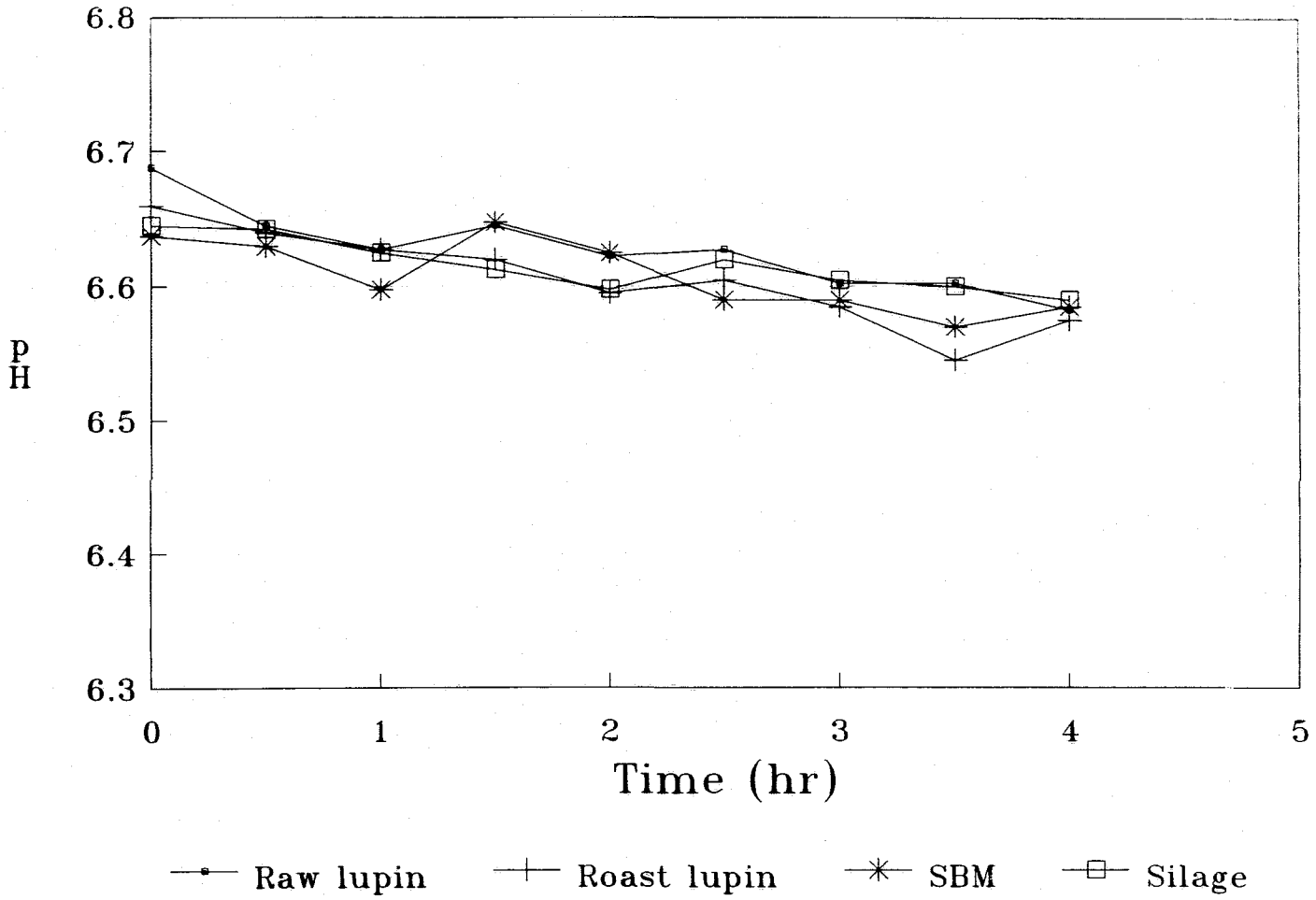

Fig 2. Influence of protein supplements on rumen fluid pH measured in vitro.
(SE = 0.016)

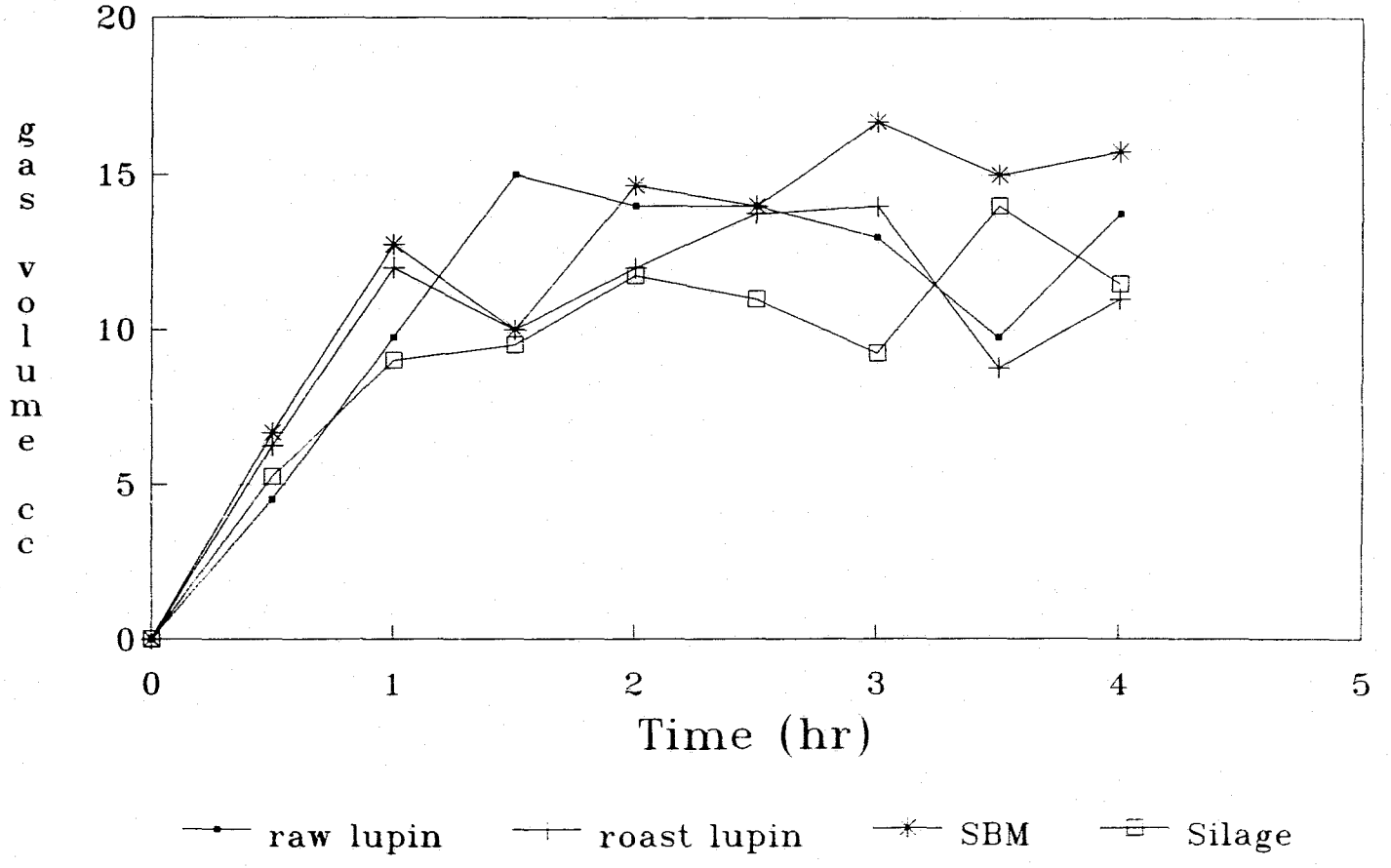

Fig 3. Influence of protein supplementation of grass silage on in vitro rumen fluid gas volume.

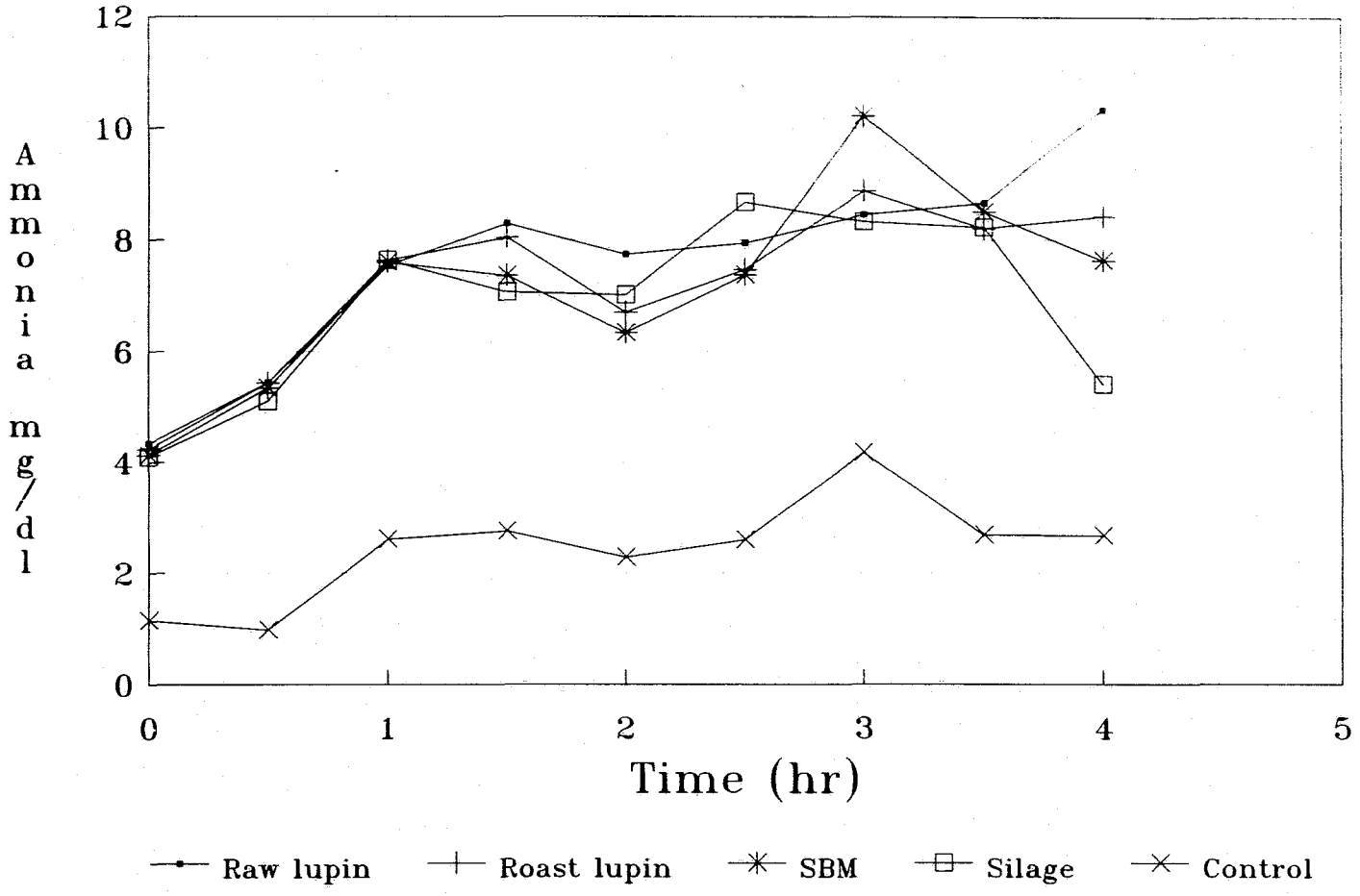

Fig 4. Influence of protein supplementation of grass silage on in vitro rumen fluid ammonia concentration.

5. SUMMARY OF RESULTS AND CONCLUSIONS

Sweet white lupin (Lupinus albus) has an indeterminant growth pattern with pod maturation apparently triggered by drought conditions or high air temperatures (> 26°C). During years when pod and seed maturation is delayed, lupin forage harvested as silage could provide high quality legume forage for ruminants.

5.1 LUPIN SILAGE

Whole plant lupin harvested and ensiled at various stages from second pod stage to senescence resulted in silages with acceptable fermentation characteristics including lactic acid type fermentations and low pH. The earliest stage of harvest yielded silage containing a higher percent crude protein (CP) and lower fiber level than silage from lupin at later stages of maturity. However, silage from the early harvest had negative attributes such as very high lactic acid contents and low pH which may limit dry matter intake.

Harvesting immature lupin silage (second pod stage) also sacrifices dry matter, CP and protein nitrogen (N) yield per hectare compared to later stages. Maximum CP, protein N and metabolizable energy (ME) yield per hectare was achieved by silage harvested from lupin at senescence. Delaying harvesting has a number of advantages in addition to maximizing yields; the lupin plant that is approaching the mature stage does not have a substantial decrease in CP but it does increase in protein N. Preservation of the true protein in silages may contribute to increased microbial synthesis of protein (Veira and Charmley, 1989). Lupin and oat planted in a ratio of 3:1 did not result in

improved silage quality and the CP content was substantially lower than in the pure lupin silage. Field wilting times were marginally improved compared to the lupin forage harvested at earlier stages.

Steers fed lupin silage had similar DM intakes of silage compared to steers fed a grass-legume silage, indicating no palatability problems with the lupin silage. There were no significant ($P > 0.05$) differences in daily gain or carcass characteristics between steers fed the lupin or a grass-legume silage. Therefore, lupin silage could replace a grass-legume silage in feedlot rations resulting in similar growth performance and carcass quality.

The metabolizable energy content of the lupin silages in the experimental silo trial as well as that fed in the steer feeding trial was relatively low. Due to relatively low ADF value, (ADF values were used to predict ME values) the earlier cut (immature) lupin, in the experimental silo trial, had the highest predicted ME value (10.3 MJ ME kg^{-1} DM) of all the silages evaluated. However, Miller (1982) reported that as much as 26 % of the ME available from silage would be in the form of lactic or volatile fatty acids. AFRC (1992) predicted a fermentable metabolizable energy (FME) value by discounting the energy from organic acids in silages as being highly digestible in the rumen but not fermentable to yield ATP for the microbes. They list a grass-clover silage with an ME of 9.8 MJ kg^{-1} DM, as having a FME of 7.6 MJ kg^{-1} DM, which reflects the lower energy actually available to the microbes for productive purposes. The immature lupin silage, in the experimental silo trial, had 23.4 % of the DM as volatile fatty acids which suggests that the ME available for tissue synthesis may not be altered but there may be a deficiency of energy for microbial synthesis.

Lupin silage had a relatively low ruminally soluble CP fraction but a significantly faster rate of N degradation (24 % h^{-1}) than the grass-legume silage (10 % h^{-1}). Non-protein nitrogen (NPN) in silage consists primarily of ammonia, short

peptides and amino acids. The lupin silage incubated in the rumen consisted of 51.6 % NPN, which could lead to higher levels of rumen ammonia if it is not efficiently captured by rumen microbes. The slow release of energy from potato starch may have led to uncoupled protein and energy metabolism by microbes. There may also have been less energy available for microbial synthesis if a portion of the ME was expended in urea synthesis due to excess ammonia production by the rumen (McLellan and McGinn, 1983). In general, rapidly degradable protein sources are matched with rapidly degradable energy sources. Similarly, the slow degradation of potato starch may have been more closely synchronized with the slower grass silage CP degradation rate, resulting in a more efficient capture of N. As a result there may have been less rumen ammonia production allowing more dry matter intake than on the lupin silage diet. Maximum dry matter intake for grass and lupin silages occurred with barley supplementation, presumably due to more fermentable energy. However, the higher dry matter intakes did not contribute to significantly higher daily gains of the steers.

There was a significant effect on dry matter intake due to energy source, with barley fed steers having significantly higher dry matter intakes compared to steers fed potato supplemented diets. However, a slight increase in DM content of the potatoes would negate the significant difference. Sauter et al. (1980) observed up to a 22 % decrease in dry matter intake when potato waste replaced barley in a steer finishing ration. These authors speculated that the decrease in performance when barley was replaced by potato waste may have been a result of the high moisture content of the ration (77.2 % moisture) and that rumen capacity may have been a limiting factor when 50 % of DM intake consisted of potato waste. The lupin-potato diet in the current study had 76.5 % moisture, and this high moisture level may have stimulated digesta passage to the small intestine.

5.2 HEAT TREATMENT OF LUPIN SEEDS

A steer feeding trial demonstrated that growing steers fed silage supplemented with the protein sources raw lupin, roasted lupin or soybean meal had significantly ($P < 0.05$) higher daily gains than steers fed silage only. Steers fed the soybean meal supplemented diet had significantly higher daily gains than the raw lupin fed steers; roasted lupin fed steers were intermediate. Dry matter intakes were lower than the maximum predicted by the NRC (1984); presumably due primarily to the lower intakes normally observed for silages as compared to hay.

Roasting the lupin seeds resulted in a significantly ($P < 0.05$) lower rate of N degradation than for raw lupin. Although protein solubility for raw lupin was substantially decreased with larger particle sizes, rumen undegraded protein predicted by the dacron bag procedure was 17.7 and 13.3 percent for roasted and raw lupin. This level of undegraded intake protein (UIP) suggests that roasting lupins at 105°C will still result in considerable rumen degradation. However, if the particle size had been as large as that of the raw lupin, UIP of roasted lupin might have been increased.

The rumen nitrogen:energy balance of the roasted and raw lupin fed steers may have affected performance. The CP of the roasted lupin was less soluble and more slowly degraded, potentially reducing excess ammonia production and loss. This sustained release of N may also have had a sparing effect on ME, as less energy would be required for urea synthesis and excretion.

The ARC (1980) recommended that maximum microbial yield can be attained with a ratio of 1.25 grams of ruminally degraded nitrogen per MJ of ME. The diets in the growing phase contained 2.09, 2.37, 2.40 and 2.55 grams N MJ^{-1}ME in the SIL, RL, ROL and SBM diets, respectively. This suggests that the supplemented diets increased the rumen degradable nitrogen more than energy. As a result, the potential

was increased for excess ammonia production, even though the N supplied by the lupin and soybean meal would be primarily in the form of true protein. This would result in the lupin diets having a higher ratio of rumen degradable N to ME than soybean meal, thereby possibly explaining the higher daily gain of soybean meal fed steers.

In both steer feeding trials the steers were exposed to air temperatures ranging from + 10 to - 20 °C during the early growth phases of the trial. As a result of the cold enviroment maintenance energy requirements may have been increased (Miaron and Christopherson, 1992), which would have contributed to lower than expected daily gains and higher feed efficiency of the growing steers.

In the finishing phase of the lupin seed supplementation trial, the steers did not appear to respond to the higher protein levels of the RL, ROL and SBM diets. They had daily gains consistent with that predicted by Kozub and Hironaka (1992) based on their total daily energy intake. Although not statistically significant ($P > 0.05$), dressing percentage, loin eye area and backfat tended to be lower for steers initially fed the SIL diet compared to steers fed the supplemented diets. The lower backfat measurements of the steers initially fed the SIL diet indicates that they had a lower proportion of body fat than the steers fed the protein supplemented diets, which can lead to lower dressing percentages.

In each of the steer feeding trials, there were seven animals per treatment. Undoubtedly the small number of observations affected our ability to detect what appeared to be substantial differences in some parameters.

Minimal processing (eg. coarse rolling) could be used in the feeding strategy of raw lupins to reduce ruminal N degradability. As a result of the rapid and extensive rumen degradation of CP, supplementation of grass or lupin silage diets may not be the

most effective use of raw lupin. Raw lupin could be most useful in dietary situations where there may be a lack of rapidly available N, such as in low protein feedstuffs or hay based diets and / or diets containing large proportions of rapidly available energy.

Roasted lupin can replace SBM in growing steer rations but further research is required to determine the optimal roasting temperatures for maximum UIP, without increasing heat damage. Roasted lupin and barley could be used in a supplement for use in silage based diets. The roasted lupin would supply a more sustained release of N than that available from the silage. Barley would supply adequate rapidly available energy primarily for silage N incorporation into microbial protein.

5.3 OVERALL CONCLUSIONS

Lupin can be successfully ensiled with a lactate fermentation at various growth stages from second pod stage to senescence. The high DM and CP yield per hectare indicates that lupin is superior to small grain silages. The chemical composition of lupin silage indicates that it is of high quality and will result in performance of beef steers similar to that of grass-legume silage fed steers. Lupin silage CP is rapidly degradable and as a result supplementation with a rapidly degradable energy source would be desirable.

The CP in raw lupin seeds is rapidly degradable. This suggests that optimal use of raw lupin seeds would be in diets containing a rapidly degradable source of energy or in low protein diets. Roasting can decrease CP degradability of lupin. Roasted lupin could replace soybean meal in growing beef cattle rations resulting in similar animal performance. Lupin is a versatile crop, it can be harvested either as whole plant silage or as a high protein seed; both of which can be utilized in beef cattle rations.

6. REFERENCES

AFRC TECHNICAL COMMITTEE ON RESPONSES TO NUTRIENTS. Report No.9. Nutritive requirements of ruminant animals:protein. Nutrition Abstracts and Reviews (series B) 1992; 62: 787-835.

AGRICULTURE CANADA. Beef carcass grading regulations, amendment. Extract Canada Gazette, Part 2, Vol.126, No.4 ; Feb.12,1992.

AKSLAND GE. Experiences and prospects for lupins in the West and Pacific Northwest. Proc Prospects for Lupins in North America. Univ. of Minnesota 1991.

AKSLAND GE, SHULTZ TA, WEAVER LD. Evaluation of six advanced lines of yield, proximate analysis and rumen digestion. Proc Prospects for Lupins in North America. Univ. of Minnesota 1991: 91-92.

ANDRIEU J, DEMARQUILLY C, LE DU J. Valeur alimentaire de la plante entiere de feverole, de lupin, de pois et de soja sur pied et apres ensilage. Bull Techn C.R.Z.V. Theix, INRA 1982; 47: 19-26.

ANDERSON VL, HANSON T, KREFT B. Lupine bean meal as a protein source for backgrounding steers. North Dakota Farm Res Bull, North Dakota State Univ, 1989; 46: 13.

AGRICULTURAL RESEARCH COUNCIL. The Nutrient Requirements of Ruminant Livestock. London: CAB, 1980.

AGRICULTURAL RESEARCH COUNCIL. Report of the protein group of the Agricultural Research Council working party on the nutrient requirements of ruminants. Commonwealth Agric. Bureaux, Slough, England, 1984.

ARONEN I. Influence of frequency and accuracy of supplement feeding on rumen fermentation, feed intake, diet digestion and performance of growing cattle. 1. Studies with growing bulls fed grass silage ad libitum. Anim Feed Sci Technol 1991; 34: 49-65.

ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS. Official Methods of Analysis. 15th ed. Arlington, VA: AOAC, 1990.

AUFRERE J, GRAVIOU D, DEMARQUILLY C, VERITE R, MICHALET-DOREAU B, CHAPOUTOT P. Predicting in situ degradability of feed proteins in the rumen by two laboratory methods (solubility and enzymatic degradation). Anim Feed Sci Technol 1991; 33: 97-116.

BARKER DJ, MAY PJ, FADLEY PER. Urea, meat meal or lupins as nitrogen supplements to barley and hay diets for yearling cattle at two levels of body condition. Aust J Exp Agric 1985; 25: 257-262.

BAUMGARDT BR. Control of feed intake in the regulation of energy balance. In: Phillipson AT, ed. Physiology of digestion and metabolism in the ruminant. Newcastle upon Tyne: Oriel Press, 1970: 235-253.

BERGEN WG, BYREM TM, GRANT AL. Ensiling characteristics of whole crop small grains harvested at milk and dough stages. J Anim Sci 1991; 69: 1766-1774.

BOLSEN KK. The use of aids to fermentation in silage production. In: McCullough ME, ed. Fermentation of Silage - A Review. National Feed Ingredients, Iowa 1978; 181-200.

BURGESS PL, NICHOLSON JWG, GRANT EA. Yield and nutritive value of corn, barley, wheat and forage oats as silage for lactating cows. Can J Anim Sci 1973; 53: 245-250.

BURTT ES, HILL GD. Yield and nutritive value of spring grown sweet lupins (Lupinus augustifolius cv.Uniharvest) for lambs grazed at four different stages of growth. 2. Nutritive value. New Zealand J Agric Research 1990a; 33: 359-365.

BURTT ES, HILL GD. Yield and nutritive value of spring sown sweet lupins (Lupinus augustifolius cv. Uniharvest) for lambs grazed at four different stages of growth. 1. Dry matter production and utilisation. New Zealand J Agric Research 1990b; 33: 353-357.

BUTTERY PJ. Aspects of the biochemistry of rumen fermentation and their implication in ruminant productivity. Proc Nutrition Conference Feed Manufacturers 1977: 8-24.

CASTLE ME, REID D, WATSON JN. Silage and milk production: a comparison between supplements of barley and soybean meal offered with white clover silage. Grass and Forage Sci 1984; 39: 287-289.

CHAMBERLAIN DG, THOMAS PC,WILSON W, NEWBOLD CJ, MacDONALD JC. The effects of carbohydrate supplements on ruminal concentrations of ammonia in animals given diets of grass silage. J Agric Sci Camb 1985; 104: 331-340.

CHERNEY JH, MARTEN GC. Small grain crop forage potential I. Biological and chemical determinants of quality and yield. Crop Sci 1982; 22: 227-231.

CHOU KC, WALKER DM. The effect on the rumen composition of feeding sheep diets supplying different starches. J Agric Sci 1964; 62: 15-25.

CLAPHAM WM, ELBERT-MAY D. Influence of population on white lupin morphology and yield. Can J Plant Sci 1989; 69: 161-170.

CLARK JH, KLUSMEYER TH, CAMERON MR. Microbial protein synthesis and flows of nitrogen fractions to the duodenum of dairy cows. J Dairy Sci 1992; 75: 2304-2323.

CONE JW. Degradation of starch in feed concentrates by enzymes, rumen fluid and rumen enzymes. J Sci Food Agric 1991; 54: 23-34.

CROS P, BENCHAAR C, BAYOURTHE C, VERNAY M, MONCOULON R. In situ evaluation of the ruminal and intestinal degradability of extruded whole lupin seed nitrogen. Reprod Nutr Develop 1991; 31: 575-583.

CROS P, MONCOULON R, BAYOURTHE C, VERNAY M. Effect of extrusion on ruminal and intestinal disappearance of amino acids in white lupin seed. Can J Anim Sci 1992; 72: 89-96.

CZERKAWSKI JW. Methane production in ruminants and its significance. World Rev Nutr Diet 1969; 11: 240-282.

DANIEL P, ROMER P. The effect of mixing whole-plant Andean lupin (Lupinus mutalibilis L.) or soybean (Glycine soja (L.) Sieb. et Zucc.) silage with maize silage on crude protein content, fodder value and silage quality. Landwirtschaftliche Forschung 1988; 41: 131-139.

DeBOEVER JL, COTTYN BG, AERTS JV, VANACKER JM, BUYSSE FX. Composition chimique, digestibilite et valeur alimentaire des pommes de terre crues. Revue d'Agriculture 1983; 36: 403-413.

DeBRABANDER DL, ANDRIES JI, AERTS JV, BUYSSE FX. Influence des pommes de terre crues sur l'ingestion de fourrage grossier, la production laitiere et la composition du lait chez la vache laitiere. Revue d'Agriculture 1982; 35: 3269-3281.

DEMARQUILLY C. Utilisation des conservateurs:quand et pourquoi les utiliser. Résultats zootechniques obtenus avec des ensilages d'herbe préparés avec des conservateurs efficaces. Int Silage Symp Rouyn-Noranda, Canada 1990: 93-104.

DePETERS EJ, MEDRANO JF, BATH DL. A nutritional evaluation of mixed winter cereals with vetch utilized as silage or hay. J Dairy Sci 1989; 72: 3247-3254.

DULPHY JP, DEMARQUILLY C. Problemes particuliers aux ensilages,prevision de la valeur nutritive des aliments des ruminants. Institute National de la Recherche Agronomique Publ 1981: 81-104.

EDWARDS RA, McDONALD P. The chemistry of silage fermentation. In: McCULLOUGH ME, Fermentation of Silage-A review. National Feed Ingredients Conf, Iowa 1978; 27-60.

ERASMUS LJ, PRINSLOO J, MEISSNER HH. The establishment of a protein degradability data base for dairy cattle using the nylon bag technique 1. Protein sources. S Afr J Anim Sci 1988; 18: 23-30.

FISHER LJ, SHELFORD JA. The relationship of feed evaluation procedures to animal performance for silage. In: Knipfel JE ed., Laboratory Evaluation of Fibrous Feeds- relationships to nutrient requirements and utilization by ruminants. Proc Sixth Intl Symp on Ruminant Physiology, Alberta 1984; 1-12.

FOREST JC, ABERLE ED, HEDRICK HB, JUDGE MD, MERKEL RA. Principles of Meat Science. Reading: W.H.Freeman and Co., 1975.

FOX DG, JOHNSON RR, PRESTON RL, DOCKERTY TR, KLOSTERMAN EW. Protein and energy utilization during compensatory growth in beef cattle. J Anim Sci 1972; 34: 310-318.

FREER M, DOVE H. Rumen degradation of protein in sunflower meal, rapeseed meal and lupin seed placed in nylon bags. Anim Feed Sci Technol 1984; 11: 87-101.

GENSTAT 5 COMMITTEE. Genstat Reference Manual. NEW YORK: Oxford Univ Press 1990.

GIBB MJ, BAKER RD. Compensatory growth and body composition changes in grazing steers following silage feeding without or with a supplement of fishmeal and monensin. Anim Prod 1991; 52: 237-247.

GLADSTONES JS. Lupins as crop plants. Field Crop Abstracts 1970; 23: 123-148.

HARRIS DJ, WILSON PE. A rapid manual method of lupin alkaloid analysis.In: Twardowski T ed. Proc 5th International Lupin Conf Poland 1988: 598-601.

HELSEL ZR, THOMAS JW. Small g ains for forage. J Dairy Sci 1987; 70: 2330-2338.

HILL GD. The composition and nutritive value of lupin seed. Nutrition Abstracts and Reviews B 1977; 47: 511-529.

Hill GD. The utilization of lupins in animal nutrition. Proc 6th International Lupin Conf. Chile 1990; 68-91.

HILL GD. Recent developments in the use of lupins in animal and human nutrition. Proc 4th International Lupin Conf Geraldton, WA 1986: 40-63.

HOLZER Z, LEVY D, SAMUEL V, BRUCKENTHAL I. Interactions between supplementary nitrogen source and ration energy density on performance and nitrogen utilization in growing and fattening male cattle. Anim Prod 1986; 42: 19-28.

HOOVER WH, STOKES SR. Balancing carbohydrates and proteins for optimum rumen microbial yield. J Dairy Sci 1991; 74: 3630-3644.

HVELPLUND T, MADSEN J. A study of the quantitative nitrogen metabolism in the gastro-intestinal tract,and the resultant new protein evaluation system for ruminants.The AAT-PBV system. The Royal Veterinary and Agricultural University, Copenhagen 1990: 214-215.

JASTER EH, FISHER CM, MILLER DA. Nutritive value of oatlage, barley/pea, pea, oat/pea, pearl millet and sorghum as silage ground under a double cropping forage system for dairy heifers. J Dairy Sci 1985; 68: 2914-2921.

Johnson JC, Miller JD, Bedell DM. Tifwhite-78 lupine seed as a feedstuff for cattle. J Dairy Sci 1986; 69: 142-147.

KOZUB GC, HIRONAKA R. Digestible energy requirements for growth in Hereford and Charolais x Hereford steers. Can J Anim Sci 1992; 72: 651-661.

KRISHMAMOORTHY U, MUSCATO TV, SNIFFEN CJ, VAN SOEST PJ. Nitrogen fractions in selected feedstuffs. J Dairy Sci 1982; 65: 217-225.

KUNG L Jr., MACIOROWSKI K, POWELL KM, WEIDNER S, ELEY CL. Lupin as a protein supplement for growing lambs. J Anim Sci 1991; 69: 3398-3405.

MacLEOD JA, IVANY JA, MARTIN RA, KIMPINSKI J. Lupins as a potential crop for P.E.I. Agriculture Canada Research Summary, Charlottetown 1987: 18.

MacPHERSON HT, SLATER JS. γ-Amino-n-butyric, aspartic, glutamic and pyrrolidone - carboxylic acid; their determination and occurrence in grass during conservation. Biochemical J 1959; 71: 654-660.

MAKONI NF, SHELFORD JA, FISHER LJ. The rate and extent of silage nitrogen degradation in the rumen as influenced by wilting and duration of regrowth. Can J Anim Sci 1991; 71: 245-248.

McDONALD P, HENDERSON AR, HERON SJE. The biochemistry of silage. Marlow Bucks, U.K.: Chalcombe Publications 1991.

McKINNON JJ, COHEN RDH, JONES SDM, CHRISTENSEN DA. Crude protein requirements of large frame cattle fed two levels of energy as weaned calves or as backgrounded yearlings. Can J Anim Sci 1993; 73: 315-325.

McLELLAN AR, McGINN R. Energy and nitrogen balance, intake and growth rate of lambs fed on unwilted grass silages treated with a formaldehyde acid mixture or untreated. Anim Feed Sci Tech 1983; 9: 107-119.

McQUEEN RE, MARTIN JP. Laboratory evaluation of nutritional quality of forages. In: McQueen RE ed. Laboratory Evaluation of Farm Grown Forage. Winnipeg, Man 1981: 87-100.

MERTENS DR. Fiber analysis and its use in ration formulation. Proc of Cornell Nutrition Conf, Syracuse NY 1989: 60-68.

MIARON JO, CHRISTOPHERSON RJ. Effect of prolonged thermal exposure on heat production, reticular motility, rumen-fluid and -particulate passage-rate constants, and apparent digestibility in steers. Can J Anim Sci 1992; 72: 809-819.

MILLER EL. The nitrogen needs of ruminants. In: Thomson DJ, Beever DE, Gunn RG eds. Forage protein in ruminant animal production. BSAP : Thames Ditton 1982: 79-87.

MILLIGAN JD, CHRISTISON GI. Effects of severe winter conditions on performance. Can J Anim Sci 1974; 54: 605-610.

MURPHY SR, McNIVEN MA, MacLEOD JA, HALLIDAY LJ. Grass and lupin silage in rations for beef steers supplemented with barley or potatoes. Anim Feed Sci Technol 1992; 40: 273-283.

NATIONAL RESEARCH COUNCIL. Nutrient requirements of beef cattle. Washington: National Academy Press 1984.

NICHOLSON JWG, CHARMLEY EE, BUSH RS. The effect of supplemental protein source on ammonia levels in rumen fluid and blood and intake of alfalfa silage by beef cattle. Can J Anim Sci 1992; 72: 853-862.

OFFUTT MS, DAVIS GV. Nutritive value of sweet white lupin forage. Ark Farm Research 1973; 22: 4.

OOMAH BD, B 'SHUK W. Characterization of lupine proteins. J Food Sci 1983; 48: 38-41.

ORSKOV ER, ANDREWS RP, GILL JC. Effect of replacing rolled barley with swedes or potatoes on the intake and rumen volatile fatty acid composition of lambs. Anim Prod 1969; 11: 187-193.

ORSKOV ER, McDONALD I. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J Agric Sci Camb 1979; 92: 499-503.

PAINE CA, CRAWSHAW R, BARBER WP. A complete exchange method for the in sacco estimation of rumen degradability on a routine basis. Forage Protein in Ruminant Animal Production 1982; 6: 177-178.

PETIT HV, FLIPOT PM. Source and feeding level of nitrogen on growth and carcass characteristics of beef steers fed grass as hay or silage. J Anim Sci 1992; 70: 867-875.

PUTNAM DH, FIELD LA, GUNSOLUS J, AYISI K, HARDMAN L, WRIGHT J. Production factors for white lupins. Lupin Production & Utilization Guide, University of Minnesota, MN 1991: 6-8.

ROBINSON PH, TAMMINGA S. Present knowledge of protein digestion and absorption in ruminants. Ubersichteu Tierernahrung 1984; 12: 119-164.

ROBINSON PH, McNIVEN MA. Nutritive value of raw and roasted sweet white lupins (Lupinus albus) for lactating dairy cows 1992; 999 (Abstr).

ROBINSON PH. Matching energy and protein for rates of rumen of digestion: does the practice fit the theory? In: Kennelly J ed. Advances in Dairy Technology, Proc. 1992 Western Canadian Dairy Seminar, Univ Alberta 1992: 84-94.

ROBINSON PH, CHARMLEY E, McQUEEN RE. Protein supplementation of high protein alfalfa silage fed to lactating dairy cows. Can J Anim Sci 1992; 72: 831-841.

ROOKE JA, ARMSTRONG DG. The importance of the form of nitrogen on microbial protein synthesis in the rumen of cattle receiving grass silage and continuous intrarumen infusions of sucrose. Brit J Nutr 1989; 61: 113-121.

ROOKE JA, ALVAREZ P, ARMSTRONG DG. The digestion by cattle of barley and silage diets containing increasing quantities of soya-bean meal. J Agric Sci 1986; 107: 263-272.

ROOK AJ, GILL M. Prediction of the voluntary intake of grass silages by beef cattle. 1. Linear regression analyses. Anim Prod 1990; 50: 425-438.

ROSS GJS. Maximum Likelihood Program version 3.08. Rothamsted Experimental Station, Oxford,U.K 1987.

SARIC O, RAMOSEVAC I. Value of white sweet lupin in production of protein fodder and feeding of animals. Proc XVI Int Grassland Congress, Lexington, Ky 1981: 204-206.

SAUTER EA, HINMAN DD, BULL RC, HOWES AD, PARKINSON JF, STANHOPE DL. Studies on the utilization of potato processing waste for cattle feed. Agric Exp Stat Research Bull nos 112, Univ Idaho 1980.

SHELDRICK RD, TAYLER RS, MAINGU Z, PONGKAO S. Initial evaluation of lupin for forage. Grass and Forage Sci 1980; 35: 323-327.

SINGH CK, ROBINSON PH, McNIVEN MA. Nutritive value of raw and roasted sweet white lupins for lactating cows 1992; 1277 (Abstr).

SPICER LA, THEURER CB, SOWE J, NOON TH. Ruminal and post ruminal utilization of nitrogen and starch from sorghum grain, corn and barley based diets by beef steers. J Anim Sci 1986; 62: 521-530.

STATISTICAL ANALYSIS SYSTEMS INSTITUTE, SAS/Stat Users Guide, 6.03 Edition. Cary NC: SAS Institute Inc 1988.

STEEL RGD, TORRIE JH. Principles and procedures of statistics. Toronto: McGraw-Hill Book Co. 1980.

STEEN RWJ. A comparison of soya-bean,sunflower and fish meals as protein supplements for yearling cattle offered grass silage-based diets. Anim Prod 1989; 48: 81-89.

TAMMINGA S, KETELAAR R, VAN VUUREN AM. Degradation of nitrogenous compounds in conserved forages in the rumen of dairy cows. Grass and Forage Sci 1991; 46: 427-435.

THOMAS PC, GILL M. Principles of silage utilization and supplementation. In: Frame J ed. Efficient Beef Production from Grass, Occasional Symposium nos.22. Hurley, Berkshire: British Grasslands Soc 1988: 115-128.

THOMAS PC, CHAMBERLAIN DG. The utilization of silage protein. In: Forage Protein Conservation and Utilization, Commission of the European Communities Seminar, Dublin 1982: 121-145.

TISSERAND JL, FAURIE F. Nutritive value of the green and ensiled whole lupin plant. Proc 2nd International Lupin Conf, Spain 1982: 322-324.

VALENTINE SC, BARTSCH BD. Fermentation of hammermilled barley, lupin, pea and fababean grain in the rumen of dairy cows. Anim Feed Sci Technol 1987; 16: 261-271.

VALENTINE SC, BARTSCH BD. Degradation of dry matter, crude protein, fat, crude fibre and nitrogen free extract in milled barley and lupin grains incubated in nylon bags in the rumen of dairy cows. J Agric Sci 1988; 110: 395-398.

VAN SOEST PJ, ROBERTSON JB, LEWIS BA. Symposium: carbohydrate methodology, metabolism, and nutritional implications in dairy cattle. J Dairy Sci 1991: 74: 3583-3597.

VAN SOEST PJ. Nutritional Ecology of the Ruminant. Oregon: O & B Books Inc.,1982.

VAN VUUREN AM, TAMMINGA S, KETELAAR RS. In sacco degradation of organic matter and crude protein of fresh grass (Lolium perenne) in the rumen of grazing dairy cows. J Agric Sci 1991; 116: 429-436.

VEIRA DM, BUTLER G, IVAN M, PROULX JG. Utilization of grass silage by cattle: Effect of barley and fishmeal supplements. Can J Anim Sci 1985; 65: 897-903.

VEIRA DM, CHARMLEY E. Proteolysis in silages and its effects on animal performance. Proc of Silage Technology and Management Workshop Technical Day, Truro N.S. 1989: 134-143.

VEIRA DM, PROULX JG, SEOANE JR. Performance of beef steers fed grass silage with or without supplements of soybean meal, fishmeal and barley. Can J Anim Sci 1990; 70: 313-317.

VETTER RL, VON GLAN KN. Abnormal silages and silage related disease problems. In: McCullough ME ed. Fermentation of silage - A review, National Feed Ingredients Assoc, Iowa 1978; 281-332.

WILLIAMS W. The current status of the crop lupins. Proc 4th International Lupin Conf, Geraldton, WA 1986: 1-13.

WRIGHT IA, RUSSEL AJF. Changes in the body composition of beef cattle during compensatory growth. Anim Prod 1991; 52: 105-113

APPENDIX A
ABBREVIATIONS

ADF	ACID DETERGENT FIBER
ADIN	ACID DETERGENT INSOLUBLE NITROGEN
ARC	AGRICULTURAL RESEARCH COUNCIL
A16	AUGUST 16 HARVEST DATE
A27	AUGUST 27 HARVEST DATE
BSN	BUFFER SOLUBLE NITROGEN
CP	CRUDE PROTEIN
DE	DIGESTIBLE ENERGY
DM	DRY MATTER
DMI	DRY MATTER INTAKE
J30	JULY 30 HARVEST DATE
ME	METABOLIZABLE ENERGY
MJ	MEGA JOULE
N	NITROGEN
NDF	NEUTRAL DETERGENT FIBER
NFE	NITROGEN FREE EXTRACT
NH_3	AMMONIA
NPN	NON-PROTEIN NITROGEN
NRC	NATIONAL RESEARCH COUNCIL
NSC	NON-STRUCTURAL CARBOHYDRATE
RL	RAW LUPIN SUPPLEMENTED DIET
ROL	ROASTED LUPIN SUPPLEMENTED DIET
SBM	SOYBEAN MEAL SUPPLEMENTED DIET
SIL	SILAGE ONLY DIET
TN	TOTAL NITROGEN
VFA	VOLATILE FATTY ACID
WSN	WATER SOLUBLE NITROGEN