THE NUTRITIVE VALUE OF WHEAT WET DISTILLERS BY-PRODUCTS AND WET BREWERS GRAINS AS SUPPLEMENTS FOR FEEDLOT AND GRAZING CATTLE.

A Thesis
Submitted to the Faculty of Graduate Studies and Research
in Partial Fulfillment of the Requirements
for the Degree of
Master of Science
in the
Department of Animal and Poultry Science
University of Saskatchewan
Saskatoon

BY

MESHACK OBWANGA OJOWI

Spring 1995

GSR 301

College of Graduate Studies and Research
University of Saskatchewan
Room 50 Murray Building, Telephone: (306) 966-5751, Facsimile: (306) 966-5756

Certification of Master's Thesis Work

We the undersigned, certify that Meshack Obwanga Ojowi
Egerton College, Kenya (Agric. Diploma); Calpoly, Pomona (B.Sc.)
(full name) (degrees)

candidate for the degree of M.Sc.

in the Department/College of Animal and Poultry Science

has presented his /her thesis with the following title: The Nutritive Value of Wheat Wet Distillers Byproducts and Wet Brewers Grains as Supplements for Feedlot and Grazing Cattle

(as it appears on the title page and front cover of thesis)

that the thesis is acceptable in form and content, and that a satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on June 12, 1995

External Examiner: Dr. G.A. Jones

Internal Examiners:

Date: June 12, 1995

In presenting this thesis in partial fulfillment of the requirements for a Postgraduate degree from the University of Saskatchewan, I agree that the Libraries of this University may make it freely available for inspection. I further agree that permission for copying of this thesis in any manner, in whole or in part, for scholarly purposes may be granted by the professor or professors who supervised my thesis work or, in their absence, by the Head of Department or the Dean of the College in which my thesis work was done. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and the University of Saskatchewan in any scholarly use which may be made of any material in my thesis.

Request for permission to copy or to make other use of material in this thesis in whole or in part should be addressed to:

Head of Department of Animal and Poultry Science
University of Saskatchewan
Saskatoon, Saskatchewan S7N 0W0

ABSTRACT

Wet distillers by-products from wheat based ethanol production and wet brewers grains (WBG) were evaluated as supplements in feedlot and grazing cattle diets. A feedlot experiment used canola meal, WBG and wet distillers grains (WDG) as protein supplements during the growing period. Three diets (control, WBG and WDG) were used in a completely randomized design experiment. Average daily gain (ADG), dry matter intake (DMI), feed conversion ratio (FCR), ultrasonic back fat thickness (USFAT) and ultrasonic ribeye area (USREA) were measured throughout the trial. Carcass fat thickness and composition were measured after slaughter. During the growing period ADG and DMI were similar across all the treatments, however, steers fed WBG diet tended ($P<0.10$) to have better feed conversions than control fed steers. During the finishing phase the control fed steers grew faster ($P<0.05$) than the WBG fed steers. Wet distillers grains fed cattle were intermediate. Fat and muscle deposition and carcass characteristics were similar across treatments. However, carcass composition indicated that WDG steers had more ($P<0.01$) intermuscular fat than control and WBG and WBG had more subcutaneous fat ($P<0.02$) compared to the WDG group. These results indicate that WDG and WBG may be used to replace standard feed ingredients in the grower ration.

An *in situ* nylon bag experiment was used to determine the dry matter (DM) and crude protein (CP) degradation from WBG and WDG collected during (WBGT; WDGT) and after (WBGP; WDGP) the trial. A completely randomized design experiment was used with one fistulated cow and four feed samples. Three separate days were used to

carry out seven rumen incubations of 2, 4, 6, 8, 12, 24 and 48 h. Dry matter and CP degradation was higher in WDG compared to WBG. Similarly, effective degradability parameters indicated that WDG is more degradable than WBG. The high degradability observed for WDG may be related to the higher soluble fraction and rate of degradation. The results show that WBG has a higher rumen undegradable protein than WDG.

The value of thin stillage as an energy and protein supplement was determined for growing cattle grazing crested wheatgrass. Forty steers were used in a trial in which ADG, fluid intake, USFAT, DMI from stillage consumption and plasma metabolite concentration were measured. Crested wheatgrass (CWG) pastures and thin stillage samples collected during the trial were subjected to proximate analysis. Results of the trial indicate that ADG, fluid intake, and DMI from stillage consumption were all higher ($P<0.05$) for stillage fed cattle relative to the water group. Fat deposition and plasma urea N, magnesium and phosphorus concentrations were also higher for stillage fed cattle. The proximate analysis of thin stillage indicated high protein and energy content. Similar analysis for CWG indicated a declining nutritional quality as the pastures matured and the dry season progressed. The higher performance for the stillage fed cattle in an indication of the higher nutritional status of the stillage fed cattle. In conclusion, the results from these trials indicate that by-products from wheat based ethanol production are valuable sources of nutrients for cattle managed under a variety of production situations.

Acknowledgments

I would like to thank my supervisor D. A. Christensen for his, tuition, patience and encouragement during the entire course of my M.Sc. program, members of my advisory committee J.J. McKinnon, G.I. Christison, C.M. Williams, R.D.H. Cohen and G.L. Campbell. Appreciation is extended to the staff at the Animal and Poultry Science laboratory particularly N. Webb for his technical assistance during analysis of experimental ration samples, V. Racz and the staff at University of Saskatchewan Feed Testing Laboratory, N. Suttle of Agriculture Canada Research for extensive use of their freeze drier. I would also like to thank the University of Saskatchewan farm manager, G. Francis, and his staff for the organization of timely supply of the ethanol distillation by-products to the feedlot and pasture trials conducted simultaneously at University of Saskatchewan feedlot and Termuende Research Station at Lanigan, Saskatchewan. Special thanks to researchers R. Bergen Department of Animal and Poultry Science and N. Kohle of Saskatchewan Agriculture and Food Technology for their ultrasound work on the feedlot as well as the pasture steers and carcass analytical work on the feedlot cattle. Special appreciation is extended to J.J McKinnon for coordination of the research projects and negotiating for research animals from Pound Maker Ag-Ventures Limited. The assistance of Pam Little and administrative staff of the Department of Animal and Poultry Science is highly appreciated. Many thanks to Kenya Agricultural Research Institute (KARI) for granting me the opportunity to pursue further studies in Canada.

Assistance from these agencies is acknowledged and highly appreciated Canadian International Development Agency (CIDA) for tuition, subsistence and

research funds and the Kenya High Commission (Ottawa) for the management of CIDA funds, Mohawk Oil company through the PoundMaker Ag-ventures, University of Saskatchewan Farm Project and the Natural Science and Engineering Research Council for provision of research assistance.

Finally and most importantly I would like to express my heart felt gratitude to my family particularly my mum, Lonah, wife Jullianne, children Ben, Maureen, Martin and Purity whose support, constant prayer and patience made it possible for me to successfully complete this program. May God bless all of you.

Table of contents

List of Tables

List of Figures

List of abbreviations

ADF	acid detergent fiber
ADG	average daily gain
ADIN	acid detergent insoluble nitrogen
ADFIP	acid detergent fiber insoluble protein
AOAC	Association of Official Analytical Chemists
ARC	Agricultural research council
BM	Barley malt
BP	borate phosphate
BV	biological value
C	Celsius
Ca	calcium
CDDG	corn dry distillers grains
CDDGS	corn dry distillers grains with solubles
CDGS	corn distillers grains with solubles
CGF	corn gluten feed
CGM	corn gluten meal
Cl	chlorine
cm	centimeter
CM	canola meal
CNCPS	Cornell Net Carbohydrate and Protein System
CO_2	carbon dioxide
CP	crude protein
CPD	crude protein disappearance
Cu	copper
CWDG	corn wet distillers grains
CWG	crested wheatgrass
CWGM	corn wet gluten meal
d	day
DCGF	dry corn gluten feed
DE	digestible energy
DEI	digestible energy intake
DM	dry matter
DMD	dry matter disappearance
DDGS	dry distillers grains with solubles
DMI	dry matter intake
ECPD	effective crude protein degradability
ED	effective degradability
EDMD	effective dry matter disappearance
EE	ether extract
FCR	feed conversion ratio
Fe	iron
g	gram

h	hour
H_2O	water
HOM	hominy feed
K	potassium
kg	kilogram(s)
L	liter(s)
LB	pound(s)
MB	malting barley
Mcal	megacalorie
ME	metabolizable energy
MF	medium frame
Mg	magnesium
MJ	megajoule
mm	millimeter
Mn	manganese
MRM	mixed rumen microorganisms
N	nitrogen
Na	sodium
NAS	National Academy of Sciences
NDF	neutral detergent fiber
NDICP	neutral detergent insoluble nitrogen
NE	net energy
NH_3	ammonia
NH_3-N	ammonia nitrogen
NPN	non-protein nitrogen
NCR	National Research Council
NSC	non structural carbohydrate
P	phosphorus
PE	protein efficiency
RUP	rumen undegradable protein
SAS	Statistical Analysis System Institute, Inc.
SBM	soybean meal
SC	structural carbohydrate
SE	standard error of means
TCA	trichloroacetic acid
TDN	total digestible nutrients
TND	true nitrogen digestibility
TS	thin stillage
USFAT	ultrasonic fat
USREA	ultrasonic rib eye area
VFA	volatile fatty acids
WBG	wet brewers grains
WDB	wet distillers by-products
DDG	dry distillers grains
WDG	wet distillers grains

WG	wheat grain
WWDG	wheat wet distillers grains
Zn	zinc

1.0 Introduction

Ruminants have two unique capabilities as food producing animals. First their rumen microbial population produces cellulases and other enzymes that degrade complex carbohydrates. They can therefore use roughages or high fiber feeds such as distillers grains as a major part of their ration. Secondly, because the rumen microbes produce proteases and urease and can also combine ammonia and carbon skeletons to form amino acids, non-protein nitrogen is converted to microbial protein. This microbial protein partially meets the ruminant protein requirements. However, not all of the ammonia is converted to microbial protein and part can be excreted via urine as urea. This is, however, an inefficient process. If there is a lack of energy available for synthesis of microbial protein, fermentation will reduce the amount of nitrogen utilized by the ruminant. Dietary protein that escapes microbial fermentation in the rumen is an advantageous nutrient to the animal as it may be more efficiently used.

Many of the less degradable protein sources arise from the processing of grains and other feedstuffs. Ethanol distillation of wheat cereal grain results in by-products such as wheat wet distillers grains and thin stillage which are excellent sources of rumen undegradable protein and energy for growing ruminants. Saskatchewan accounts for the largest portion (14 million tonnes) of Canadian wheat production. Approximately 37,000 tonnes of this wheat are used to produce 14 million liters of fuel ethanol at the PoundMaker plant at Lanigan, Saskatchewan. This produces 11,728 tonnes of wet

distillers grains of which 28.9% is dry matter and 50,400 tonnes of thin stillage with 7-8% dry matter.

Most of the research data available on the nutritive value of distillers by-products involves corn distillers by-products and has been obtained in the USA where corn is readily available for ethanol production. In western Canada, wheat is more readily available than corn, hence ethanol production is wheat-based rather than corn-based. During the ethanol distillation process, large quantities of by-products (wet distillers grains and thin stillage) are generated. These by-products have to be disposed of without becoming a burden to the ethanol enterprise. This may be achieved by feeding the by-products to livestock with minimum operating expenses. Other ways of disposal include, use as organic fertilizers and dumping. However, both these two options are less appealing and unpopular to potential users.

The nutritive value of corn dry distillers grains (CDDG) and thin stillage or corn dry distillers grains with solubles (CDDGS) has been evaluated and recommended as suitable for inclusion in ruminants rations. The recommendation for use of the two by-products as cattle supplements is based on their high energy and protein content. During the distillation process, cereal grains are ground, slurried with water and cooked to gelatinize the starch. The resultant mash is cooled to fermentation temperature, inoculated with yeast and allowed to ferment for a period of three to five days. Distillation of the fermented mash results in ethanol alcohol and a liquid (whole stillage) which is processed further to make distillers by-products. Whole stillage is passed over screens to remove coarse unfermented portions of grains. Mechanical pressing yields wet

distillers grains (Figure 1.1). A similar process (except for the distillation part) to that described in Figure 1.1, is used to produce wet brewers grains from barley malt. Figure 1.2 provides a brief description of this process.

Wheat wet distillers grains (WWDG) contains approximately 20% dry matter, 36% total dietary fiber and 26% crude protein. Thin stillage from ethanol fermentation of durum wheat contains small particles of grain, yeast cells and other soluble nutrients with very high nutritive potential. This stillage is composed of about 3% to 5% dry matter (DM), which contains 42% to 43% crude protein (CP), 31% total dietary fiber, 5.6% fat and 5.3% ash (Lee et al. 1991). Studies by Davis et al. (1983) revealed that wet brewers grains (WBG) contains 31% DM, 27% CP and 25% acid detergent fiber (ADF).

Early interest in thin stillage as a supplementary feed for cattle was based on the idea that it contained stimulatory factors for fiber digestion. The stimulatory factor referred to in this research may have included vitamins, proteins, amino acids, carbohydrates and some lipids which are known to stimulate microbial activity (Hatch 1993a). This assumption may be related to the high energy and protein content of thin stillage. Addition of corn distillers dried grains with solubles (CDDGS) to cattle diets was observed to enhance fiber digestion. Thin stillage has been found to contain superior energy and protein content compared to the cereal grains from which it is produced. These high nutrient values may provide additional energy to the bacteria for use in fiber digestion above that supplied by a grain supplement. Recent research in this area has focused on the rumen undegradable protein value of thin stillage rather than its effect on fiber digestion.

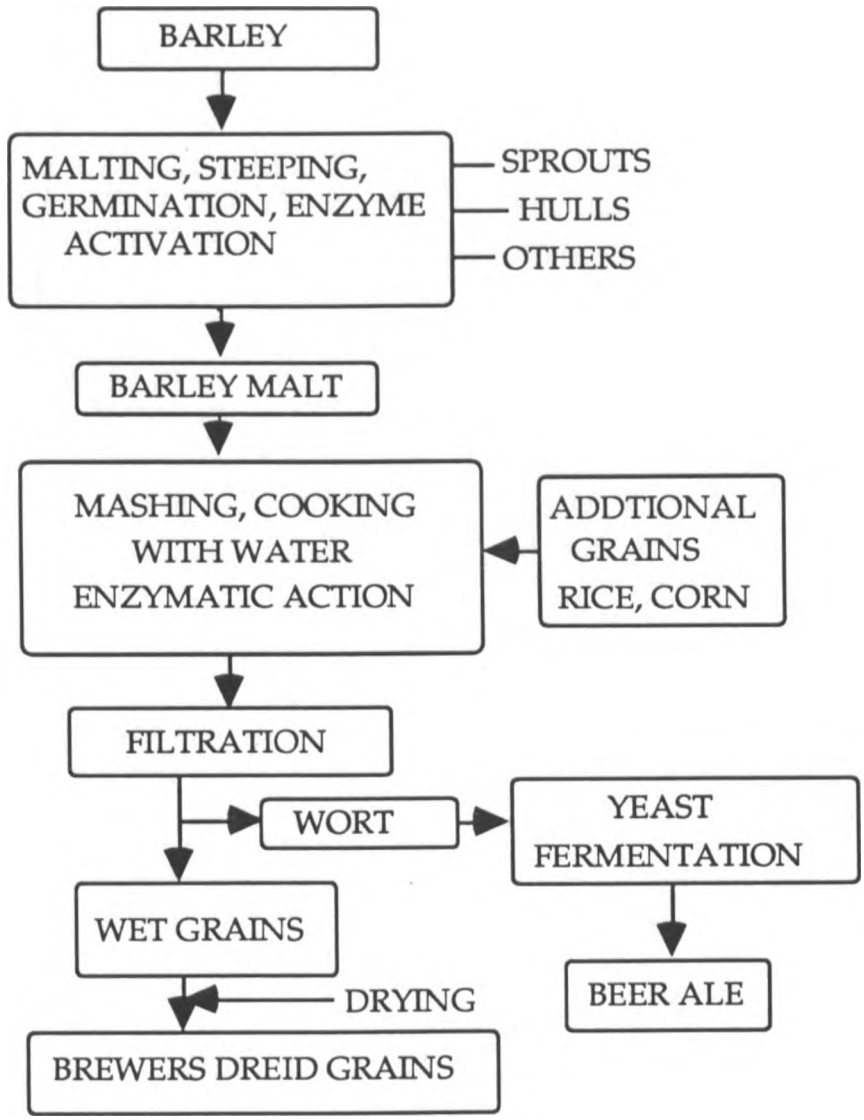

Figure 1.2 Beer brewing process and byproducts feeds (Adapted from Ensminger et al. 1990)

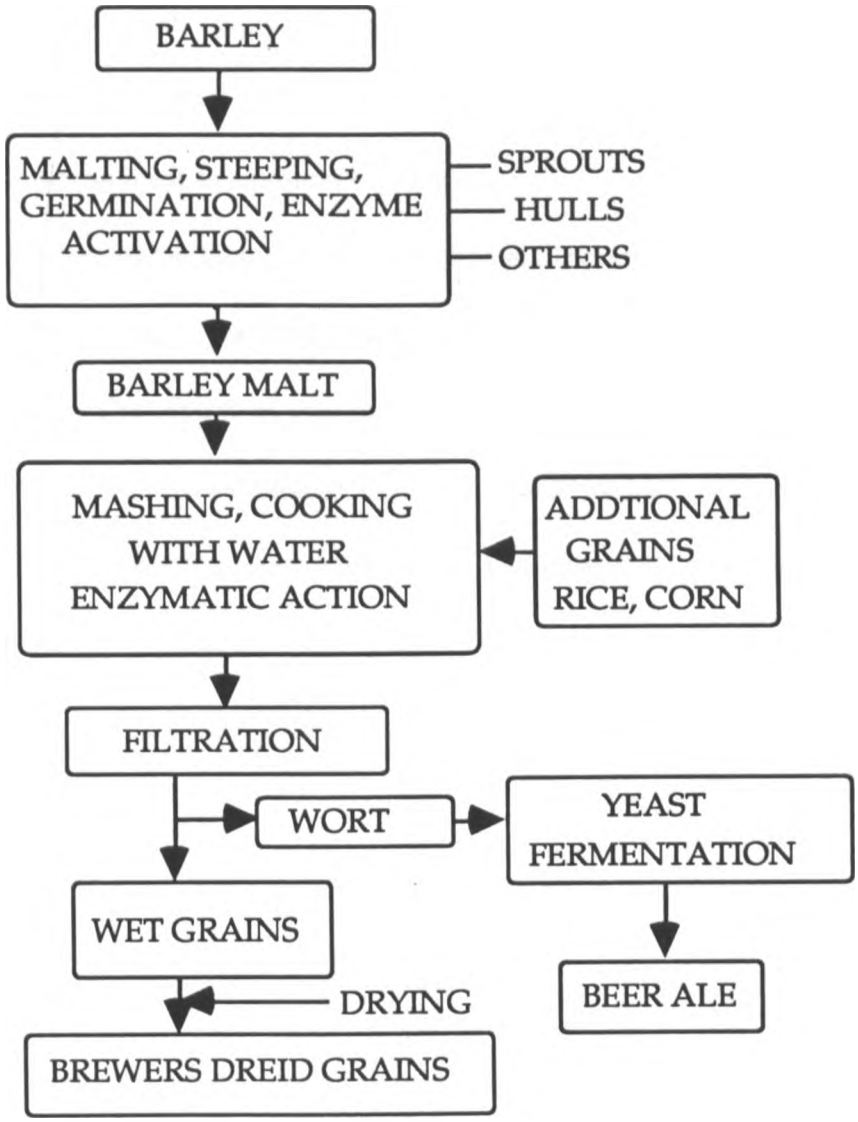

Figure 1.2 Beer brewing process and byproducts feeds (Adapted from Ensminger et al. 1990)

Corn dry distillers grains with solubles has a rumen escape value of about 60% compared to between 30 and 40% for soybean meal (SBM) (Aines et al. 1986). This implies that ruminants supplemented with CDDGS will receive substantial rumen undegradable protein (RUP), for lower gastrointestinal tract digestion compared to those receiving soybean meal as a protein supplement.

The objective of the literature search was to review work on rumen microbial energy and protein utilization of standard feed sources used in North America as supplements in ruminant diets. The review covers research work on rumen microbial fermentation of feed sources and the importance of RUP in the diets of high producing ruminants. An attempt has been made to review work carried out on brewers grains and corn, as well as wheat distillers by-products.

2.0 Review of literature

2.1 Energy and protein requirement systems for cattle

With an increasing world population there is an ever growing need to maximize food production on limited land resources and maintain a high quality of life. This is only possible if efficient production techniques are employed to meet the animals' nutritional requirements and produce high quality products required by the consumer. Efficient animal performance requires adequate dietary energy and protein supply. Several methods are available for estimation of the energy requirements of different classes of cattle. These include total digestible nutrients (TDN), digestible energy (DE), metabolizable energy (ME) and net energy (NE). Of these methods, NE is the most accurate for the estimation of the energy requirements of ruminants (National Academy of Science, National Research Council (NAS-NCR 1984)). The NE system is used to estimate energy for maintenance and gain and accounts for the energy losses in the process of energy utilization by the animal. Reviews (Huber and Kung, 1981; Chalupa 1974; Chalupa 1984; Clark 1974; Clark et al. 1992 and Oldham 1993) have reviewed in depth the various aspects of protein metabolism in ruminants. The purpose of this review is to briefly cover aspects of protein feeding to ruminants and specific areas which should be focused on when formulating cattle rations. The review will emphasize feeding ethanol by-products to feedlot and grazing cattle with particular focus on distillers grains and thin stillage.

Several feeding systems have been used to predict the requirements of animals based on biological information and feedstuffs available to the producer, scientist or ration

formulator. Of these systems, the most widely used is the NAS-NCR and the Agricultural Research Council (ARC) for North America and the UK, respectively. In the NAS-NCR system, NE requirement for a growing calf is estimated as NE for maintenance and NE for growth (NAS-NCR 1984). The net energy for growth is estimated as the amount of energy deposited as non-fat organic matter (mostly protein) plus that deposited as fat (NAS-NCR 1984). The calorific value of fat is estimated as 9.4 kcal g^{-1}, and that for nonfat organic matter has an average value of 5.6 kcal g^{-1} (NAS-NCR 1984). The Cornell net carbohydrate and protein system (CNCPS) makes an attempt to quantitatively estimate fermentation end products (the metabolizable energy from volatile fatty acids, microbial protein and ammonia) and materials escaping rumen degradation (carbohydrates, proteins and undegraded peptides). Rumen bacteria are categorized into two groups according to the carbohydrate type they ferment (Russell et al. 1992). The structural carbohydrate fermentors act only on the cell wall carbohydrates. The non-structural carbohydrate fermentors act on starch, pectin, sugar and the other non-cell wall carbohydrates.

The energy component of feedstuffs is divided into four fractions which are considered of carbohydrate origin. Total carbohydrate is defined as 100- (CP + Fat + Ash) with four fractions A, B_1, B_2 and C. The A fraction is composed of soluble sugars that are very rapidly fermented (100% to 350% per hour) by the NSC bacteria. The B_1 fraction is composed of starch and pectin and has an intermediate fermentation rate (5% to 40% per hour). This fraction is also fermented by the NSC bacteria. This fraction is estimated as 100 - CP - Fat - Ash - (NDF-NDICP). Where NDICP is the amount of CP

insoluble in neutral detergent solution. The B_2 fraction includes the available cell wall (part of the NDF) and is slowly fermented by the SC bacteria (5% to 10% per hour). Lastly, the C fraction composed of the unavailable cell wall and consists mostly of indigestible fiber (Sniffen et al. 1992).

When feeding cattle on low protein diets (5% of diet DM intake), 70% of the CP intake will be composed of recycled nitrogen, mostly ammonia and urea. When the dietary protein intake is high (20%), the contribution of recycled nitrogen decreases to 11% of the dietary CP intake (NAS-NCR 1985 and 1989). The CNCPS uses the NAS-NCR (1984) equation for recycled nitrogen

$$Y = 121.7 - 12.01X + 0.3235X^2$$

where Y = the urea nitrogen recycled (percentage of nitrogen intake) and X = intake of CP as a percentage of diet DM (Russell et al. 1992).

The rumen environment plays an important role in microbial fermentation. A faster rate of protein degradation than carbohydrate fermentation results in large quantities of nitrogen lost as ammonia. If the rate of carbohydrate fermentation exceeds protein degradation then microbial protein growth decreases. Gut fill limits dry matter intake with slowly degradable feedstuffs. Lastly, slow or high rumen outflow rate (depending on the feed particle size, saliva production rate and water intake) affects degradability such that slow rumen turnover leads to more feed degradability and high rumen turnover leads to less degradation (Russell et al. 1992).

The CNCPS divides the protein into five fractions; (A, B_1, B_2, B_3, and C). The A fraction is composed of NPN, soluble in trichloroacetic acid (TCA) and buffer solution.

The B group, or the true protein fraction, is further subdivided. The B_1 fraction is soluble and rapidly degraded in the rumen. The A and B_1 fractions are fermented at rates of 120% to 250% per hour. The B_2, fraction is the buffer insoluble protein minus cell wall crude protein (B_3) and is fermented at rate of 5% to 15% per hour. The B_3 fraction is the cell wall nitrogen which is insoluble in neutral detergent solution and has a very slow rate of fermentation (less than 1% per hour). Lastly the C fraction is the unavailable protein which cannot be fermented by rumen bacteria. It is the protein nitrogen associated with the lignin, tannins and maillard products. Identification of the specific energy and protein fractions and degradation rates, has made it possible to improve the accuracy of the prediction of cattle requirements for these nutrients. When formulating rations for feedlot cattle, it is important that careful attention be paid to meeting the nutritional requirements so as to realize the expected levels of performance anticipated by the producer.

2.1.1 Protein supplements in cattle rations

The feeding of protein supplements to ruminants is to satisfy the protein needs of both the animal and the microbial population in the rumen (NAS-NCR 1984). There is need for crude protein (nitrogen, amino acids and peptides) for bacterial fermentation and post ruminal amino acids for animal tissues and production purposes (NAS-NCR 1984). At high protein intakes, efficiency of protein utilization is reduced because more protein is available than the host can process for beneficial purposes (Broster 1972). Low protein intakes result in high efficiencies of utilization because of salivary nitrogen recycling to the rumen as urea and reduced urea losses through the kidneys as urine

(Botts et al. 1979). In the rumen, increased nutrient retention time, depressed intakes and lowered capacity to digest organic matter results from very low protein intakes, most likely due to curtailing of microbial fermentation (Egan 1980).

Feedlot cattle are expected to grow fast, hence their energy and protein supplements reflect their requirements in terms of maintenance and production. When choosing the protein supplement for these animals, two factors that need to be considered are the quantity and quality of crude protein and its solubility or rumen degradability. Highly soluble proteins tend to have poor rumen undegradable protein values (RUP) while those with low solubility have higher RUP values. The quality of the protein is, however, measured not only by the degree of degradability in the rumen but also by the availability of the protein for absorption in the small intestines.

The nitrogen absorbed from the digestive tract has two metabolic fates. It is either stored as tissue nitrogen or excreted as urinary nitrogen (Satter and Roffler 1974). It is important to be able to predict the point at which ammonia produced in the rumen is efficiently utilized for conversion to protein. Non-protein nitrogen (NPN) in excess of 12.5% crude protein, in diets of lactating dairy cattle is not converted into microbial protein and is excreted in the urine (Satter and Roffler 1974). Ammonia is the primary N source for rumen bacteria utilizing structural carbohydrate while both peptides and ammonia are needed by those utilizing non-structural carbohydrates (Chalupa 1972; Russell et al. 1992).

Since the majority of the rumen bacteria can use ammonia as their nitrogen source, it is an important determinant of microbial protein production (Byrant and Robinson

1962). For efficient synthesis of amino acids, and therefore microbial protein, ammonia should be available in optimal concentrations. The rumen ammonia concentration of 5 to 8 mg N/100 ml rumen fluid has been suggested as the point at which there is equilibrium between production and utilization of rumen ammonia (Satter and Slyter 1974). Degradation of protein occurs via bacterial (usually cell surface) proteases and peptidases. The highly degradable, soluble protein is rapidly absorbed into the bacterial cell while the slowly degradable, insoluble portion is passed on down the digestive tract (Nugent et al. 1981).

Rumen microbes produce a wide variety of enzymes including ureases which are important microbial enzymes that degrade urea recycled to the rumen. Ammonia is combined with feed carbohydrates during microbial growth to form amino acids. When protein intake is low (5% CP in the ration DM) the recycled nitrogen, entering the rumen may be as much as 70% of the nitrogen entering the rumen. Feeding of protein sources susceptible to ruminal degradation increases microbial protein synthesis and microbial nitrogen flow to the small intestines compared to protein feeds more resistant to rumen degradation (McCarthy et al. 1989; Rook and Armstrong, 1989 and Cecava et al. 1990). The extent of degradation of feed and conversion to microbial matter depends on its rumen degradability, energy available in the diet and retention time in the rumen (Storm and Ørskov 1983). For a wide range of diets, 60% to 85% of the protein passing through to the small intestine is of microbial origin (Smith 1979; ARC 1980). Protein recycling is a dynamic process which contributes as a supplementary source to the dietary protein source. The sources of endogenous proteins in the ruminant include salivary proteins,

sloughed mucosal cells, mucopolysaccharides and urea of blood plasma transferred to the rumen (Leng and Nolan, 1984). These sources may account for a substantial quantity of the nitrogen supply to the rumen bacteria.

2.1.2 Effect of N and carbohydrate source on microbial protein synthesis

For accurate formulation of a ration that will satisfy the protein requirement of the animal, attention must also be paid to the requirements of the microorganisms and their role in fermentation of the feed. Coleman (1980) suggested accounting for protozoal predation of bacteria by lowering the theoretical maximum bacterial growth yield from 50% to 40% of the bacterial protein synthesized. *In vitro* studies indicate that efficiency of microbial growth declines significantly when the rumen pH drops below 6.0 (Strobel and Russell, 1986).

The microbial population in the rumen can broadly be divided into two categories according to the carbohydrate they ferment. By understanding the fermentative needs of rumen microbes, it is possible to make the most efficient use of available feed by ensuring that they are provided in the appropriate quantities. There are microbes that ferment non-structural carbohydrates (NSC) and those that ferment structural carbohydrates (SC). The division reflects nitrogen utilization and growth efficiency, as well as the partition of energy source and utilization (Russell et al. 1992).

Storm et al. 1983a reviewed research carried out by several scientists to determine the nutritive value of rumen microorganisms in the ruminant (Table 2.1).

Table 2.1 **True nitrogen digestibility, biological value and net utilization of mixed rumen microorganisms.**

Source	Method used	TND (%)[z]	BV (%)[y]	NNU (%)[x]
Harris & Mitchell (1941)	Sheep given purified diets with urea as main	89	62	55
Jonson et al. (1944)	nitrogen source.	55	66	36
McNaught et al. (1950)	} Rats given purified diets with isolated MRM	73	88	64
McNaught et al. (1954)	} Rats given purified diets with isolated MRM	74	81	60
Bergen et al. (1968)	} as the main source of protein	75	85	64
Storm et al. (1983)a	Intragastric infusion of MRM in eight sheep	81	67	54

(Adapted from Storm et al. 1983).

[z]TND = true nitrogen digestibility.

[y] BV = biological value.

[x] NNU = net nitrogen utilization MRM = mixed rumen microorganisms.

In contrast to plant proteins, the amino acid composition of microbial protein is constant under a variety of nutritional regimens (Bergen et al. 1967; Bergen et al. 1968 and Syvaoja and Kreula 1979).

Feeding of protein sources susceptible to ruminal degradation increases microbial protein synthesis and/or microbial nitrogen flow to the small intestine compared to proteins resistant to ruminal degradation (McCarthy et al. 1989; Rook and Armstrong 1989 and Cecava et al. 1990). However, protein sources with greater resistance to ruminal degradation have higher non-ammonia non-microbial nitrogen flow to the duodenum when compared to those with highly degradable protein sources (Stokes et al. 1991). This is important for ruminant animals since in some production situations, they may need rumen undegradable protein to supply limiting amino acids lacking in the microbial sources. Endogenous protein results from sloughing of intestinal tissues. The digestion of endogenous protein and its impact on ruminant nutrition is difficult to ascertain and is usually discounted during ration formulation (Huber and Kung 1981). Considering that endogenous protein is part of the urea recycled via saliva, it should be noted that this protein source partially meets the microbial nitrogen requirement thereby helping meet the animal's amino acid requirements (Leng and Nolan 1984).

2.1.3 Importance of dietary rumen undegradable protein (RUP) and effect of processing on protein utilization.

Most soluble proteins and non-protein nitrogen are very rapidly degraded in the rumen. Insoluble plant proteins are generally resistant to breakdown and contain slowly degradable protein (prolamines and glutelins) (Van Soest 1982). Dietary protein that

escapes rumen degradation and reaches the duodenum is important to the ruminant animal, however, it is a smaller fraction compared to the microbial fraction. The importance of this fraction is due to its complementary effect to the microbial protein in meeting the limiting amino acid needs of the animal (Clark et al. 1992).

Ruminants, as well as non-ruminants, need preformed essential amino acids at the tissue level. Ruminants obtain their amino acid supply from microbial protein synthesized by rumen microbes and dietary RUP. The emphasis on RUP content of dietary protein is both on the proportion escaping rumen microbial digestion and the amino acid profile reaching the tissue level (Mantysaari et al. 1989). If the amino acid profile of the absorbed protein does not meet the needs of the animal, both the productivity and protein efficiency will decrease with adverse economic results (Mantysaari et al. 1989). Cattle grazing winter pastures and supplemented with escape protein have an improved forage intake, abomasal protein flow to the hindgut and more protein digestibility, thereby reducing protein deficiency without affecting fiber digestibility (Donaldson et al. 1991). Diets containing slowly degradable protein generally supply more amino acids to the intestines than diets containing more degradable protein from sources such as soybean meal (SBM) (Santos et al. 1984). Normal procedures in the manufacture of feed ingredients can influence the magnitude of protein degradation in the rumen. Certain grain processing procedures can either increase or decrease ruminal degradation of proteins. Disruption of the protein matrix may result in increased degradation while heat generated or applied during processing can decrease ruminal degradation (Hale 1973). Methods for estimation of energy and

protein degradability in the rumen can be broadly categorized as *in vitro* and *in vivo* techniques. The nylon bag technique is the best way to mimic rumen utilization with a given feeding regime except for the lack of mastication, rumination and passage which would make it the total ruminal experience. With this procedure non-digestible bags containing a feedstuff are placed in the rumen of a fistulated animal for various time intervals and the amount of nitrogen removed over time is measured (Nocek 1988). An extensive review by Michalet-Doreau and Ould-Bah (1992) has been published. These authors emphasized the use of the nylon bag technique, the most common non-commercial (not routinely used in industry) method, for estimating the rumen degradability of proteins. Despite its non-commercial application the nylon bag technique is a necessary method for generating databases for use in developing *in vitro* prediction equations (Roe and Sniffen 1990). Factors such as initial lag time required for solubilization, microbial attachment, variations in microbial populations and supply of enzymes affect rates at which proteins are broken down. The rate at which a pure feed protein is digested in the rumen when enzyme supply is not limiting, depends on the quantity of the protein and its properties which determine the degradation rate constant (Van Soest 1982).

2.1.4 Relationship of acid detergent insoluble nitrogen to protein solubility

Heat damage has detrimental effects to protein quality and has been associated with an increase in acid detergent insoluble nitrogen (ADIN). Acid detergent insoluble nitrogen has been associated with the insolubility of protein by several researchers (Van Soest 1965; Goering 1972; Yu and Thomas 1976). These workers suggested that

increasing ADIN level in forage proteins directly decreases nitrogen digestibility. ADIN has also been used as a measure of heat damage in non-forage plant proteins sources (Van Soest and Sniffen 1984). In a recent research article, Nakamura et al. (1994) has proposed that ADIN is partially digestible and therefore not a true measure of protein indigestibility in non-roughage proteins. It may therefore be concluded from the results of this research that ADIN can not reliably be used as an indicator of protein digestibility for heat damaged proteins. Further research may be necessary before the controversy surrounding ADIN is resolved.

The process of maximizing the utilization of rumen escape protein is reflected in improved animal responses where protected protein or amino acids are introduced into the lower gastro-intestinal tract. The improvement results from a combination of two effects. The greater quantity of essential amino acids and the higher true digestibility of feed quality proteins as compared with the crude protein in rumen organisms (Van Soest 1982).

2.2 Sources of protein for ruminants

Ruminal bacteria use various sources of nitrogen (primarily ammonia, amino acids and peptides), energy (derived from fermentation) and minerals for growth. Any of these factors can limit bacterial digestion of organic matter in the rumen consequently reducing feed intake. The amount of protein that escapes degradation may vary considerably, with most management and feeding conditions in the dairy and feedlot industry, an escape rate of 40% for dietary protein probably represents an acceptable average. The remaining 60% is almost entirely degraded to ammonia and peptides

(Satter and Roffler, 1974). Van Soest (1982) has classified protein sources according to their solubility, binding to ADF fraction, and the insoluble but available portion (Table 2.2). This classification is important when choosing the protein supplement for a given class of ruminant, since it provides the approximate portion that will finally get to the abomasum for absorption and utilization by the animal. The ultimate decision concerning the choice of the protein supplement, must consider the benefits to the animal, cost and the acceptability of the product.

2.3.1 Soybean meal

Soybean meal has been used extensively as a protein supplement in cattle rations for the past several decades with satisfactory results. It is evident from nutritional reports that SBM is a moderately rumen degradable protein. Some of the original amino acids reach the duodenum for absorption (Santos et al. 1984). Treatment of dietary proteins with various agents to decrease ruminal degradation has received considerable attention. The main reason for this is to increase the outflow and balance of amino acids to the duodenum by protection of the protein from microbial fermentation in the rumen (Windshitl and Stern 1988). The effect of heat during oil extraction and toasting to destroy trypsin inhibitory activity reduces the high degradability of soybean protein allowing more bypass to reach the small intestines. Diet supplements containing low rumen degradable protein such as corn gluten meal, wet brewers grains and corn dry distillers grains will generally supply more amino acids to the intestines than SBM for every 100 g of crude protein ingested (Santos et al. 1984).

Table 2.2 Soluble and degradable protein fractions in various feedstuffs.

Types of feed	%Crude protein (DM basis)	% of Crude protein		
		Soluble[z]	ADFIP[y]	Potentially degradable[w]
Solubility				
High				
Corn germ meal	29.4	63	2.8	35
Corn bran	29.4	63	2.8	35
Corn gluten feed	22.2	55	2.6	50
Wheat middlings	18.4	37	2.3	61
Medium				
Oats	12.9	31	4.8	64
Soybean meal	52.3	24	1.8	75
DDGS[x]	29.1	19	15.3	65
Low				
Cotton seed meal	44.3	12	3.1	85
Corn	9.6	15	5.0	80
Dry brewers grains	28.9	6	13.2	81
Dry distillers grains	26.7	6	18.8	76
Corn gluten meal	66.2	4	10	85

(Adapted from Van Soest 1982)

[z] Fraction *a* , the rapidly soluble protein fraction (Ørskov and McDonald, 1979).

[y] The protein fraction bound to acid detergent fiber.

[w] Fraction *b*, the potentially degradable protein fraction (Ørskov and McDonald, 1979).

[x] Dry distillers grains with solubles.

Soybean meal protein without further treatment has a rumen escape value of 50% for high producing dairy cattle at a rumen outflow rate of 8% h^{-1} (Ørskov 1992). The treatment of SBM with xylose or calcium lignosulfonate is effective in reducing ruminal protein degradation without severely restricting small intestinal availability of the SBM protein (Windschitl and Stern 1988). Using the procedure for controlled non-enzymatic browning by heating SBM in the presence of reducing sugars, Cleale et al. (1987a), showed xylose to be the most effective sugar in reducing the degradation of SBM by rumen microbes. The addition of xylose at 3 moles $mole^{-1}$ of lysine in soybean meal increased the rumen undegradability of soybean meal protein from 13.1% to 33.7% (Cleale et al. 1987b). The implication of this at the high rate of rumen outflow of 8% per hour is that the xylose treated SBM has a potential undegradability or escape value of 67%.

2.3.2 Canola products for cattle

Canola meal is widely used as a protein supplement (37% CP in DM) in ruminant rations. However, its crude protein fraction is readily digested by rumen microorganisms and thus canola is relatively a poor source of rumen undegradable protein (Deacon et al. 1988, Khorasani et al. 1989). Canola is more rapidly degraded in the rumen than many other supplements hence treatment of canola meal to increase its rumen undegradable fraction may be desirable (Kennelly and de Boer 1986). Untreated whole canola seed has an effective CP degradability of 83.5%. Application of dry heat for a short period (Jet-sploding at 315°C) has successfully decreased this rate to 43.2% (Deacon et al 1988). Kennelly et al. (1993) reported jet-sploding canola seed at 150°C for short periods of

time and inclusion in the dairy cattle diet at 4.5% of the dietary dry matter is the most beneficial combination to the animal. This product due to its high fat content can only be used at 5% of the dietary dry matter without adversely affecting dry matter intake (Khorasani et al. 1991). A combination of formaldehyde treatment and encapsulation with oil from canola seed reduces the effective degradability of canola meal to 36% from 58% (Deacon et al. 1988). The detrimental effect of the treated canola products is due to its high oil content. The antibacterial action of polyunsaturated fatty acids has been shown to inhibit cellulolytic bacteria (Palmquist 1988). Acetic acid treated canola meal increases RUP of canola meal without necessarily increasing milk yield or total protein supply to the duodenum due to lower microbial protein production (Kennelly and Khorasani 1993). McKinnon et al. (1991) have reported higher levels of RUP when moderate heat (125-145^{o}C) was applied for short periods of time (10-30 minutes). The study concluded that moderate heating of canola meal for short periods increased the ruminally undegradable protein fraction, however, the intestinal utilization of the undegraded protein required further investigation.

2.3.3 Ethanol distillation by-products for cattle

During the process of producing alcohol from grains, two by-products, distillers grains and thin stillage are generated. In this process high energy feedstuffs are converted to high protein by-products. The protein concentrations in the dry matter of corn distillers grains and thin stillage are almost equal and almost three times that in corn grain (Larson et al. 1982a). Characteristics of the nutrient composition in the two products are quite different due to the variations in processing and stage of harvest

(Aines et al. 1986). During the fermentation of cereal grains by yeast to produce the alcohol, the remaining material is referred to as whole stillage (usually 90% water). It is screened or centrifuged to produce thin stillage and distillers grains. Thin stillage (often called distillers solubles) contains yeast cells, soluble nutrients and small corn (wheat) particles. The distillers grains contain unfermented corn residues, including protein, and a large fraction of digestible fiber and fat (Aines et al. 1986).

2.3.3.1 The nutritive value of distillers grains

Distillers grains combined with NPN sources have been found to be an excellent protein supplement for growing ruminants (Waller et al. 1980) due to their low rumen degradable protein. The drying of corn distillers grains for use as a protein supplement in ruminant rations has been promoted by transportation costs, poor shelf life and storage characteristics and the bulkiness of the wet distillers grains. However, drying wet corn distillers solubles or wet grains is expensive and may account for over 40% of the energy cost incurred by the alcohol plant (Ham et al. 1994). The nutritional value of dry corn distillers grains has been debated and the increasing fuel costs may make the wet corn distillers grains a more attractive and economical feed (Ham et al. 1994). No difference has been observed between the rumen degradability of CWDG and CDDG (Abrams et al. 1983). Corn wet distillers grains has a greater value as a protein supplement when fed to growing lambs on high forage diets and gaining 53 to 114 g d^{-1} or for steers gaining 420 to 600 g d^{-1} relative to soybean meal (Abrams et al. 1983). Corn distillers wet grains due to its high moisture content tends to spoil soon after the distillation process. Attempts have been made to preserve and extend their shelf life. One of the attempts to

preserve CWDG has been through ensiling. However, Abrams et al. (1983) reported increases in the soluble nitrogen content, lowering its value as a source of RUP.

The performance of cattle fed high roughage rations supplemented with CDDG has been reported to be superior to those fed dry corn gluten feed (DCGF). This was explained by greater duodenal particulate nitrogen flow, lower NH_3-N flow and greater non-ammonia, non-bacterial nitrogen and total nitrogen flow to the duodenum (Firkins et al. 1986). This study showed that nitrogen of CDDG escaped ruminal fermentation to a greater extend than did nitrogen in DCGF (Firkins et al. 1986). This shows that there is a decreased flow of nitrogen to the duodenum in steers fed DCGF relative to those fed CDDG. Growing calves fed a combination of milo, dry distillers grains and urea have been reported to be 50% more efficient in protein utilization than calves fed soybean meal (Waller et. al. 1980). Corn distillers grains has been found to be more resistant to microbial degradation than SBM and casein (Little et al. 1968). The limitation to the amount of DDG from most of the cereal grains used for ethanol production that may be incorporated into ruminant diets is the low lysine content of the byproduct (Santos et al. 1984; Boila and Ingalls 1994).

2.3.3.2 Distillers grains as an energy source

Despite the high energy value of CDDG, the economic value of feeding the byproduct as a protein supplement is twice that as feeding it as an energy source (Aines et al. 1986). The energy value of CDDG is equal or slightly superior to corn because it contains highly digestible fiber and three times as much fat (Aines, et al. 1986).

Farlin (1981) reported increased feed intake, and feed efficiency when he included CWDG at 43% of the ration, as an energy source, replacing corn. Risk et al. (1982) using CWDG to replace all the corn in the diet reported reduced daily gains and DM intake, however, feed efficiency increased with higher levels of CWDG. Improved daily gains of cattle were reported by Firkins et al. (1985) when CWDG was included at 50% of the ration and attributed the improvement to higher digestible energy value for CWDG than suggested in NAS-NCR (1976) or that the absence of starch in CWDG may have resulted in higher rumen pH relative to the control ration and consequently fiber digestion may have improved. These studies suggest that feeding CWDG as a substitute for grain in finishing cattle rations at replacement level up to 50% of the ration does not result to decreased animal performance and suggest better performance. Wet corn distillers grains fed to finishing cattle replacing 21% corn in the ration, resulted in similar daily weight gains, feed intakes and feed conversion ratios as the control group fed dry rolled corn (85% corn, 10% hay and 5% supplement). Increasing the level of WCDG to 41% increases daily weight gains while feed intake is unaffected but feed conversion ratio is increased by 10% (Aines et al. 1986). Further increases in the level of WCDG up to 75% of the ration do not elicit any beneficial performance results (Table 2.3).

Cattle fed wet distillers by-products gained faster ($P<0.05$) and more efficiently ($P<0.10$) than cattle fed dry rolled corn (Ham et al. 1994). Compared to corn, wet distillers by-products contain 45.8% more energy while dry by-products contain 24% more energy. Therefore wet distillers by-products are superior energy sources compared

to CDDGS and are both superior to dry rolled corn for finishing cattle. The steers fed thin stillage had lower ($P<0.10$) ruminal pH (5.5) compared to the other diets (6.1). The total volatile fatty acid concentration was similar across the diets but the propionate concentration tended to be higher ($P<0.10$) for thin stillage steers resulting in a reduced acetate to propionate ratio. The infusion of thin stillage into the rumen through the rumen canula of the fistulated steers may have increased particulate passage rates which combined with lower ruminal pH may have resulted in suboptimal conditions for the survival of acetate producing bacteria. This condition may be responsible for reduced acetate to propionate ratio. The increased propionate would improve energy utilization and would help explain the improvement in feed efficiency from wet distillers by-products (WDB) observed in the finishing trial (Ham et al. 1994) (Table 2.4; 2.5).

Ham et al. (1994) based on the nutritive value of corn distillers byproduct suggested that:

1. There were no differences in performance for calves fed wet or dry distillers grains.
2. No matter what level of ADIN (low medium or high) in CDDG the performance of steers was not affected when CDDG was fed as an energy source.
3. Calves fed both CWDG and CDDG as an energy source gained faster and more efficiently than calves fed dry rolled corn.
4. Despite similar gains, calves on fed CWDG were more efficient than those fed CDDG, since they consumed less feed. It may therefore be safe to conclude from these results of this study that:

Table 2.3 The energy values of distillers grains for beef cattle.

Reference	Level in ration (% of DM)	Energy value (% of corn)
Rouse and Trenkle (1980)	15	116
Farlin (1981)	25	100
Farlin (1981)	50	124
Farlin (1981)	75	115
Hanke and Lindor (1982)	14.6	94
Risk et al. (1982)	10.5	83
Risk et al. (1982)	24.9	122
Risk et al. (1982)	43.6	110
Firkins et al. (1985)	25	103
Firkins et al. (1985)	50	122

(Adapted from Aines et al. 1986)

Table 2.4 Performance of calves fed corn distillers by-products supplements.

Supplemental protein[z]	ADG (kg d $^{-1}$)[y]	PE[x]	(%) RUP [w]	(%) ADIN CP[u]
Urea	**0.45**	-	-	-
WDG + TS	**0.66**	**2.6**	**54.9**	-
CDDGS				
low ADIN	**0.67**	**2.0**	**38.0**	**9.7**
medium ADIN	**0.67**	**1.8**	**47.4**	**17.5**
high ADIN	**0.70**	**2.5**	**49.4**	**28.8**

(Adapted from Ham et al. 1994).

[z] CDDGS = corn distillers dry grains with solubles, WDG = wet distillers grains and TS = thin stillage, dry matter intake averaged 2.3% (DM) of body weight.

[y] Average daily gain averaged across levels of supplemental protein.

[x] protein efficiency calculated as gain above urea controls divided by protein intake above urea controls (slope of regression lines).

[w] Rumen undegradable protein estimates after 12 hours of nylon bag incubation, values given as percentage of crude protein.

[u] acid detergent insoluble nitrogen used as a measure of the effect of heat damage its effect on digestibility.

Table 2.5 Effect of corn distillers by-products on performance of finishing cattle.

			DDGS[z]		
Item	**Control**	**WDB**	**ADIN Low**	**ADIN Medium**	**ADIN High**
Daily gain (kg d $^{-1}$)	**1.5^{b}**	**1.7^{c}**	**1.7^{c}**	**1.7^{c}**	**1.7^{c}**
DMI (kg d $^{-1}$)	**10.9^{de}**	**10.7^{d}**	**11.5^{ef}**	**11.3^{ef}**	**11.7^{f}**
Feed/gain	**7.5^{d}**	**6.4^{e}**	**6.9^{f}**	**6.7^{f}**	**6.9^{f}**

(Adapted from Ham et al 1994).
WDB = wet distillers by-products (40% of ration dry matter).
ADIN = acid detergent insoluble nitrogen.
DMI = dry matter intake.
[z] distillers grains with solubles (40% of the ration DM).
[b, c, d, e, f] means within a row with unlike superscripts differ ($p < 0.05$).

- Acid detergent insoluble nitrogen is a poor indicator of protein availability or utilization in distillers by-products.

- Drying does not affect protein efficiency but reduces net energy for gain.

- The increased propionate ratio in the thin stillage fed cattle would help explain the observed improvement in feed efficiency from the wet distillers by-products (WDB) during the finishing trial. This improvement in performance may be linked to an increased rate of passage which coupled with lower ruminal pH result in suboptimal conditions for the survival of acetate producing bacteria. This may the possible explanation of the reduction of the acetate to propionate ratio (Table 2.6).

2.3.3.3 The nutritive value of distillers grains as a source RUP

Faster rumen disappearance of dry matter (DM) and nitrogen (N) has been observed for wet and dry corn gluten feed compared to wet and dry corn distillers grains. Consequently, both wet and dry corn distillers grains register higher rumen undegradable protein values than wet and dry corn gluten feeds (Firkins et al. 1985).

Improvement in performance of steers fed wet corn distillers grains, as a replacement for up to 50% of dry or wet corn gluten feed of the ration, suggests that wet corn distillers grains is not only an important protein but also energy source for growing and finishing steers (Firkins et al. 1984). Wet and dry corn distillers grains, dry distillers grains with solubles and wet corn stillage supplements in high forage diets increases dry matter intake, apparent total tract digestibility, and crude protein digestibility (Muntifering et al. 1985). Dry matter, nitrogen and amino acids are less degraded for dry distillers grains

Table 2.6 Effect of corn by-products on ruminal pH and VFA concentrations.

	Treatments[z]					
Item	**DRC**	**WDG**	**TS**	**HOM**	**DCGF**	**WCGF**
Ruminal pH	**6.1[b]**	**5.9[b]**	**5.7[c]**	**6.1[b]**	**6.1[b]**	**6.1[b]**
Total VFA (mM/L)	**112.7**	**111.6**	**115.0**	**112.2**	**111.2**	**108.5**
Acetate (mM/L)	**59.0**	**59.5**	**49.3**	**59.6**	**56.6**	**56.9**
Propionate (mM/L)	**32.4[b]**	**26.5[b]**	**45.4[c]**	**31.1[b]**	**29.7[b]**	**29.8[b]**
Acetate:Propionate	**1.9[b]**	**2.4[b]**	**1.2[c]**	**2.1[b]**	**2.1[b]**	**1.9[b]**

(Adapted from Ham et al. 1994).

[z] DRC = dry rolled corn, WDG = wet distillers grains.
TS = thin stillage, HOM = hominy feed, DCGF = dry corn gluten feed and WCGF = wet corn gluten feed.
[b, c] Means within a row with unlike superscripts differ ($p < 0.05$).

than canola when effective degradability is measured. Rumen undegradable protein values of 44-53% for dry distillers grains have been reported (Hatch, 1993b). Ingalls (in Hatch, 1993b) reported, that when evaluating wheat dry distillers grains and canola meal, the major difference occurred in the rumen where degradability of nitrogen and amino acids was 50% higher for canola meal than for wheat dry distillers grains. In the same study, the order of limiting amino acids for dry distillers grains was identified as lysine, isoleucine, tyrosine, valine and threonine, whereas for canola meal the five most limiting amino acids were isoleucine, tyrosine, lysine, valine and leucine. Several workers have compared the protein value of distillers dried grains with or without solubles with soybean meal (Table 2.7). All these workers reported higher value of distillers grains relative to SBM (Table 2.7). Higher acid detergent fiber in wheat based dry distillers grains is responsible for a smaller soluble fraction and a larger potentially degradable fraction. The slower rate of degradation of this fraction results in a smaller effective degradability of DM and CP at each of the rumen outflow rates of 2%, 5% and 8% (Boila and Ingalls 1994) (Table 2.8).

2.3.3.4 Thin stillage as a potential supplement for ruminants

Thin stillage, a byproduct of ethanol production from grains, is obtained from the separation of whole stillage by screening pressing or centrifugation. The ethanol distillation process solubilizes over one half of the mineral content of the original grains, with most of this being found in thin stillage (Larson et al. 1982a). Thin stillage contains about 4.5% dry matter of which 40% is crude protein (Lee et al. 1991).

Table 2.7 RUP values of distillers by-products determined with fistulated steers.

Reference	By-product[z]	Rumen undegradable protein estimate	
		% of protein	% of SBM protein
Rounds (1975)	CDDGS	49	408
Rounds (1975)	CDDGS	43	358
Rounds (1975)	CDDGS	74	239
Rounds (1975)	CDDGS	40	129
Waller (1978)	CDDG	48	-
Waller (1978)	CDDGS	39	-
Brown (1983)	CDDG	46	229
Firkins et al. (1984)	CWDG	47	-
Firkins et al. (1984)	CDDG	54	-
Santos et al. (1984)	CDDGS	53	182

(Adapted from Aines et al. 1986).

[z] CWDG = Corn wet distillers grains, CDDG = Corn dried distillers grains and CDDGS = corn dried distillers grains with solubles and SBM = soybean meal. These values strongly support the theory that distillers products are relatively high in bypass protein and are potentially better sources of protein for ruminants than SBM.

Table 2.8 Disappearance and the effective degradability for dry matter and nitrogen in wheat-based distillers dried grains.

	Disappearance parameters[z]				Effective degradability[y]		
Item	***a*** **(%)**	***b*** **(%)**	***c*** **%(10^{-3} h^{-1})**	***d*** **(h^{-1})**	**2 (%)**	**5 (%)**	**8 (%)**
DDG[x]							
Dry matter	**28.5**	**53.2**	**36.7**	**0.10**	**63.5**	**51.3**	**45.3**
Nitrogen	**22.6**	**75.1**	**25.5**	**0.28**	**66.2**	**48.8**	**41.0**
Amino acids							
Lysine	**21.8**	**60.6**	**38.6**	**0.00**	**62.3**	**48.6**	**41.7**
Threonine	**22.1**	**76.6**	**23.2**	**0.12**	**64.9**	**47.3**	**39.6**
Phenylalanine	**18.7**	**80.0**	**25.9**	**0.10**	**65.6**	**47.2**	**38.9**
Tyrosine	**24.8**	**73.1**	**27.3**	**0.07**	**68.3**	**51.3**	**43.6**
Leucine	**14.1**	**84.6**	**22.7**	**0.67**	**61.0**	**41.5**	**33.0**
Valine	**17.2**	**81.5**	**21.8**	**1.03**	**61.5**	**42.5**	**34.4**
Isoleucine	**16.5**	**82.2**	**20.8**	**0.79**	**60.2**	**41.4**	**33.5**
Arginine	**17.3**	**78.6**	**27.6**	**0.21**	**64.6**	**46.4**	**38.1**
Histidine	**16.5**	**81.8**	**26.5**	**0.07**	**64.7**	**45.9**	**37.5**
Aspartate	**16.8**	**79.1**	**23.1**	**0.27**	**61.0**	**42.8**	**34.9**
Glutamate	**22.0**	**76.7**	**29.2**	**0.18**	**69.0**	**51.2**	**42.9**
Serine	**21.2**	**77.6**	**25.1**	**0.10**	**66.0**	**48.1**	**40.0**
Glycine	**23.4**	**65.0**	**36.9**	**0.00**	**66.3**	**51.5**	**44.1**
Alanine	**20.8**	**77.1**	**21.9**	**0.25**	**62.8**	**45.1**	**37.5**
Proline	**30.8**	**68.0**	**29.7**	**0.10**	**72.3**	**56.4**	**49.0**
Methionine	**-10.1**	**107.1**	**21.4**	**0.93**	**48.3**	**24.1**	**13.8**
Cystine	**-1.1**	**99.6**	**20.8**	**0.57**	**52.8**	**30.4**	**20.9**

(Adapted from Boila and Ingalls 1994).

[z] The disappearance parameters: ***a*** = soluble fraction; ***b*** = potentially degradable fraction; ***c*** = rate of degradation; ***d*** = lag time.

[y] Effective degradability (ED) estimated at rumen particulate outflow rates of 8%, 5% and 2% per hour.

[X] DDG = distillers dried grains.

Early research interest in thin stillage was based on the idea that when it was consumed by cattle it stimulated fiber digestion (Little et al. 1964; Little et al. 1970; and Chen et al. 1977). Beeson (1975) reviewed studies which indicated that the addition of dry distillers grains (DDG) or thin stillage at relatively low levels (0.5% of ration DM) to high urea liquid supplements increased nitrogen retention in ruminants.

Recent attention to thin stillage has focused on its use as a protein source for ruminants with particular interest in its RUP value (Aines et al. 1986). Growing calves and lactating dairy cows have high protein requirements and often benefit from RUP for high performance (Aines et al. 1986). Thin stillage offered to calves on pasture can potentially serve as an important source of nutrients. Various reports indicate that cattle fed high forage diets and supplemented with protein increase feed intake (Delcurtoo et al. 1990). Considering the high protein content of thin stillage and little research data on the product, there is a need to further study the effects of feeding this material to growing cattle.

2.3.4 Brewers grains as supplements for cattle

Wet brewers grains (WBG) are a byproduct from the beer brewing industry in which barley malt is fermented to produce beer. Wet brewers grains are by-products to the breweries and can be important sources of nutrients for livestock. The importance of WBG as a supplement for cattle, particularly growing cattle, may be attributed to its protein content and low rumen solubility. These factors make WBG a better choice under some circumstances over other soluble or highly rumen degradable products such as soybean and canola meals. Brewers grains is suitable as a protein supplement for high

producing ruminants such as dairy cows. Analysis of dried brewers grains indicates that its dietary undegraded crude protein (42%) is equivalent to corn gluten meal (41%) but with a superior amino acid balance than either soybean meal (SBM) (36%) or CGM (Cozzi and Polan 1994). The favorable production response for cattle fed dried brewers grains compared to those fed SBM or a combination of SBM and either DBG or CGM can be explained by a more favorably balanced amino acid profile in the ruminally undegraded protein than in the other diets (Cozzi and Polan 1994). Brewers grains (BG) and corn gluten meal (CGM) are about 6 times higher in rumen undegradable protein (RUP) than SBM. The high RUP of CGM is attributed to its gelatinous nature and lack of surface exposure in the nylon bags (Stern and Satter 1982) while the RUP of BG may be related to the alteration of the protein matrix due to heat during the brewing process. Higher performances of cattle fed DBG as a partial replacement of SBM may be attributed to the contribution of the RUP and energy that meets the amino acid needs that are limiting or co-limiting to higher animal performance (Cozzi and Polan 1994). WBG may be more digestible than the equivalent dry brewers grains (Porter and Conrad 1975). Murdock et al. (1981) has suggested that WBG can be utilized as a protein supplement and supply crude protein equivalent to SBM in lactating dairy cattle for milk production. Grenawalt et al. (1981) reported satisfactory milk production from cows fed rations containing 20% dry matter as WBG, however, milk production was depressed when WBG was increased to between 30% and 40%. The reason for the observed depression in dry matter intake may have been the high moisture content which because of rumen fill may be a limiting factor in dry matter intake. Dry brewer grains (DBG) have been

reported to supply similar duodenal microbial nitrogen flow when fed at 13% of the ration dry matter as soybean meal fed at 16% of the ration dry matter (Armentano et al. 1986). The resistance of DBG protein to ruminal degradation is optimized when used in combination with NPN or more degradable protein sources (Polan 1988).

2.5 Summary of literature review.

Distillers grains with and without solubles as ration ingredients have been used in ruminant diets for a long time. Most of the information available on distillers by-products has been investigated using corn distillers products. However, there is less information on the value and feeding potential for wheat distillers by-products. Information available on wheat distillers by-products is limited to the dry product with little or no information on the wet products (wet distillers grains and thin stillage).

In western Canada the major cereal cash crops include wheat, barley and oats. The ethanol industry in western Canada should therefore focus on utilizing the locally available wheat or barley by-products. The by-products from the ethanol industry including wet or dried distillers grains and thin stillage or dried thin stillage from wheat should be used to supplement high producing cattle where such supplementation is economical. Based on the literature one can conclude:

1. Corn dried distillers grains (CDDG) can be used to supplement growing cattle as a source of protein replacing 40% of the protein supplement.

2. Corn dry distillers grains has also been successfully utilized as an energy source replacing up to 40% of grain corn in the ration. Similarly wheat dry distillers grains has also been used as an energy supplement for growing ruminants.

3. There is little difference in the nutritive value of corn wet distillers grains (CWDG) and CDDG when fed to ruminants as protein supplements. However, the feeding of CWDG is more economical since it eliminates the drying process. The limitation to using CWDG is the short shelf life due to mold growth within 5 to 6 days.

4. Brewers grains is another good quality, high rumen bypass protein but is limited by location of the producer relative to the brewery and producers do not have equal access to the available sources of the grains.

5. There is need to evaluate wheat wet distillers by-products from production of ethanol.

However, in light of the lack of research on wet distillers by-products from wheat based fermentation for ethanol production, the objectives of this thesis were:

1. To evaluate the performance and carcass quality of cattle fed diets containing wet distillers grains from wheat based ethanol production and to contrast this performance to that obtained from diets based on wet brewers grains or standard feed ingredients common to western Canada, during the growing and finishing periods.

2. To examine the rate and extent of dry matter and protein digestion in the rumen from wet distillers grains, from wheat based fermentation, and to compare it to wet brewers grains, a commonly used protein supplement.

3. To investigate the chemical composition of thin stillage from wheat based ethanol production and its nutritive value for growing cattle grazing crested wheatgrass pastures.

3.0. Evaluation of wet brewers and distillers grains as a feed source for feedlot cattle.

3.1 Introduction

Optimum performance from any livestock enterprise depends to a large extent on how well the nutrient requirements are met. The two most crucial requirements are for protein and energy. Growing and finishing feedlot cattle require balanced diets in order to reach their full production potential. When producers are formulating diets for cattle, they should exercise care that the supply of nutrients meets the needs for the desired level of production. The most widely used system of nutrient estimation in North America, is the National Academy of Science-National Research Council (NAS-NCR 1984). This system allocates costs to every activity that the animal is engaged in and attempts to account for metabolic nutrient losses. The estimated energy and protein requirements for growing and finishing feedlot cattle are based on factors such as stage of growth, body frame size, level of production, age of the cattle, types and sources of the nutrients and period in which the end product is expected to be ready (NAS-NCR 1984). The protein requirement for growing and finishing cattle includes not only tissue growth but also rumen microbial growth. Since the rumen microbes contribute to the amino acid supply of cattle, it is important to take their requirements into account when formulating diets (NAS-NCR 1984).

Protein supplements for feedlot cattle in North America include soybean and canola meals. Canola meal is more widely used in western Canada than soybean meal because it is more readily available (Deacon et al. 1988; Khorasani et al. 1989). Other protein sources that are now available on the market include distillers grains with or without

solubles from cereal grain ethanol production. The supply of these supplements has increased due to the recent focus on the use of energy sources that do not contain lead and produce less ozone layer depleting gases than those produced by the fossil fuels (Distillers Feed Research Council 1982).

Ethanol production in western Canada is from wheat rather than corn as in the United States. Wheat dried distillers grains (DDG) has been evaluated as a source of rumen undegradable (RUP) protein due to its low protein degradability (Boila and Ingalls 1994). This makes it an attractive alternate to other more widely used protein supplements such as canola or soybean meal (SBM). The cost of drying wet distillers grains with or without solubles is, however, prohibitive and ultimately uses for the wet by-products could decrease the cost of protein supplementation. Wet distillers grains (WDG) from corn-based fermentation has been shown to be an excellent protein source for feedlot cattle (Aines et al. 1986; Ham et al. 1994; Firkins et al. 1984). Similarly, work with wet brewers grains (WBG) has shown it to be an excellent protein source that may be used in growing and finishing feedlot cattle diets (Porter and Conrad 1975; Grenawalt et al. 1981; Murdock et al. 1981). However, there is little or no work on the feeding value of wet distillers grains from wheat-based, ethanol production, for feedlot cattle. The objective of this trial was to evaluate the performance and carcass quality of cattle fed diets containing wet distillers grains (WDG) from wheat based ethanol production and to contrast performance to that obtained from diets based on wet brewers grains (WBG) or standard feed ingredients common to western Canada, during the growing and finishing periods.

3.2 Materials and methods

3.2.1 Experimental animals and housing

One hundred and twenty medium frame (MF) steers were purchased from commercial sources during May of 1992. The steers were fed and housed in outdoor pens at the University of Saskatchewan Beef Research Station at Saskatoon, Saskatchewan. The steers were managed according to the guidelines of the Canadian Council of Animal Care (Olfert et al. 1992). The cattle were adapted to feedlot conditions for a period of 14 days prior to the start of the trial. The experimental protocol is given in Table 3.1. The cattle with an average weight of 311 ± 24 kg (mean ± SD) were randomly allotted to 15 pens of 8 steers each. Allotment of steers in each pen was stratified to give a uniform weight across the fifteen pens. Each pen was assigned to one of the three dietary treatments.

3.2.2 Experimental diets and feeding protocol

Three dietary treatments were formulated. The control diet was formulated using standard feed ingredients common to western Canada. These included barley grain, alfalfa-brome hay, wheat straw and canola meal as a protein supplement during the growing period. The remaining two treatments used wet brewers or distillers grains as protein and energy supplements in the growing and finishing phases. The diets were formulated to provide 2.9 and 3.4 Mcal kg^{-1} of digestible energy (DE) in the growing and finishing phases, respectively. An outline of the experimental protocol of the feedlot trail is presented in Table 3.1.

Table 3.1 Outline of the experimental protocol for the feedlot feeding trial, 1992.

Date	Day	Activity
May 24	0	Steers arrived at U. of S. Feedlot, were vaccinated, dewormed, treated for transport disease and weighed. They were fed an adjustment diet. This diet was formulated to introduce steers to grain based diets 14 days prior to start of test diets.
May 28-June 10	1-14	Feeding of growing (concentrate MO1 used for the control and MO2 for brewers and distillers grains diets). Start of test weight calculated using the mean weight of days 13 and 14 weights. Thereafter steer weights and ultrasonic fat thickness were measured and recorded on a fortnightly basis up to end of test.
June 11-Aug. 18	15-84	Growing diet fed. End of growing period weight determined using the mean weight of days 82 and 83 (August 17 and 18).
August 19	85	Feeding of finishing diet starts concentrate diet MO3 used for all diets.
September 10		Feeding of revised finishing ration for the rest of the trial.
October 12	139	First group of steers shipped for slaughter at Intercontinental Packers plant at Saskatoon.
November 14	171	Last group of steers slaughtered, marking end of feedlot feeding trial.

A minimum of 12% crude protein was formulated for both the growing and finishing periods. Feed ingredients used in diet formulation, included barley grain, alfalfa-brome hay, wheat straw, limestone and a mineral, vitamin premix. Diet formulation was based on the NAS-NCR (1984) requirements for a 300 kg MF steer gaining 1.1 kg d^{-1} in the growing period, and maximum growth in the finishing phase. The steers were fed *ad libitum* twice daily at 0800 and 1600h. Each complete mixed ration was delivered to the steers by a feeder wagon, equipped with a mixing auger, and a weigh scale. Orts were collected and weighed every fourteen days. Data obtained was used to estimate dry matter intake (DMI) and feed conversion (kg feed kg^{-1} of gain) of cattle fed each treatment.

3.2.3 Data collection and analytical procedure

Body weights of steers at the start and end of the growing and finishing periods were determined from the mean of two consecutive weights. During the remainder of the trial period, daily weight gain was determined from fortnightly measurements. Steers were measured between the 12^{th} and the 13^{th} ribs for subcutaneous fat thickness (USFAT) and the area of the *longissimus dorsi* muscle (USREA) at the start of the trial, and on days 51, 73, 92, 107, 120, and at the end of the trial using the procedure of Perkins et al. (1992). This data was used to estimate carcass characteristics and composition of the live animal.

Complete mixed rations from feedbunks were collected every fourteen days and dried in a forced air oven (60°C for 72 hours) for dry matter determination. The samples

were ground through a 1 mm screen and analyzed for dry matter (DM) (method 7.003, Association of Official Analytical Chemists (AOAC) 1984), crude protein (CP) (Kjedahl-N method 7.015 AOAC 1984) acid (ADF) (method 7.076 AOAC 1984) and neutral (NDF) detergent fiber (Goering and Van Soest 1976). Calcium (Ca) and phosphorus (P) was determined using an atomic absorption spectrophotometer (Zazoski and Burau 1977).

The WBG was supplied by the Great Western Brewing Company Limited in Saskatoon, Saskatchewan. The WDG was from the PoundMaker Ag-Venture Ltd. ethanol plant at Lanigan, Saskatchewan. Due to the high moisture content and the possibility of spoilage, it was necessary to make a weekly trip to ensure an adequate supply of these ingredients.

Carcass data was obtained on all animals through Agriculture Canada's Blue Tag program. The left side of each carcass was cut on the morning after slaughter between the 12^{th} and 13^{th} ribs. Measurements taken on the exposed surface of the *longissimus dorsi* included thickness of the subcutaneous fat cover, *longissimus dorsi* area, cutability and marbling score. Randomly selected carcasses from the three dietary treatments (19, 25 and 18 steers, respectively, for canola control, WBG and WDG) were used for measurement and evaluation of carcass composition. Carcass composition was determined from 7-bone rib samples according to the method of McKinnon et al. (1993). Each rib was physically dissected into muscle, fat and bone components.

3.2.4 Statistical analysis

The experiment was a completely randomized design. Pen was used as the experimental unit. The data for the growing and finishing phases of the trial was analyzed using the General Linear Model of the Statistical Analysis System (SAS Inc. 1990). Rates of fat deposition and muscle growth were determined from ultrasonic measurements of animals backfat thickness and ribeye area during the trial. Simple regressions were used to analyze the effect of diet on carcass composition. Single degree of freedom contrasts were used to compare treatment effects on feedlot performance and carcass composition (Steel and Torrie 1980). Differences among contrasts were considered significant if a "P" value of less than 0.05 was noted. Contrasts of interest were: A = Control versus WBG; B = Control versus WDG; C = WBG versus WDG.

3.3 Results and Discussion

Ingredients and analysis of the concentrate mixes for the growing and finishing phases are given in Table 3.2. The concentrate for the control in the growing period contained 15.4% canola meal. The composition of the diets fed in the growing period is given in Table 3.3. The DM content of the WBG and WDG used in the trial was 22% and 28%, respectively (Table 4.2). During the growing period the WBG and WDG diets contained 44% and 32% WBG and WDG (% as fed) (16 and 13% DM), respectively. All three diets fed during the growing period met the minimum crude protein levels set by the NAS-NCR (1984) for growing medium frame steers.

Table 3.2 Ingredient composition and analysis of concentrate used in the growing (MO1 and MO2) and finishing (MO3) periods of the trial.

	Period		
	Growing		Finishing
Parameter	MO1	MO2	MO3
Ingredient (% as fed)			
Barley	81.1	97.0	97.0
Canola meal	15.4	-	-
Limestone	1.0	1.0	1.0
Mineral/Vitamin/ mix[z]	1.9	2.0	2.0
Ingredient (% DM)			
Barley	81.3	96.7	96.8
Canola meal	15.3	-	-
Limestone	1.0	1.1	1.2
Mineral/Vitamin/ mix[z]	1.7	2.0	2.0
Concentrate analysis (% DM)			
Dry matter	89.2	73.7	73.7
Total digestible nutrients	78.5	80.7	80.1
Crude protein	16.8	11.8	14.2
Acid detergent fiber	10.6	8.0	7.2
Neutral detergent fiber	22.5	18.0	20.6
Calcium	0.7	1.2	1.0
Phosphorus	0.5	0.5	0.3

[z] The mineral/vitamin premix contained 440,040 IU vitamin A, and 88,009 vitamin D kg^{-1} premix. Trace minerals in the mineral premix were: 19% calcium, 19% phosphorus, 5025 ppm zinc, 413 ppm iodine, 188 ppm iron, 8025 ppm manganese, 3000 ppm and 100 ppm cobalt.

Table 3.3 Composition and analysis of diets fed to the steers during the growing period of the trial

	Diet (%)[z]		
Parameter	**Control**	**WBG**	**WDG**
Concentrates (% as fed)			
MO1	59.0	-	-
MO2	-	30.0	37.0
Wet grains (% as fed)			
Wet brewers grains	-	44.0	-
Wet distillers grains	-	-	32.0
Forages (% as fed)			
Wheat straw	30.0	19.0	23.0
Alfalfa/brome hay	11.0	7.0	8.0
Concentrates (%DM)			
MO1	59.1	-	-
MO2	-	39.6	42.2
Wet grains (%DM)			
Wet brewers grains	-	18.4	-
Wet distillers grains	-	-	14.6
Forages (%DM)			
Wheat straw	29.9	30.7	32.1
Alfalfa/brome hay	11.1	11.3	11.2
Diet analysis (% DM)			
Dry matter	89.2	72.7	72.7
Total digestible nutrients	65.1	65.0	65.3
Crude protein	12.9	13.8	13.1
Acid detergent fiber	26.3	25.3	25.7
Neutral detergent fiber	44.7	47.5	46.8
Calcium	0.6	0.7	0.7
Phosphorus	0.4	0.6	0.4

[z] WBG = wet brewers grains and WDG = wet distillers grains.

Estimated energy levels during the growing diets were 65, 64.9 and 66.7% TDN for control, WBG and WDG, respectively (Table 3.3). The analyzed (dry matter basis) crude protein level for WBG (13.8%) was, however, slightly higher than that of the control (12.9%) and WDG (13.1%) diets (Table 3.3). Acid detergent fiber, NDF, Ca and P levels during the growing period were similar across diets. During the finishing phase of the trial, the forage to concentrate ratio was changed to provide higher energy levels (Table 3.4). This was achieved by reduction of the fiber content from hay while maintaining straw at 8% or less in control, WBG and WDG diets, respectively (Table 3.4). Wet brewers grains and WDG composed 19% and 13% (as fed) and 5.2% and 4.5% (DM basis), respectively, of the WBG and WDG finishing diets. Estimated energy in the finishing diets were 78.4, 78.3 and 78.7% TDN (Table 3.4). Chemical analysis indicates that the fiber fraction of the diets was reduced by approximately half, from 25% ADF during the growing period to 10% and 46% to 26% NDF during the finishing period. Protein levels were maintained at a minimum of 12% for the finishing phase (Table 3.4).

No differences were observed in weight gain and dry matter intake (DMI) over the course of the growing period (Table 3.5). Steers fed WBG tended ($P<0.10$) to have better feed conversions than steers fed the canola meal based control. The control steers consumed 7.5 kg of feed kg^{-1} weight gain, the WBG fed cattle consumed 6.8 kg of feed for every kg of weight gain. Cumulative bi-weekly gains during the period indicated, however, that the cattle fed WDG exhibited superior weight gains relative to the control fed animals through day 56 ($P<0.06$) and day 70 ($P<0.03$). The WBG fed cattle were intermediate in gain (Table 3.5).

Table 3.4 Composition and analysis of diets fed to the steers during the finishing period of the trial.

	Diet (%)[z]		
Parameter	Control	WBG	WDG
Concentrate (% as fed)			
MO3	93.0	76.0	79.0
Wet grains (% as fed)			
Wet brewers grains	-	19.0	-
Wet distillers grains	-	-	13.0
Forages (% as fed)			
Wheat straw	7.0	5.0	8.0
Alfalfa/brome hay	-	-	-
Concentrate (% DM)			
MO3	93.0	86.2	84.1
Wet grains (% DM)			
Wet brewers grains	-	6.8	-
Wet distillers grains	-	-	5.5
Forages (% DM)			
Wheat straw	6.9	6.9	10.4
Alfalfa/brome hay	-	-	-
Diet analysis (% DM)			
Dry matter	89.6	80.1	84.0
Total digestible nutrients	77.6	77.7	76.7
Crude protein	12.1	13.2	12.8
Acid detergent fiber	10.9	10.5	13.1
Neutral detergent fiber	28.8	25.5	25.9
Calcium	0.5	0.5	0.6
Phosphorus	0.4	0.5	0.4

[z] WBG = wet brewers grains and WDG = wet distillers grains.

Table 3.5. Summary of the performance of cattle fed wet brewers (WBG) and wheat wet distillers (WDG) grains or the control diet during the growing period of the trial.

	Treatment				Contrasts of interest (P>F)[z]		
	Control	WBG	WDG	SE[y]	A	B	C
Parameter							
Initial wt. (kg)	313.70	309.20	310.10	2.13			
Final wt. (kg)	420.80	424.60	424.70	3.60			
Days on feed	84.00	84.00	84.00	-			
DM Intake (kg)	9.47	9.12	9.71	0.28			
Feed conversion	7.50	6.80	7.20	0.30	0.10		
ADG[x] (kg d^{-1})							
Period (days)							
1-14	2.16	2.04	2.01	0.15			
1-28	1.56	1.66	1.60	0.07			
1-42	1.40	1.57	1.52	0.09			
1-56	1.41	1.53	1.57	0.05		0.06	
1-70	1.39	1.46	1.57	0.05		0.03	
1-84 (cumulative gain)	1.26	1.36	1.35	0.05			

[z] Contrasts of interest: A = Control versus WBG, B = Control versus WDG, C = WBG versus WDG

[y] SE = standard error of the mean.

[x] ADG = average daily gain.

The faster rate of gain observed during the biweekly periods may be the result of the higher rumen undegradable protein (RUP) in the WDG diet. Studies carried out using wet corn distillers grain, have attributed superior weight gains to protein which bypassed the rumen and became available for digestion in the duodenum (Firkins et al. 1985; Firkins et al. 1984; Risk et al. 1982 and Ham et al. 1994). Abrams et al. (1983) reported improved weight gain for cattle supplemented with corn wet distillers grains compared to cattle fed soybean meal. DeHaan et al. (1982) have suggested that corn wet distillers grains supported greater weight gains, improved feed conversion and superior protein efficiency than soybean fed cattle. Results of the present study, which show improvement in early weight gains, with WDG from wheat may be attributed to the high RUP content of the diet. Boila and Ingalls (1994), for example, have reported higher RUP levels for both CP and amino acids from dried wheat distillers grains relative to canola meal. A greater amount of protein would have escaped degradation in the rumen and thus become available for postruminal digestion and absorption in the WDG diets. The failure to see a consistent response to WDG over the entire growing period may be due to the fact that bypass protein needs decrease as the animal matures and develops. Several studies have shown, for example, that only young rapidly growing cattle respond to supplemental bypass protein (NAS-NCR 1985; McKinnon 1992).

The control fed steers gained faster ($P<0.05$) than the WBG fed steers during the finishing period (Table 3.6). Cattle fed WDG were intermediate. Other parameters examined including DMI and feed conversion did not show any differences during this period (Table 3.6).

Table 3.6. Summary of the performance of cattle fed wet brewers (WBG) and wheat wet distillers (WDG) grains or the control diet during the finishing period of the trial.

	Treatment				Contrasts of interest (P>F)[z]		
	Control	WBG	WDG	SE[y]	A	B	C
Parameter							
Initial wt.	420.80	424.60	424.70	3.60			
Final wt.	513.50	506.80	505.70	3.90			
Days on feed	66.60	66.00	61.50	2.40			
DM Intake (kg d^{-1})	10.47	10.06	10.91	0.41			
Feed conversion	7.53	8.07	8.32	0.45			
ADG (kg d^{-1})							
Period (days)							
85-99	1.68	1.22	1.51	0.21			
85-113	1.11	1.02	1.30	0.10			0.08
85-127	1.39	1.23	1.39	0.05	0.03		0.04
85-141	1.39	1.21	1.49	0.06	0.07		0.01
85-slaughter (cumulative gain)	1.40	1.25	1.32	0.05	0.05		

[z] Contrasts of interest: A = Control versus WBG; B = Control versus WDG; C = WBG versus WDG.

[y] SE = standard error of the mean.

[x] ADG = average daily gain.

If one examines the cumulative weight gains of the cattle, it can be seen that the control fed cattle gained faster than the cattle fed WBG from day 42 onward (Table 3.6). Similarly the cattle fed WDG gained at faster rates ($P<0.08$) than WBG fed cattle from day 28 (Table 3.6). Dry matter intakes were similar across treatments for the trial. Cattle fed the control diet had the lowest feed conversion ratio, this, however, was not significant ($P<0.05$). Weight gain by the control fed cattle was 12% higher than the WBG fed cattle. The most probable explanation for this observation is that the control cattle benefited from compensatory growth due to their relative poor performance during the growing phase. During the growing period the control fed steers did not gain at the same rate as the other treatment groups, particularly during the first 56 to 70 days. When the performance of cattle fed the three dietary treatments was compared over the total period, there was no influence of treatment on overall performance (Table 3.7). No differences were seen in gain, intake or feed conversions. This would indicate that diets based on WDG from wheat based fermentation will support growth at similar levels to that found with diets based on wet brewers grains or standard feedlot ingredients.

Development of fat and muscle throughout the trial as measured by ultrasound is given in Figures 3.1 and 3.2. Fat deposition was found to be linear for cattle fed all three treatments (Table 3.8). The rate of fat deposition for the control, WBG and WDG fed cattle were 0.049, 0.051 and 0.055 mm d^{-1} throughout the trial (Table 3.8). There were no significant differences noted in the rate of fat deposition between the three treatments.

Table 3.7 Performance of cattle fed wet brewers (WBG) or wheat wet distillers (WDG) grains or canola meal control over the course of the entire feeding period.

	Treatment				Contrasts of interest (P>F)[z]		
	Control	WBG	WDG	SE[y]	A	B	C
Parameters							
Start of test wt. (kg)	313.70	309.20	310.10	2.13			
End of test wt. (kg)	513.50	506.80	505.70	3.90			
Days on feed	151.60	151.00	146.50	2.40			
Daily gain (kg)	1.32	1.31	1.34	0.03			
DM Intake (kg d^{-1})	9.96	9.59	10.30	0.32			
Feed conversion	7.60	7.30	7.70	0.30			

[z] Contrasts of interest: A = Control versus WBG, B = Control versus WDG, C = WBG versus WDG.
[y] SE = standard error of the mean.

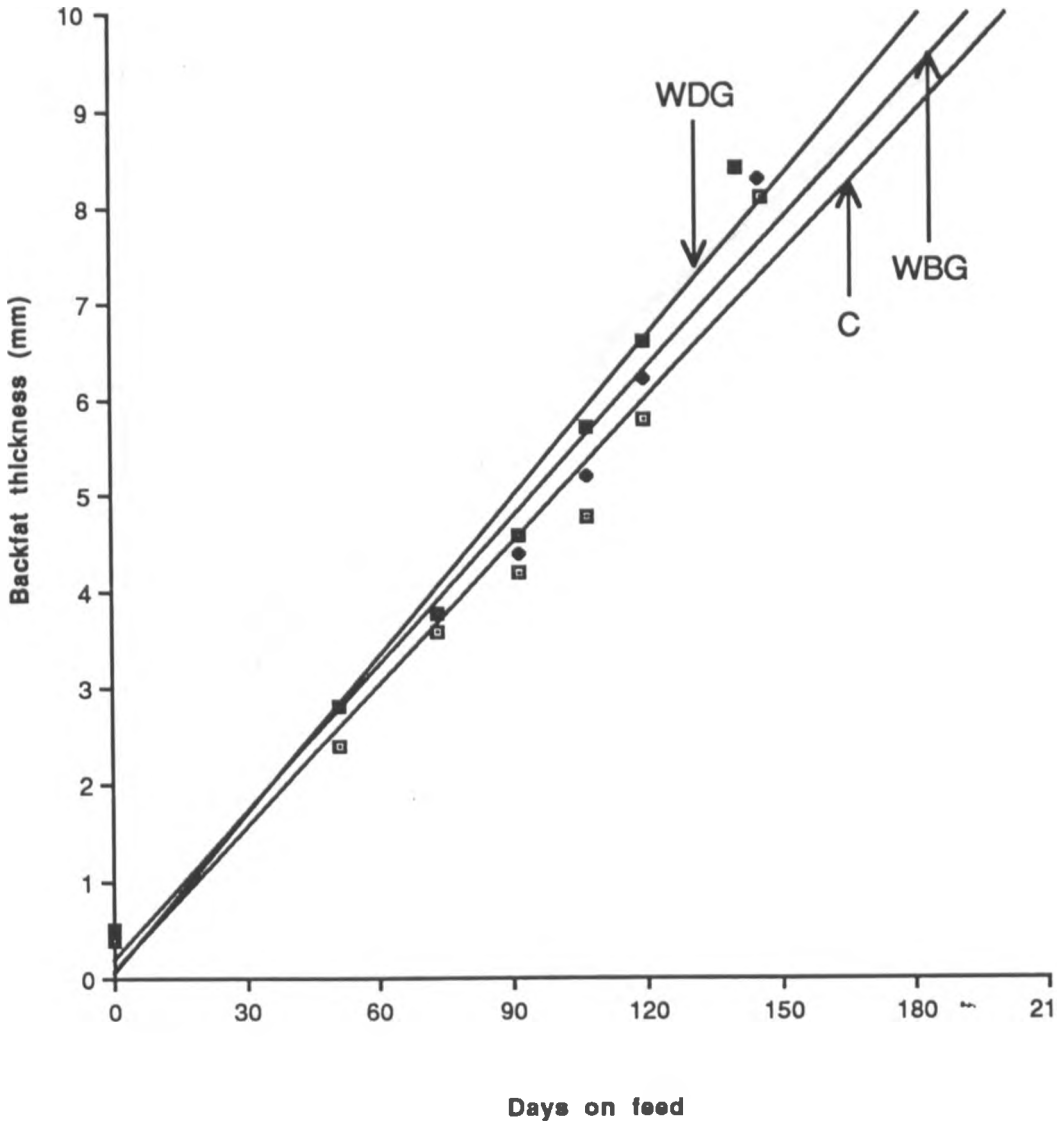

Figure 3.1 Fat development in cattle fed the control (C), wet brewers (WBG) or distillers (WDG) grains diets.

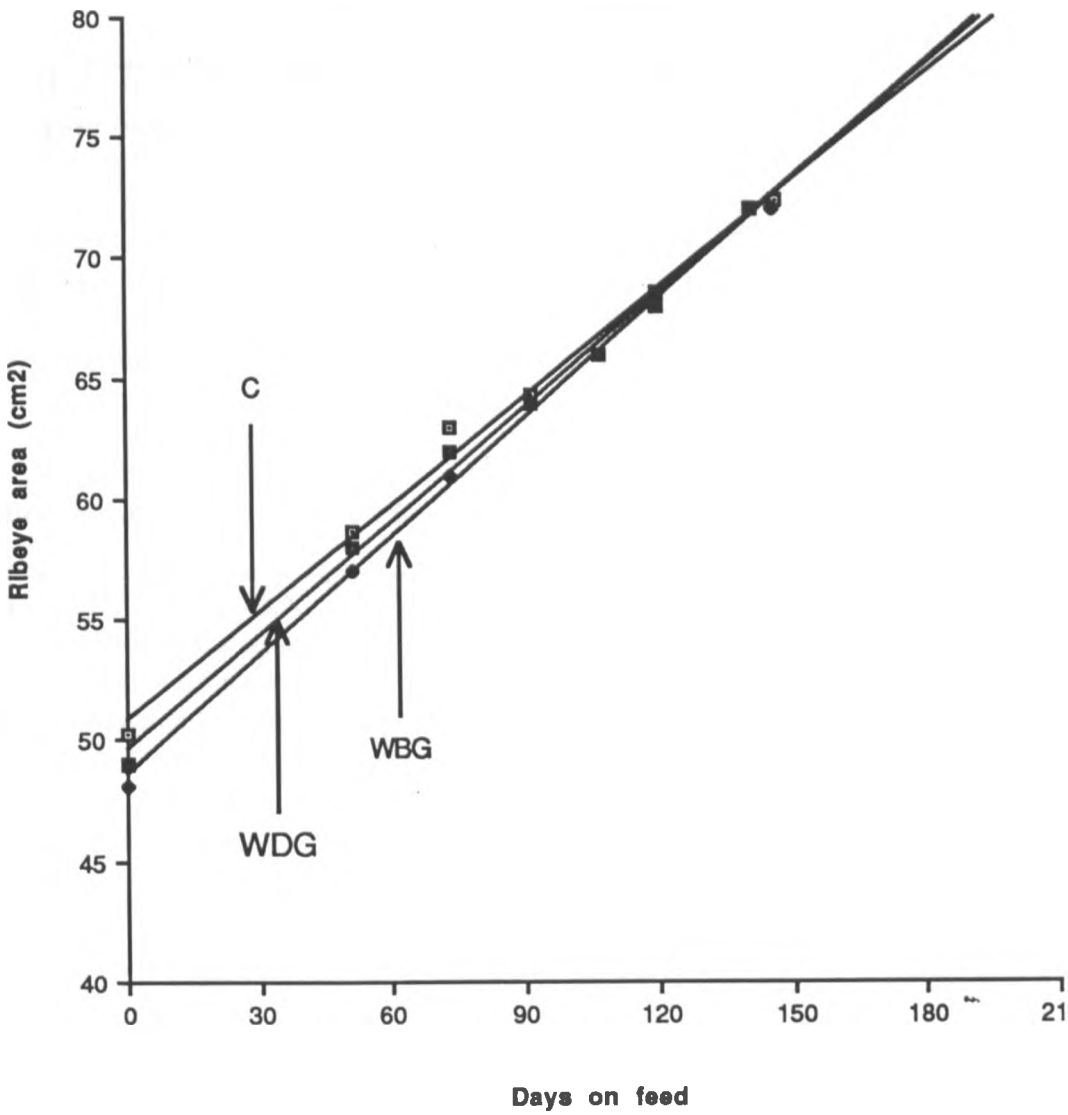

Figure 3.2 Muscle development in cattle fed the control (C) wet brewers (WBG) or wet distillers (WDG) grains diets.

Table 3.8 Linear regression parameters for rate of fat (mm d^{-1}) and ribeye (cm^2 d^{-1}) development for steers fed the control, wet brewers (WBG) and wheat wet distillers grains (WDG) diets.

	Tissue development			
	Slope[z]	SE[y]	r^2	R SD
Fat development (mm)				
Control	0.049	0.002	0.65	1.56
Wet brewers grains	0.051	0.002	0.67	1.55
Wet distillers grains	0.055	0.002	0.74	1.41
Rib eye development (cm^2)				
Control	0.150	0.009	0.43	6.64
Wet brewers grains	0.167	0.009	0.55	6.03
Wet distillers grains	0.158	0.009	0.56	5.52

[z] No quadratic effects detected.
[y] SE = standard error of the slope.
r^2 = Coefficient of determination.
RSD = Residual standard deviation.

The rate of USREA muscle development was 0.15, 0.17 and 0.16 cm^2 d^{-1} in the control, WBG and WDG diets, respectively (Table 3.8). No significant differences were observed between the three treatments. These values while similar to those obtained by other workers (Hamlin et al. 1991; Bergen, personal communication) indicate that cattle fed the WDG diet exhibited similar growth characteristics for carcass fat and muscle over the course of the feeding period as cattle fed the WBG diet or the control based on standard feed ingredients.

Similarly carcass traits collected at slaughter (Table 3.9) did not show any significant differences among treatments. Contrasts for carcass composition indicated higher ($P<0.05$) percent intermuscular fat for cattle fed WDG relative to both WBG and control fed cattle. WBG fed cattle had higher ($P<0.02$) subcutaneous fat than the WDG fed cattle (Table 3.9). These results and that of the live animal ultrasound indicate that carcass growth and development and quality at slaughter will be similar for cattle fed WDG as a protein supplement relative to conventional fed cattle. Hanke and Lindor (1982) observed similar results for cattle fed corn wet distillers grains. These workers found no differences in carcass characteristics over those fed high moisture corn and urea. All carcass characteristics examined in this study including carcass weight, marbling score, kidney, heart and pelvic fat, ribeye area, fat depth quality grade and yield and yield grade, were similar.

Table 3.9 Carcass characteristics and composition of cattle fed the control, wet brewers (WBG) or wheat wet distillers (WDG) grains diets.

	Treatment				Contrasts of interest (P > F)[z]		
	Control	WBG	WDG	SE[y]	A	B	C
Carcass characteristics							
Weight (kg)	273.60	269.40	269.90	3.00			
Dressing (%)	55.10	55.00	55.10	0.30			
Rib Eye Area (cm^2)	74.60	72.90	74.20	1.50			
Cutability (%)	59.90	59.20	59.50	0.30			
Average fat (mm)	7.50	7.90	8.00	0.30			
Marbling score	1.10	1.20	1.20	0.06			
Carcass composition							
Bone (%)	21.50	21.40	21.40	0.30			
Lean (%)	53.60	54.10	54.40	0.70			
Fat (%)	24.90	24.40	24.20	0.70			
Intermuscular fat (%)	51.00	50.80	52.80	0.30		0.01	0.01
Subcutaneous fat (%)	36.20	37.50	34.70	0.60			0.02
Body cavity fat (%)	12.80	11.70	12.40	0.50			

[z] Contrasts of interest: A = Control versus WBG, B = Control Versus WDG and C = WBG Versus WDG.
[y] SE = standard error of the mean.

3.4 Conclusion

In this trial, there were few differences noted between the performance of cattle fed conventional feeds, WBG or WDG in the growing and finishing phases. Some improvement in growth was noted during the growing phase with cattle fed WBG relative to the control. This effect was not, however, seen over the entire period. Cattle fed WDG from wheat based fermentation exhibited performance at least equal to that from cattle fed control or WBG diets during the growing period. Similarly cattle fed WDG gained equally as well during the finishing period. No adverse effects were seen on carcass composition or live animal muscle or fat development. Based on this work it can be concluded that WDG from wheat based fermentation from ethanol production is a satisfactory ingredient for growing and finishing cattle. This implies that this product can be effectively utilized as a protein and energy supplement for ruminants.

4.0. *In Situ* rumen disappearance of dry matter and crude protein from wet brewers and distillers grains.

4.1 Introduction.

In order to establish the amounts and ratios of nutrients necessary for optimal microbial and animal growth, one must first predict the degree to which the nutrients are available in the rumen. There are several techniques that have been used to estimate the contribution of feed protein or carbohydrate to rumen fermentation. Techniques for estimation of ruminal protein and carbohydrate digestion have been extensively reviewed (Hoover et al. 1991; Czerkawski and Breckennridge 1977; Broderick 1978; Krishnamoorthy et al. 1982; Nocek 1988; Erdman et al. 1987; Campling 1990 and McAllister 1990). The energetic value of a diet or a feed depends on organic matter digestion in the rumen and in particular, on starch digestion (Cerneau and Michalet-Doreau 1991). Starch digestion by ruminants is governed by the site (ruminal or intestinal) of digestion, nature of the feed and degree of processing (Cerneau and Michalet-Doreau 1991). In view of the importance of rate and extent of degradation of dietary protein, a lot of attention has been focused on this area of protein digestion (Ørskov 1982). Soluble proteins become attached very rapidly to bacterial cell walls and are thus rapidly degraded (Nugent et al. 1983). Feed sources that contain less soluble protein become attached to rumen bacteria, but are slowly or poorly degraded. Chemical properties of proteins such as number of disulfide bridges and tertiary structure may be partly responsible for lower degradability. Other enzymatic activities such as endopeptidases and exopeptidases may also be partially involved in the slow degradability of some protein supplements (Ørskov 1982). Estimates of the degradability

of protein in the rumen are essential for the application of systems for the evaluation of protein requirements of the ruminant (National Academy of Sciences-National Research Council (NAS-NCR 1989)). The most extensively evaluated and utilized procedure is the *in situ* nylon bag technique (Nocek 1988).

Distillers grains and brewers grains are by-products of industries that produce alcohol through yeast fermentation of cereal grain. A conversion of starch to alcohol results in the production of a byproduct with higher cell wall and protein content than the original grain substrate. Both wet brewers and dry brewers grains have been extensively evaluated as protein supplements in cattle diets (Porter and Conrad 1975; Murdock et al. 1981; Grenawalt et al. 1981; Davis et al. 1983; Polan et al. 1985; Armentano et al. 1986; Polan 1988 and Cozzi and Polan 1994). Wet and dry corn distillers grains have also been evaluated as protein supplements in cattle diets (Rounds 1975; Waller et al. 1980; Firkins et al. 1984; Santos et al. 1984; Muntifering et al. 1985; Aines et al. 1986; Beyla et al. 1989; Delcurtoo et al. 1990 and Ham et al. 1994). Corn-based distillers grains has higher protein content than the grain from which it is produced (Beyla et al. 1989). Furthermore, the corn-based distillers grains has a rumen undegradable protein (RUP) value of 55%, making it a more valuable protein source for dairy cattle than the corn itself. The high RUP content is a result of the distillation process where the cooking temperature exceeds 120^{o}C. Recent research has focused on the value of wheat distillers grains as a protein source for cattle. Most of this evaluation work on wheat distillers grains has been done on dried distillers grains (Heinemann 1986; Hatch 1993a and Boila and Ingalls 1994). As with corn, dry distillers grains from wheat based fermentation has

been shown to be high in RUP. For example, Boila and Ingalls (1994) noted that wheat dried distillers grains had high rumen undegradable protein and amino acids compared to canola meal. No work has been carried out to evaluate the nature of the protein from wet distillers grains from wheat based fermentation. This is important because drying results in further heating and may alter the protein degradation characteristics. The objectives of this study were to look at the rate and extent of dry matter and protein digestion in the rumen from wet distillers grains, from wheat based fermentation (WDG), and to compare it to wet brewers grains (WBG), a commonly used bypass protein supplement.

4.2 Materials and methods

4.2.1 Experimental animal and housing

A 650 kg fistulated Holstein cow was housed in a 10 x 10 m pen in the University of Saskatchewan, Animal and Poultry Department metabolism barn. The cow was kept in an individual pen for effective management during the experimental protocol. The cow was fed twice daily at 0800 and 1400h. The diet consisted of 2.5 kg concentrate, 0.5 kg alfalfa hay and 5.5 kg barley silage (as fed basis per feeding). Water and salt were provided *ad libitum.* The cow was managed according to the guidelines of the Canadian Council of Animal Care (Olfert et al. 1992).

4.2.2 Experimental treatments and *in situ* rumen incubation procedure

This study examined *in situ* nutrient disappearance from two products of cereal grain processing. Wet brewers grains (WBG) and wet distillers grains (WDG). Wet brewers grains was supplied by the Great Western Brewing Company at Saskatoon,

Saskatchewan. Wet distillers grains was supplied by PoundMaker Ag-Ventures Ltd., at Lanigan, Saskatchewan. Two samples of each grain were evaluated. Samples of WBG and WDG, were collected over the winter of 1991/92, from the feeding trial described in Chapter 3, and dried in a forced air oven at 40°C for 72 h, composited and ground through a 1 mm screen. These samples were designated as wet brewers grain trial (WBGT) and wet distillers grain trial (WDGT). A second sample of each grain type was collected from each source after the feeding trial in 1992. These post trial samples were designated wet brewers grains post trial (WBGP) and wet distillers grains post trial (WDGP). Wheat grain and barley malt were collected from the same sources for laboratory analysis. Duplicate samples (6 g) of each treatment were incubated in nylon bags (12 x 19 cm with 50 μm porosity) in the rumen for 2, 4, 6, 8, 12, 24 and 48 h. Bags were put in the rumen in the morning before the cow was fed. The bags were put in the rumen starting with the 48 h first and 2 h incubation last. All bags were removed at the same time. Three separate incubations were carried out and were used as replicates in the study. Following removal from the rumen, the bags were washed according to the procedure described by McKinnon et al. (1991) and dried in a forced air oven at 60°C for 3 d. Samples were then analyzed for DM and CP according to AOAC methods described in Chapter 3. Nutrient disappearance was calculated from DM and CP residues in the nylon bags following each incubation period. Rumen kinetic parameters were calculated according to the equation of Ørskov and McDonald (1979) using an interactive nonlinear regression procedure of the Statistical Analysis System Institute Inc. (SAS Inc. 1990):

$$P = a + b(1-e^{-ct})$$

where ***P*** represents the amount degraded at time ***t***; ***a*** the rapidly soluble fraction, ***b*** the potentially degradable fraction and ***c*** the fractional rate constant at which ***b*** is degraded with the constraint that $a + b \leq 100$. Effective degradability (ED) in the rumen for DM or CP was estimated using the equation of Ørskov and McDonald (1979):

$$ED = a + (b*c)/(c+k)$$

where ***k*** represents the rumen dilution rate (5% h^{-1}) and ***a***, ***b*** and ***c*** refer to the nonlinear parameters described above.

4.2.3 Statistical analysis

The experiment was a completely randomized design (Steel and Torrie 1980) with four treatments. These included wet brewers (WBGT and WBGP) and wet distillers (WDGT and WDGP) grains collected during and after the trial, respectively. Data analysis was performed using the General Linear Model of the SAS Inc. (1990). Mean separation was accomplished using single degree of freedom contrasts (Steel and Torrie 1980) for *in situ* DM and CP disappearance and effective DM and CP degradability. Contrasts of interest were: A. WBGT versus WDGT; B. WBGP versus WDGP; C. average of WBG versus average of WDG feeds.

4.3 Results and Discussion

Analysis of the feeds fed to the cow used in the *in situ* incubations is presented in Table 4.1. These feed ingredients are standard feeds for dairy cattle in western Canada. The nutrient composition of the wet brewers and distillers grains used in the *in situ* incubations are given in Table 4.2. Crude protein concentration was slightly higher for brewers than distillers grains (Table 4.2). Average values were 28.5 and 25.5%,

Table 4.1 Ingredient make up of the barley based concentrate and chemical analysis of the feed used in the fistulated cow ration.

Ingredient		DM	CP	ADF	NDF	Ca	P
Concentrate (% as fed)							
Barley	**74.50**						
Soybean meal	**8.05**						
Canola meal	**7.93**						
Canola oil	**0.96**						
Dicalcium-phosphate	**0.96**						
Sodium chloride	**0.74**						
Phosphorus (25%)	**0.93**						
Mineral-Vitamin premix[z]	**5.93**						
Analysis (DM basis)							
Concentrate		**89.8**	**15.8**	**5.8**	**20.9**	**0.8**	**1.0**
Hay		**86.6**	**17.7**	**28.4**	**36.4**	**1.8**	**0.2**
Silage		**35.9**	**16.6**	**31.7**	**58.2**	**0.3**	**0.3**

[z] Mineral-Vitamin premix contained: Vitamin A = 333334 IU kg^{-1}; Vitamin D_3 = 60000 IU/kg; Vitamin E (SD) = 1000 IU/kg; Iron(carbonate) = 1050 ppm; Zinc (oxide) = 2100 ppm; Manganese (oxide) = 1500 ppm; Copper (sulfate) = 533.33 ppm; Iodine = 45 ppm; Cobalt (carbonate) = 15 ppm; Selenium (sodium selenite) = 12 ppm; Mg = 3.33%; K = 1.8%; S = 1.0%; Na = 6.3%; Chloride = 10.35%; Ca = 16.10% and P = 8.5%.

Table 4.2 Chemical analysis of pre (barley malt and wheat grain) and post (wet brewers and wet distillers grains) fermentation products used in the incubation study.

Ingredient[z]	DM	CP	EE	ADF	NDF	Ash	Ca	P
Pre fermentation products								
Barley malt	92.7	13.1	2.3	5.2	20.2	2.4	0.0	0.3
Wheat grain	90.5	15.9	1.8	3.5	19.6	1.9	0.0	0.3
Post fermentation products								
WBGT[y]	21.2	28.9	6.7	23.2	65.4	4.2	0.3	0.1
WBGP	22.4	27.9	6.5	22.9	65.5	4.5	0.3	0.2
WDGT[y]	29.2	25.6	6.2	23.9	66.7	2.8	0.2	0.6
WDGP	28.3	25.5	6.3	24.1	65.9	2.7	0.2	0.6

[z] analysis reported on dry matter basis

[y] WBGT and WBGP = wet brewers grains used in the trial and post trial, WDGT and WDGP = wet distillers grains used in the trial and post trial.

respectively. Acid detergent fiber and NDF were similar for both WBG and WDG collected during and after the feeding trial. Wet brewers grains exhibited slightly higher fat levels (6.6 versus 6.3%) than WDG. Phosphorus levels were three times as high for WDG relative to WBG (0.6 versus 0.15%). Table 4.2 also shows values for barley malt and wheat grain. Fermentation has concentrated the nutrients in the post fermentation products. This result has been observed by numerous workers (Heinemann 1986; Boila and Ingalls 1994; Grenawalt et al. 1983; Davis et al. 1983; Cozzi and Polan 1994).

The wet brewers grains and WDG used in the *in situ* incubations were air dried in a forced air oven at 40°C for 72 h. This procedure was carried out to dry the products. A low drying temperature was chosen to avoid heat damage to the protein fraction of the grains. Heat damage to protein results in lower rumen protein degradability (McKinnon et al. 1991; Kennelly and De Boer 1986). Boila and Ingalls (1994) observed reduced ruminal degradation of dry matter and protein as a result of drying wheat distillers grains.

Dry matter disappearance from wet brewers (WBG) and distillers (WDG) grains is presented in Figures 4.1 and 4.2. Results were similar for samples collected during (Figure 4.1) and after (Figure 4.2) the trial for both feed sources. Dry matter disappearance was greater from WDG ($P<0.05$) at 8, 24 and 48 h for trial samples (Figure 4.1) and at 2, 4, 24 and 48 h for post trial samples (Figure 4.2).

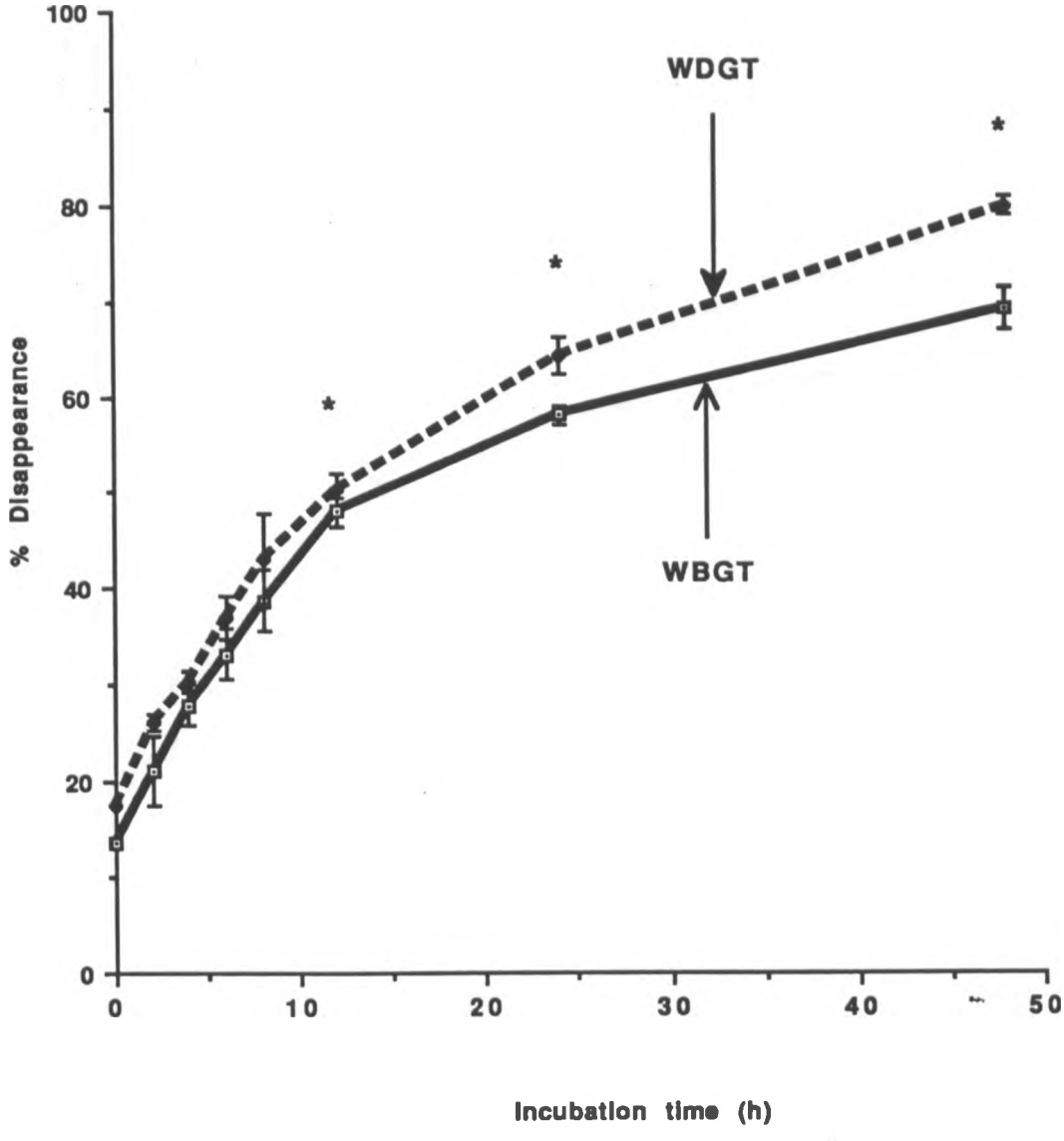

Figure 4.1 Dry matter disappearance from wet brewers (WBGT) and distillers (WDGT) grains collected during the trial (* significant difference P<0.05).

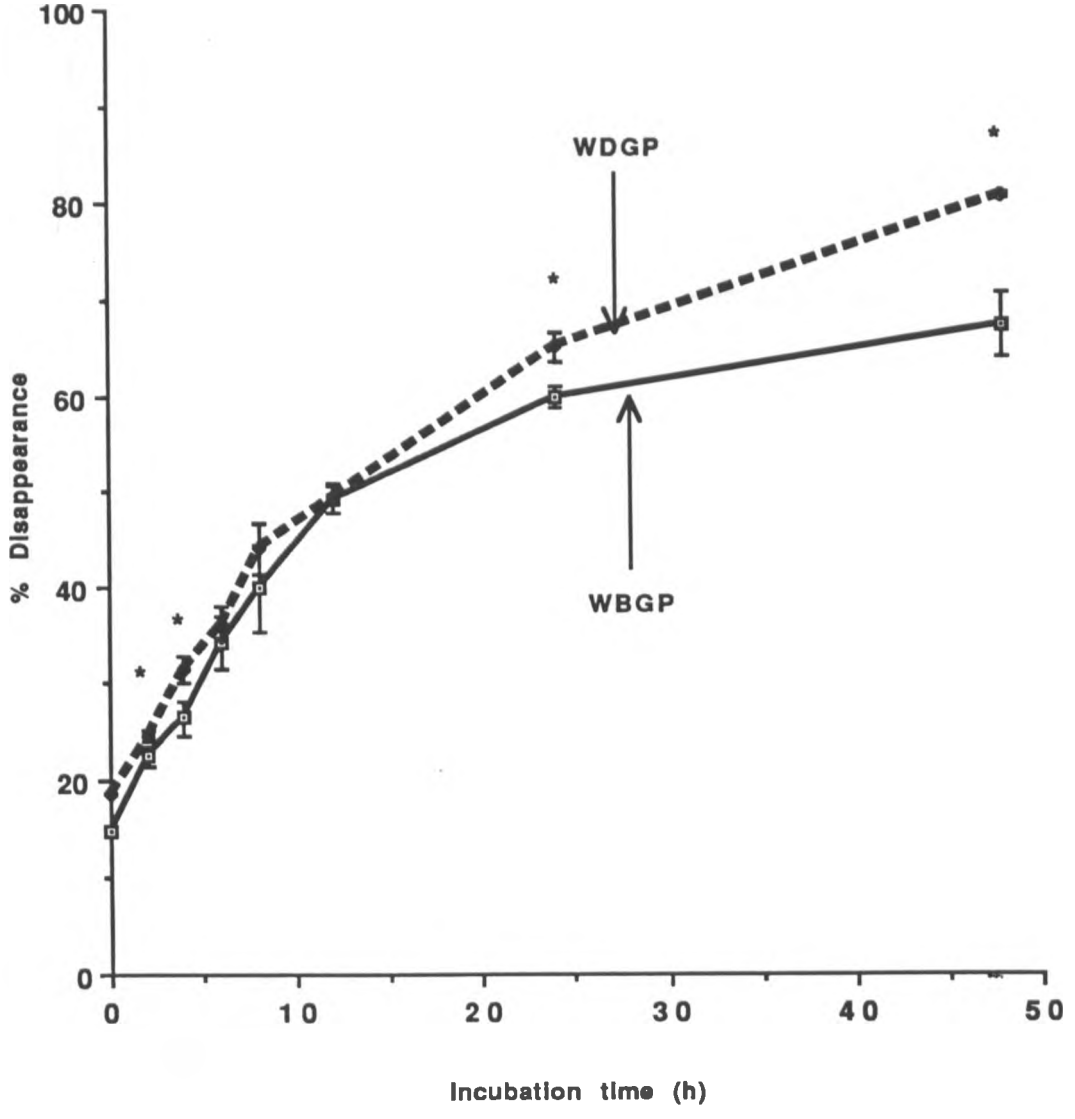

Figure 4.2 Dry matter disappearance from wet brewers (WBGP) and distillers (WDGP) feeds collected after the feeding trial (* significant difference $P<0.05$).

These results are reflected in the *in situ* kinetic parameters for dry matter which are presented in Table 4.3. These parameters were used to calculate the effective dry matter degradability (Ørskov and McDonald 1979). Wet brewers grains exhibited a lower ($P<0.05$) soluble DM fraction (***a***) and a lower ($P<0.05$) (***b***) or potentially degradable fraction. No significant differences were noted in ***c*** values or rates of DM digestion although when the values were averaged, WBG tended ($P<0.08$) to be degraded faster (7.57 versus 5.38 % h^{-1}). As a result of the differences in ***a*** and ***b*** fractions, WDG exhibited a greater ($P<0.01$) effective DM degradability (sample averages 47.2 versus 52.8%).

With respect to CP, WDG exhibited greater CP loss at all incubation times except the 2 and 4 h incubation for the samples collected during the trial (Figure 4.3). Similarly, for the post trial samples greater CP losses were seen at 8, 24 and 48 h incubations (Figure 4.4). These results would indicate that the protein from WBG is more resistant to rumen degradation than that from WDG. Examination of the *in situ* kinetic parameters shows that WBG and WDG have similar ***a*** or soluble CP fractions (range 24.7-27.9%) (Table 4.3). Averaged across samples, WBG had a higher ($P<0.05$) potentially degradable fraction (***b***) (62.9 versus 57.8%) than WDG (Table 4.3). The two WBG samples exhibited similar rates (***c*** value) of CP disappearance (average 7.14% h^{-1}). The WDGP exhibited a similar ***c*** value or rate of CP disappearance as WBG samples (7.17% h^{-1}). However, the WDG trial sample exhibited a significantly higher ($P<0.01$) rate of CP disappearance (14.2% h^{-1}).

Table 4.3 Dry matter (DMD) and crude protein (CPD) disappearance and effective degradability (EDMD and ECPD) from wet brewers (WBG) and distillers grains (WDG).

	Treatment[z]						Contrasts of interest P>F[x]		
	WBGT	WBGP	Average	WDGT	WDGP	Average	SE[y]	A	B	C
DMD[w]										
a	13.70	13.93	13.82	18.47	18.70	18.58	0.74	0.01	0.01	0.01
b	57.23	54.97	56.10	65.90	67.00	66.45	1.41	0.01	0.01	0.01
c	7.22	7.92	7.57	5.49	5.28	5.38	1.12	NS	NS	0.08
EDMD										
k = 5%	47.07	47.37	47.22	52.77	53.00	52.88	0.86	0.01	0.01	0.01
CPD[w]										
a	27.90	25.57	26.74	24.83	24.73	24.78	1.41	NS	NS	NS
b	57.07	58.57	57.82	61.67	64.80	62.94	1.99	NS	0.05	0.02
c	7.97	6.85	7.14	14.12	7.17	10.65	0.83	0.01	NS	0.01
ECPD										
k=5%	62.97	59.33	61.15	70.40	62.77	66.59	0.78	0.01	0.01	0.01

[z] Treatment are brewers grain used in trial (WBGT) and those collected post trial (WBGP), distillers grains used in trial (WDGT) and those collected post trial (WDGP).

[y] SE is standard error of the mean.

[x] Contrasts of interest: A = WBGT versus WDGT, B = WBGP versus WDGP and C = average of WBG versus average of WDG feeds.

[w] Disappearance parameters *a* = rapidly degradable fraction (%), *b* = potentially degradable fraction (%), *c* = degradation rate constant for *b* fraction ($\%h^{-1}$) and *k* = the rumen particulate outflow rate used for estimation of EDMD and ECPD.

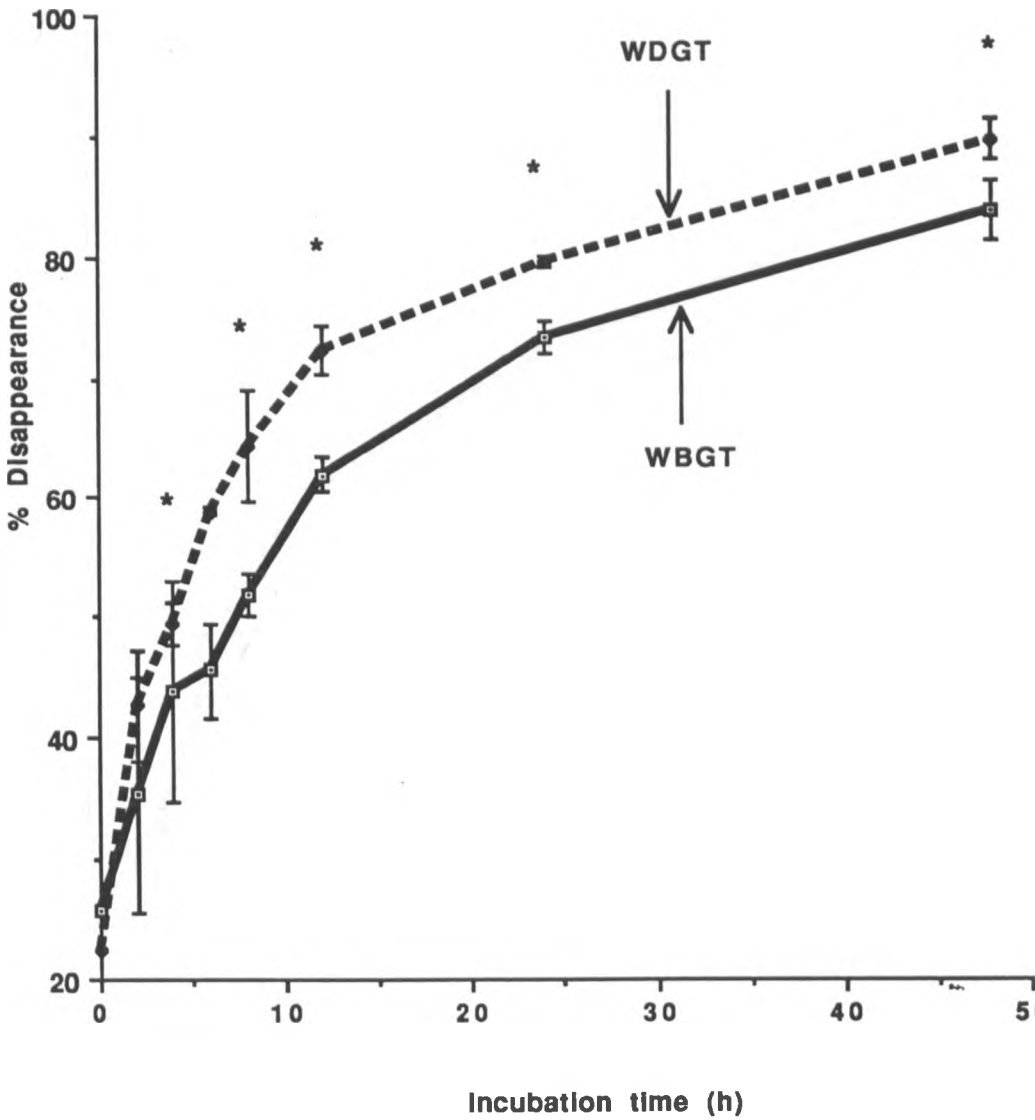

Figure 4.3 Crude protein disappearance from wet brewers (WBGT) and distillers (WDGT) grains collected during the trial (* significant difference P<0.05)

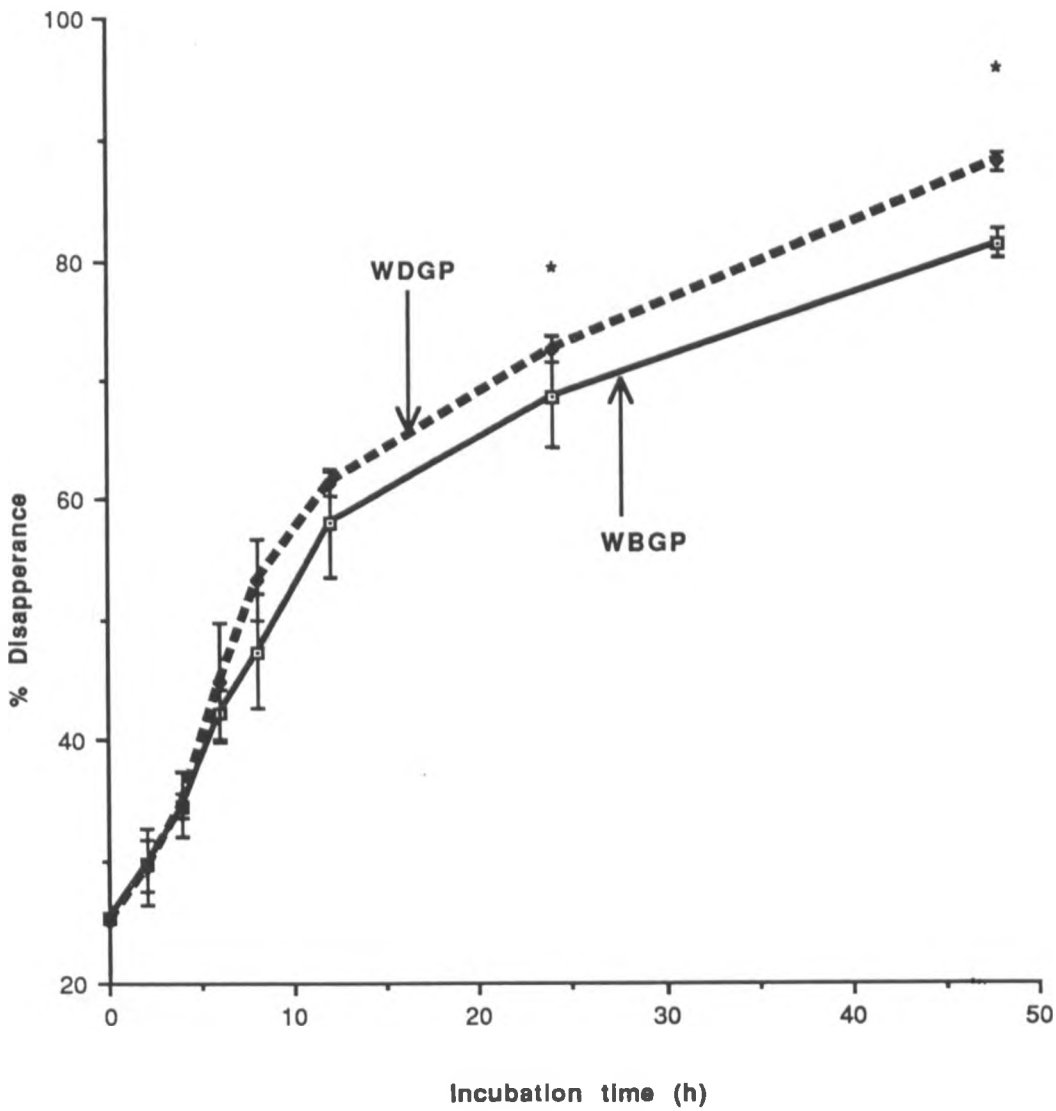

Figure 4.4 Crude protein disappearance from wet brewers (WBGP) and distillers (WDGP) grains collected after the feeding trial (* significant difference $P<0.05$).

Examination of the data shows no apparent reason for this discrepancy other than the fact that in this data set, protein disappeared faster at all incubation times. The extent of protein disappearance was similar at 24 hours of incubation. When samples were averaged, the WBG exhibited a slower rate ($P<0.01$) of CP disappearance (7.1 versus 10.7% h^{-1}) (Table 4.3). Consequently, effective CP degradability was greater ($P<0.01$) for WDG (66.6%) than for WBG (61.2%).

The soluble fraction (***a***) of WDG reported in this trial for DM disappearance (18.6%) is smaller than that (28.5%) reported by Boila and Ingalls (1994). This difference is unexpected because the samples of Boila and Ingalls (1994) underwent further drying, a process which should reduce the (***a***) value. No reason for this disappearance is apparent. The potentially degradable fraction (***b***) observed in this study (66.5%) was higher than (53.2%) that reported by Boila and Ingalls (1994). Examining the ***c*** value, WDG used in this study exhibited a higher rate of degradability (5.4% h^{-1}), compared to that (3.6% h^{-1}) observed by Boila and Ingalls (1994). This would be expected because of the heat applied to DDG during the drying process. Despite these differences in rumen kinetic parameters and processing of the distillers grains used in the two studies, the EDMD, reported by Boila and Ingalls (51.3%) is close to that (52.9%) observed in this study. Other studies using distillers grains from various cereals grains have been carried out. Shelford and Tait (1986) reported non-significant differences in EDMD from rye (67%) and corn (68%) distillers grain. Weiss et al. (1989) compared barley distillers grains and SBM. No significant differences in dry matter degradability between the two protein sources were noted. Offer and Offer (1992b) observed EDMD

from malt barley distillers grains of 43%, estimated at a rumen outflow of 6% h^{-1}, in sheep. The effective dry matter degradability value for WBG feeds reported in this study (47.2%) is close to those reported by Santos et al. (1984) (52%) and Davis et al. (1983) (55%).

The sum of the soluble fraction (***a***) and the potentially degradable DM fraction (***b***) averaged 85% for the average of the two WDG samples, respectively. Boila and Ingalls (1994) noted a value of 81% in dried distillers grains for fractions ***a*** and ***b.*** The difference between the two trials may be attributed to the extra drying applied to the dried distillers grains used by Boila and Ingalls (1994). The drying process has the effect of alteration of the protein properties of the feedstuff, thereby increasing its rumen undegradability.

Effective crude protein degradability for distillers grain averaged 66.6% at 5% h^{-1} rumen outflow rate. This value is higher than 48.8% reported by Boila and Ingalls (1994). The difference in ECPD observed in these two trials may be attributed to the same explanation used for the differences observed in EDMD. The extra heat applied during drying increases the RUP content of the byproduct. Shaver (1992) reviewed research papers and quoted average RUP content from dried and wet corn distillers grains at 55 and 50%, respectively. The effective crude protein degradability from WBG averaged 61.2%. Work carried out using other cereal grains has been documented. Weiss et al. (1989) noted an ECPD from dried barley distillers grains of 57.6%. Shelford and Tait (1986) reported ECPD from dried rye distillers grains with solubles (73.4%) and dried corn distillers grains with solubles (73.9%).

Effective nutrient disappearance from WBG and WDG was characterized by larger soluble CP than DM fractions (Table 4.3). As observed with EDMD, the effective crude protein disappearance from WDG feeds was higher ($P<0.01$) than from WBG feeds. The larger soluble and potentially degradable fractions may have contributed to the larger ECPD (Table 4.3). The rate of degradation **(c)** of the degradable crude protein fraction (***b***) did not differ except for the WDGT sample which showed a high value (14%) compared to an average of (7%) for the other feeds (Table 4.3). This higher value in this sample contributed to the high ECPD (70%) for the WDGT and WDG (average) (66.6%) compared to the WBG (average 61.2%) samples.

The sum of the soluble and degradable CP fractions (***a***) and (***b***) was 88% compared to 98% reported by Boila and Ingalls (1994). However, the effective crude protein disappearance from this study estimated at a rumen outflow rate of 5% was 66.6% compared to the 48% reported by Boila and Ingalls (1994). The differences in the present study compared to Boila and Ingalls (1994) may be attributed to the extra heat applied to distillers grains during drying. The review by Shaver (1992) indicates that the RUP in wet corn distillers grains is 50%. In dried distillers grains the RUP value was 55% (Shaver 1992). The RUP value for wet distillers grains from wheat in the present study was 33%. The high rate of degradation (***c***) in the WDGT sample played a role in making the ECPD higher than expected. The implication of this result is that the microbes degraded WDG at a much faster rate than was the case for the Boila and Ingalls (1994) trial. Cozzi and Polan (1994) reported 42% ECPD for dry brewers grains. This value is much lower than that reported in this study (61%). The large difference in

the ECPD for these two products may be explained by the effect of drying the brewers grains by Cozzi and Polan (1994) compared to the product used in this study.

Work has also been carried out to determine the rumen digestibility from other protein sources. Mustafa et al. (unpublished data) have estimated EDMD and ECPD from borage meal (BM), soybean meal (SBM), canola meal (CM) and corn gluten meal (CGM). These workers found EDMD values for BM, SBM, CM and CGM of 48.8, 78.7, 64.5 and 32.5%, respectively. In the same trial, ECPD was estimated as 61.7, 71.2, 68.0 and 11.2% for BM, SBM, CM and CGM, respectively. Kirkpatrick and Kennelly (1987) examined the EDMD and ECPD from barley, CM, SBM and meat and bone meal (MBM). The results of their study indicated that MBM had the lowest EDMD and ECPD while the other protein sources used in the trial ranged from 63 to 74% for EDMD and 60 to 73% for ECPD. These values give an indication of the role that may be played by wheat wet distillers grains as a source of RUP for ruminants. If one compares the EDMD for WBG and WDG in the present study to these values, one could conclude that these supplements have relatively high bypass values for DM compared to canola meal or SBM. Effective CP disappearance values are, however, only slightly lower than reported values for canola meal or SBM. Compared to high bypass sources such as corn gluten meal, these products would at best be considered as intermediate sources of bypass DM and protein.

4.4 Conclusion

The results of this study indicate that WBG had lower disappearance of both DM and CP than WDG. This implies that if both products are fed to cattle, those fed WBG could benefit more from RUP than those fed WDG. The lower DM and CP degradation observed in the dry wheat distillers grains used by Boila and Ingalls (1994) relative to the values in the present study may be attributable to the extra heating applied to DDG prior to rumen incubation. Compared to canola meal and soybean meal, the two by-products used in the present study would be expected to have high rumen undegradable dry matter values but only slightly higher bypass protein values. Wheat wet distillers grains or WBG may be used to replace the standard protein supplements currently used in western Canada and supply slightly higher levels of RUP. The use of these two by-products may be limited due to the cost involved in transportation for producers who are not close to processing plants.

5.0. Thin stillage from wheat based fermentation as a water source for cattle grazing crested wheatgrass pastures.

5.1 Introduction.

Distillers by-products are produced when whole stillage is screened, centrifuged or pressed. Such a processing results in wet distillers grains and the pressed liquid or thin stillage (Aines et al. 1986). Thin stillage from corn based fermentation has a total solids content of 4 to 8%. It consists primarily of suspended and dissolved particles that include spent grains, yeast cells and soluble nutrients that are not utilized during the fermentation process. Corn thin stillage has been shown to be an excellent source of crude protein (28-30%) calcium (1.4%) and phosphorus (2.1%) (Aines et al. 1986) and an excellent source of nutrients for growing and finishing cattle (Larson et al. 1982; Aines et al. 1986; Ham et al. 1994). Early interest in corn thin stillage was based on the idea that it stimulated fiber digestion (Little et al. 1964; Little et al. 1970 and Beeson 1975). More recent work on corn thin stillage has focused on the rumen undegradable protein content of stillage (Larson et al. 1982a; Aines et al. 1986; Ham et al. 1994).

In western Canada, extensive corn production is not viable due to the climate. However, wheat production which is common can be an alternate cereal substrate for ethanol production. Thin stillage from wheat based ethanol production may differ in nutritive value than that from corn based ethanol production. Lee et al. (1991), for example, showed that thin stillage from western Canadian ethanol production plants, contains 4.5% DM of which 45% is CP. There has been no research which has examined the nutritional value of thin stillage from wheat based ethanol production as a nutrient source for cattle.

Cattle fed low quality roughages or grazing winter grasses have been shown to improve their performance when provided with protein supplements. Barton et al. (1992) reported improvement in utilization of intermediate wheat grass in terms of total organic matter intake, higher ruminal ammonia and total volatile fatty acids (VFA) for steers supplemented with cottonseed cake compared to the control steers. Similarly, Hannah et al. (1991) reported an improvement in forage utilization for steers supplied with protein supplements. Hennessy (1983) and Pitts et al. (1992) reported improvement in the rate of weight gain for grazing cattle supplemented with protein sources. Hennessy (1983) used a protein pellet composed of cotton seed cake (80%), meat (10%) and fish meal (10%). Pitts et al. (1992) used cotton seed meal as the source of protein.

Drying thin stillage to produce dry distillers solubles (DDS) is an expensive method of utilizing this product as a supplementary source of nutrients for cattle. One alternative to drying would be to feed this product in liquid form close to the ethanol plant. Growth of cattle on pasture is often limited by energy and protein supply. Often available nutrients are insufficient to meet requirements. An attractive means of supplementing thin stillage would be to make this product available to grazing cattle as a replacement for water. No work has been done, however, on the feeding value of wheat based thin stillage to grazing cattle that are in an active stage of growth. The objective of this trial was to investigate the chemical composition of thin stillage from wheat based ethanol production and its nutritive value for growing cattle grazing crested wheatgrass pastures.

5.2 Materials and methods

5.2.1 Experimental animals and housing

Forty medium frame steers (265 ± 4.0 kg) were purchased from commercial sources during May 1992. The steers were processed and housed at Termuende Research Station at Lanigan, Saskatchewan. The steers were managed according to the guidelines of the Canadian Council of Animal Care. The cattle were randomly assigned to 1 of 8 crested wheatgrass paddocks (2 ha each). Five cattle were assigned to each paddock. The paddocks were then assigned to one of two dietary treatments. These included water or thin stillage as a drinking source. Two adjacent pastures were allotted to the same treatment since they shared one drinking trough. This enabled ten animals to drink from the one trough.

5.2.2 Experimental diets and feeding protocol

Each 2 ha pasture of crested wheatgrass was grazed by five steers with access to water or thin stillage. Thin stillage and water levels were monitored and the 1136 liter troughs were refilled daily, to ensure that there was an *ad libitum* supply of fresh water or thin stillage for each group of steers.

5.2.3 Data collection and analytical procedure

Fluid consumption of steers on each treatment was measured using a calibrated meter rule. The amount of water or thin stillage in the trough before and after filling was recorded daily. Dry matter and digestible energy intake from thin stillage were estimated from daily consumption of thin stillage.

Daily weight gains were calculated from body weights taken at the start and at 14 day intervals throughout the test and at the end of test. Start of test and end of test weights were the mean of two consecutive daily weights. Pasture samples were clipped in all experimental pastures every 14 days and analyzed for crude protein (CP), acid detergent (ADF) and neutral detergent (NDF) fiber, calcium (Ca) and phosphorus (P) contents using AOAC procedures as outlined in Chapter 3. Ultrasound backfat measurements were carried out at the start and end of trial, using the procedure outlined in Chapter 3. Six samples of thin stillage were collected using two liter containers during the trial, freeze dried and analyzed for CP, ADF, NDF, Ca and P using AOAC methods outlined in Chapter 3.

5.2.4 Statistical Analysis

Results of the experiment were analyzed using the General Linear Model of Statistical Analytical System (SAS) Inc. (1990). Mean comparison was accomplished using a Student's T-Test (Steel and Torrie 1980). For average daily gain (ADG) and ultrasound data, the pasture with 5 animals was considered the experimental unit (N=8). For fluid consumption, the experimental unit was the two adjacent pastures with access to one drinking trough (N=4).

5.3 Results and Discussion

The analysis of thin stillage (Table 5.1) shows high CP (average 48.5 ± 1.83%) and fat levels (9.63 ± 1.63%). Average CP and fat values for number one Canadian hard spring wheat are 14.8 and 1.73%, respectively (Saskatchewan Feed Test Lab.). The

relatively high levels in thin stillage are a reflection of nutrient concentration during fermentation and for CP in particular, the addition of yeast cells used for fermentation. The fat value reported in this study is similar to that reported by Aines et al. (1986) (9.0%) for corn dry distillers solubles and Ham et al. (1994) (9.2%) for thin stillage from corn. Phosphorus levels in the present study were three times those of the original grains (Table 4.2).

Acid and neutral detergent fiber values were 3.5 and 34.5%, respectively. Additional energy would have been available from the fiber in thin stillage. The acid detergent fiber (3.5%) is lower while the NDF (34.5%) is higher than that reported by Huhtanen and Miettinen (1992) (6.0% ADF and 10% NDF) for wet distillers solubles (WDS). Crude protein and fat contents were also lower in the Huhtanen and Miettinen (1992) study relative to the present study. Their product was, however, based on corn and not wheat as in the present study. The fat level in the present study was reflected in a high energy value for thin stillage. The energy (DE) value of thin stillage was estimated at 3.96 Mcal kg^{-1} DM. This energy value was determined from the average proximate analysis of the samples collected throughout the study. The regression equation of Bath et al. (1986) was used to determine this value.

The nutritive value of CWG pastures declined throughout the trial (Figure 5.1).

Table 5.1 Analysis of thin stillage samples collected throughout the during grazing trial.

	Nutrient[z]												
Sample number	DM %	CP %	Fat %	ADF %	NDF %	Ash %	Ca %	P %	Mg %	Cu ppm	Zn ppm	Mn ppm	Fe ppm
1	8.52	49.40	9.47	3.26	28.60	8.38	0.30	1.12	0.62	12.80	54.30	94.30	481.80
2	9.10	50.50	12.80	2.88	38.80	8.52	0.40	1.21	0.62	13.00	73.80	118.40	617.60
3	8.12	47.20	9.07	3.41	33.40	6.86	0.29	1.10	0.66	13.00	71.20	101.10	316.90
4	8.01	50.20	8.86	4.10	37.20	6.71	0.31	1.12	0.64	12.00	74.30	108.20	402.00
5	8.51	45.80	9.55	3.04	-	8.57	0.45	0.98	0.70	10.20	73.50	108.30	388.90
6	8.30	48.00	8.06	3.63	-	8.88	0.46	0.99	0.70	10.50	69.10	100.30	377.40
Mean	8.42	48.50	9.63	3.39	34.49	7.99	0.37	1.09	0.66	11.90	69.40	105.10	430.70
SD[y]	0.35	1.83	1.63	0.44	4.55	0.95	0.08	0.09	0.04	1.28	7.65	8.40	105.80

[z] Expressed as % of dry matter or parts per million (ppm DM basis).
[y] SD = standard deviation.

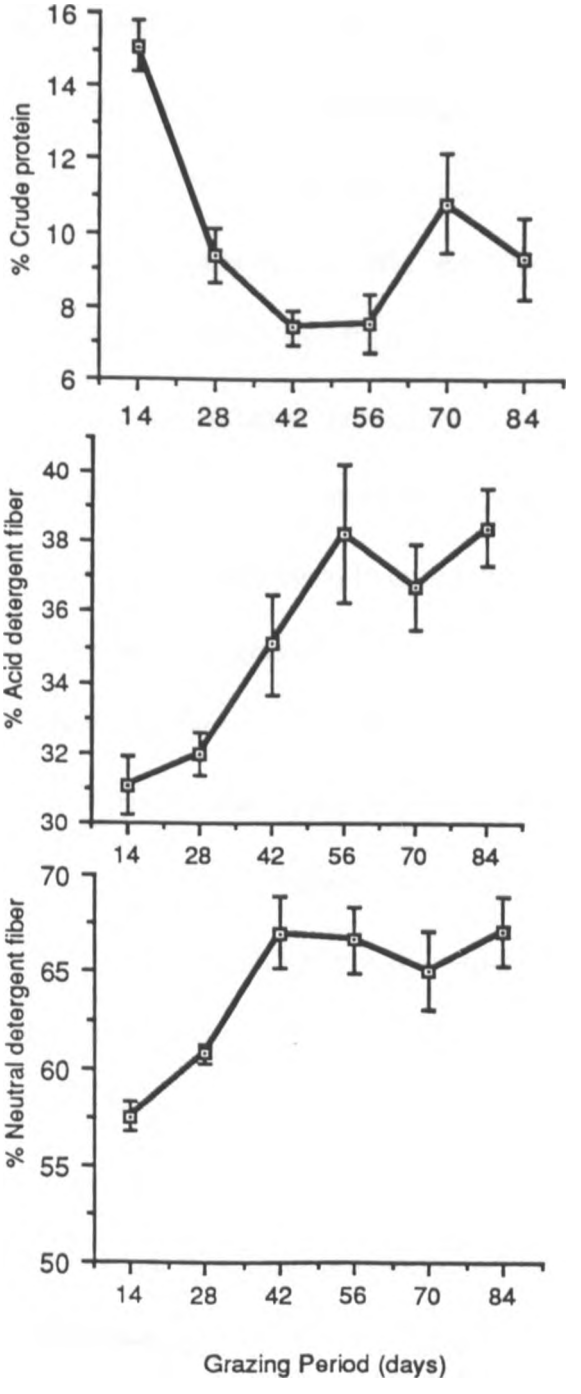

Figure 5.1 Average crude protein, acid and neutral detergent fiber contents for crested wheatgrass pastures over an 83 day grazing trial.

The decline in the CP content combined with an increase in the levels of both ADF and NDF (Figure 5.1) are indications of lower nutritional status of the CWG pasture towards the end of the trial. Crude protein content decreased from 15% to 9% while ADF and NDF both increased in content from 31% to 38% and 57% to 67%, respectively (Figure 5.1). In contrast Ca (0.43 to 0.48%) and P (0.21 to 0.12%) values stayed relatively constant and did not show great variation throughout the trial. Similar seasonal declines in plant nutrient composition have been reported for crested wheatgrass (Wright 1986; McCaughey 1989). These workers attempted to minimize this decline in nutritive quality of CWG as the pasture season progressed, by application of nitrogen fertilizer. Their results showed that the application of N fertilizer to crested wheatgrass pastures improved the status of the pasture and supported higher ($P<0.05$) growth rates in grazing cattle. These results are encouraging because they show that effective management practices can be used to improve the growth of cattle grazing CWG.

Table 5.2 shows that despite slightly lower start of test weights, cattle fed thin stillage had higher ($P<0.05$) end of test weights. Consequently average daily gain over the course of the trial was greater for cattle with access to thin stillage (1.39 versus 0.91 kg^{-1}). Figure 5.2 illustrates that this improvement in performance was significant from day 42 of the trial. At the start of test, fat depth as measured by ultrasound was zero for both stillage and water fed cattle (Table 5.2). However, at the end of test, stillage supplemented cattle had accumulated more fat ($P < 0.05$) (2.52 versus 0.60 mm) than the water treatment group (Table 5.2).

Table 5.2 Performance of cattle grazing, crested wheatgrass pastures, with access to water or thin stillage.

	Treatment			
Parameter	Water	Stillage	SE[z]	P < F
Body weight (kg)				
Start	269.6	262.0	3.9	-
End	362.7[a]	402.0[b]	6.5	0.05
Daily gain	0.9[a]	1.4[b]	0.1	0.05
Ultrasound fat (mm)				
Start	0.0	0.0	-	-
End	0.6[a]	2.5[b]	0.3	0.05
Fluid intake (Liters d^{-1})				
Actual	32.7[a]	44.8[b]	2.3	0.05
Corrected for DM	32.7[a]	41.2[b]	2.3	0.05
Nutrient intake from stillage				
DM (kg d^{-1})	0.00[a]	3.58[b]	0.19	0.05
DE (Mcal d^{-1})[y]	0.00[a]	14.18[b]	0.19	0.05

[a,b] Means in rows with different superscripts differ P<0.05.
[z] SE = standard error of the mean.
[y] Estimated from the regression equation of Bath et al. 1986.

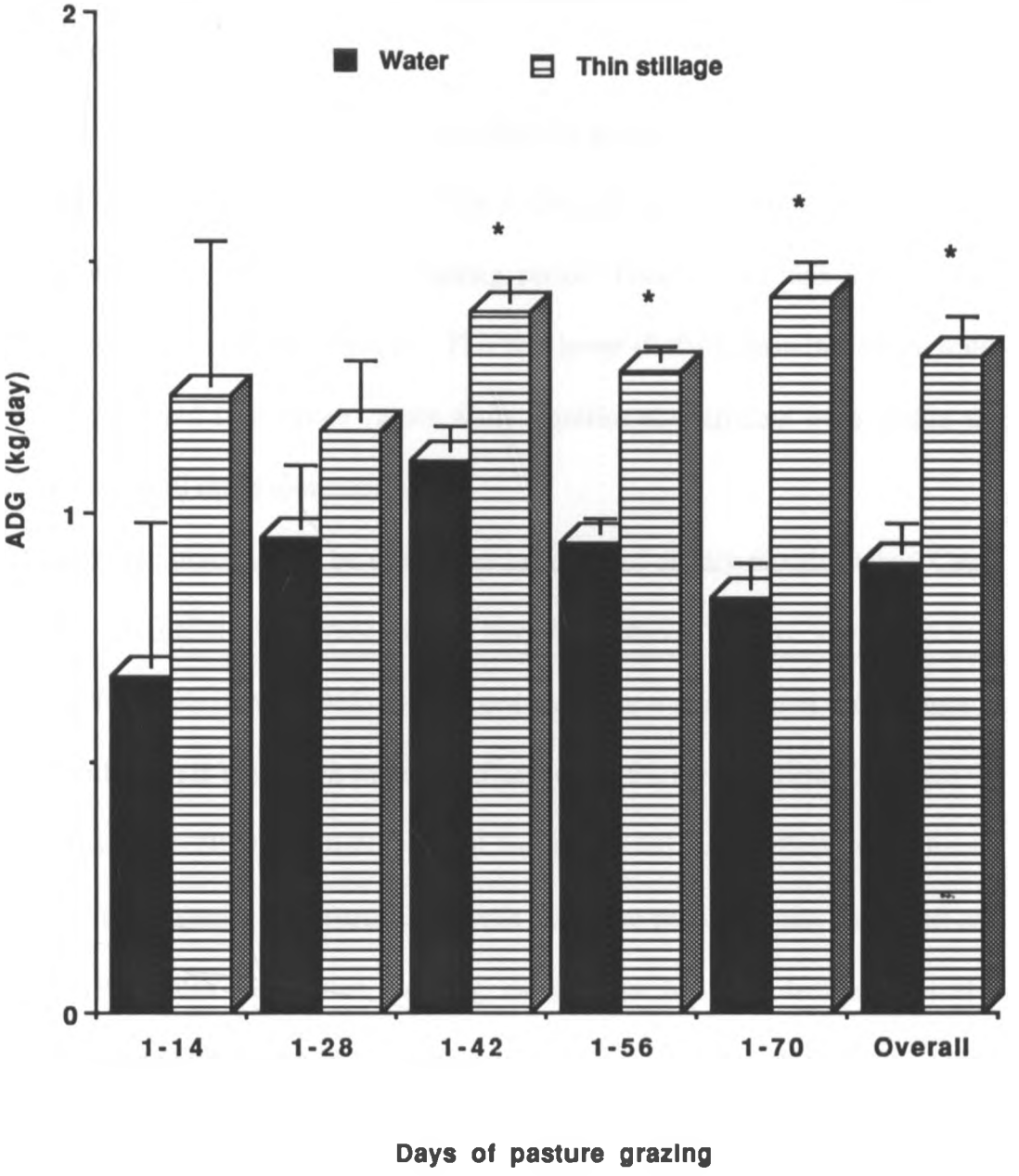

Figure 5.2 Average daily gain (mean ± SEM) of cattle with access to water or thin stillage (* = means differ P<0.05).

Fluid intake, both actual and DM corrected, was higher ($P<0.05$) for stillage fed cattle (Table 5.2). Figure 5.3 shows that this response was evident from day 28 of the trial. The estimated daily dry matter (DMI) and digestible energy (DEI) intake from the consumption of thin stillage by steers was 3.58 kg of DM and 14.2 Mcal of DE, respectively (Table 5.2 and Figure 5.4).

Plasma concentration of blood metabolites is given in Table 5.3. Samples were take on day 42, 56 and 70 of the trial. Blood urea nitrogen was higher ($P<0.05$) for stillage supplemented cattle at each sampling period. Plasma creatinine levels of the stillage fed cattle averaged 100 mmol L^{-1}. This was lower ($P<0.05$) than that of the water fed cattle (129 mmol L^{-1}). These values while significantly different were within the normal physiological range (Swanson 1982).

Blood urea nitrogen can be used as an indicator of dietary protein status. Cattle fed diets that are deficient in crude protein have been shown to have low blood urea nitrogen (BUN) levels (Lewis 1958). Blood urea levels are a reflection of the changes in ammonia production in the rumen which is influenced by the level of dietary nitrogen. In this study, the higher ($P<0.05$) BUN levels of the stillage fed cattle reflect the improved nutritional status of these cattle, particularly with respect to protein intake. Huhtanen and Miettinen (1992) also found that lactating dairy cows fed wet distillers solubles exhibited a higher level of blood urea nitrogen.

Table 5.3 Plasma concentration of blood metabolites of cattle with access to water or thin stillage on crested wheatgrass.

		Plasma metabolites (mmol/Liter)								
	Treatment	Na	K	Cl	Ca	P	Mg	Urea	Creatinine	Glucose
Period 1	Day 42									
	Water	145.30	5.11	105.30	2.62[a]	2.92	0.81[b]	4.40[b]	137.10	4.80
	Stillage	145.50	5.06	106.80	2.48[b]	2.53	0.89[a]	7.81[a]	116.00	3.41
	SE[z]	0.99	0.12	0.76	0.04	0.16	0.02	0.37	6.99	1.04
Period 2	Day 56									
	Water	143.90	4.81	105.90	2.51	2.80	0.94[b]	7.59[b]	123.00[a]	3.73
	Stillage	143.40	4.80	104.80	2.44	2.95	1.08[a]	8.85[a]	97.80[b]	3.80
	SE[z]	0.83	0.11	0.80	0.04	0.06	0.03	0.35	6.37	0.24
Period 3	Day 70									
	Water	142.00	4.90	102.30	2.56[a]	2.30[b]	0.85[b]	5.41[b]	129.00[a]	3.35
	Stillage	141.60	4.80	102.30	2.42[b]	2.79[a]	1.05[a]	7.78[a]	88.50b	3.75
	SE[z]	0.88	0.09	0.71	0.04	0.08	0.04	0.30	6.69	0.26

[a,b] = means within a column and period differ ($p < 0.05$).

[z] SE = standard error of the mean.

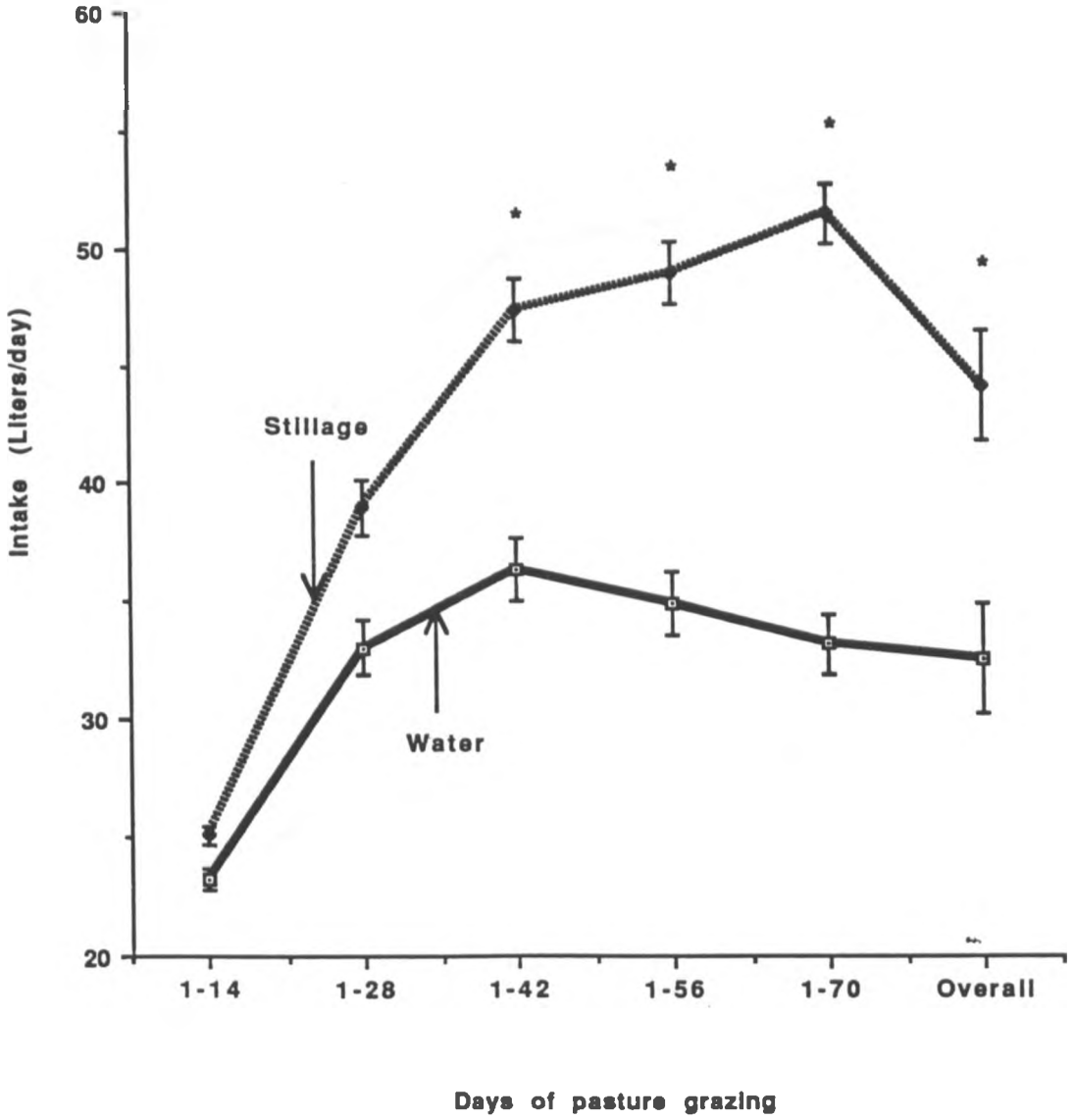

Figure 5.3 Cumulative fluid Intake (L d^{-1} mean ± SD) for cattle with access to water or thin stillage (* significant difference P<0.05).

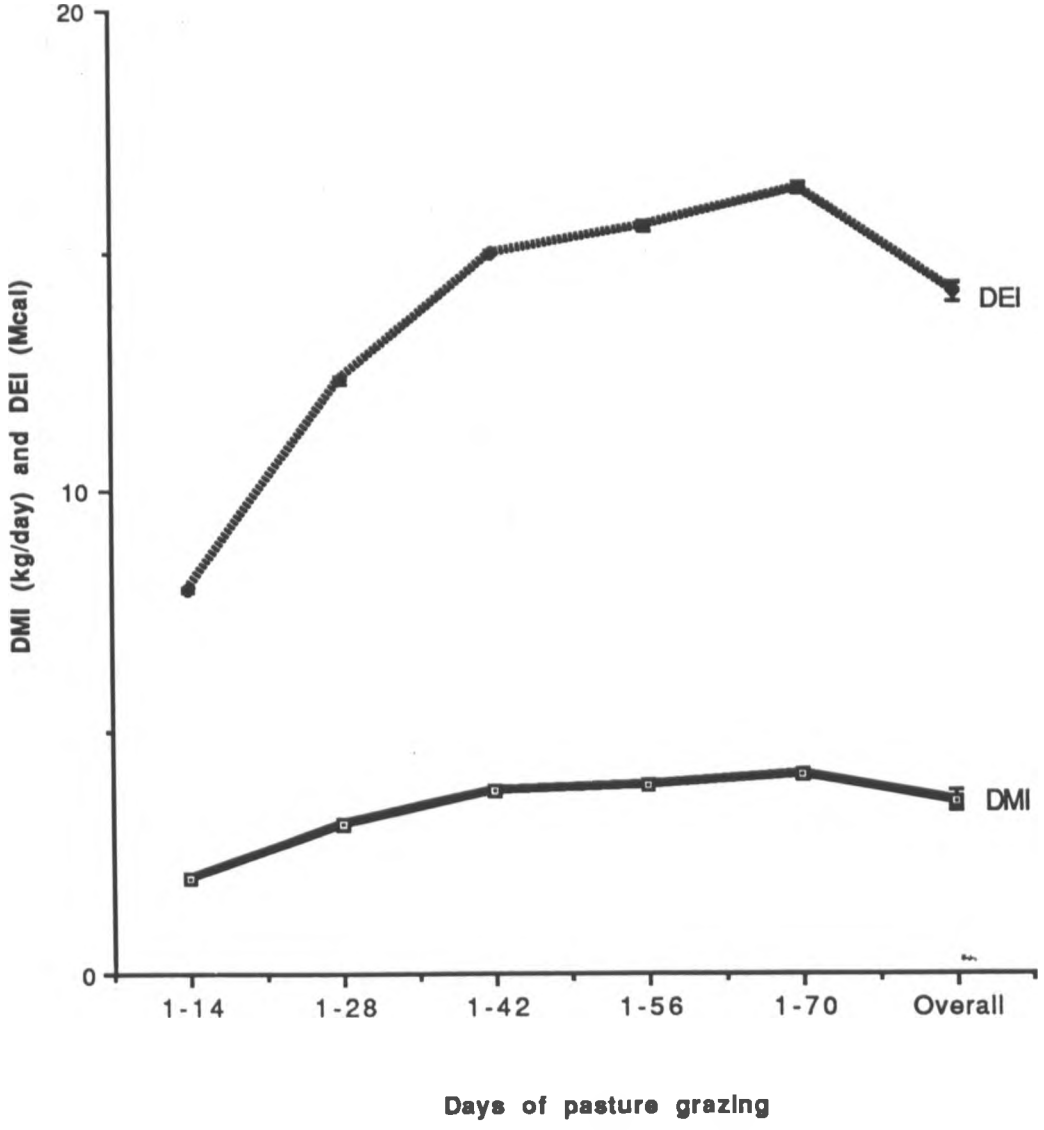

Figure 5.4 Dry matter (DMI kg d^{-1}) and digestible energy (DEI Mcal d^{-1}) intake from consumption of stillage for cattle grazing crested wheat grass.

Plasma concentration of magnesium shows that cattle fed thin stillage had higher ($P<0.05$) levels than the water group (Table 5.3). Values ranged from 0.89 to 1.05 mmol L^{-1} for thin stillage fed cattle compared to 0.81 to 0.94 mmol L^{-1} for the water group. The higher plasma magnesium with stillage feeding may benefit cattle that are susceptible to grass tetany. Magnesium is a required nutrient and insufficient supply may result in many metabolic problems. In particular, cattle in early lactation or growing cattle grazing lush rapidly growing pastures can be susceptible to grass tetany. The most constant and significant biochemical problem associated with this disease is hypomagnesaemia (Blood et al. 1980). Thin stillage feeding which elevated plasma magnesium levels in this study may benefit cattle that are susceptible to this disturbance. Phosphorus levels for thin stillage fed cattle during the third sampling period were higher ($P<0.05$) relative to the water group. In contrast, calcium levels were lower. Both calcium and phosphorus are important nutrients for cattle since they both play important metabolic roles in the body. Calcium is the mineral with the most physiological functions in the animal's body. It is used in bone formation, milk production, transmission of nerve messages, regulation of cardiovascular activities, blood clotting, enzymatic stabilization, nutrient transport and muscle excitement (NAS-NCR 1984). The significance of the lower plasma calcium levels in this study due to thin stillage supplementation is not clear. The actual difference while significant was small (2.56 versus 2.42 mmol L^{-1}). Furthermore NAS-NCR (1984) state that plasma calcium levels are not good indicators of calcium status.

Phosphorus like calcium has important metabolic and physiological roles for normal function. It is involved in cell permeability, energy transfers in the body via high energy adenosine triphosphate (ATP) bonds, activation of several B-vitamins to form coenzymes and control of genetic material transfer between generations (NAS-NCR 1984). Many forages have been reported to contain low phosphorus contents (NAS-NCR 1984; Wright 1986). The presence of high iron levels in the ruminant diet may form insoluble phosphate bonds that may result in phosphorus deficiency. Phosphorus deficiency may result in decreased growth rates, inefficient feed utilization and a depraved appetite (NAS-NCR 1984). Thin stillage supplementation may provide supplemental phosphorus in the diet of grazing cattle.

The results of this study show that cattle grazing CWG with access to thin stillage gained faster ($P<0.05$) and put on more body fat ($P<0.05$) than those on similar pasture with access to water as a fluid source. The higher ($P<0.05$) plasma levels of urea N, magnesium and phosphorus indicate that stillage supplemented cattle had an improved nutritional status . The most likely explanation for this improved performance and nutritional status is that thin stillage was a nutritional supplement for the cattle in this trial. The declining nutritional quality of the CWG pasture (Figure 5.1) did not supply sufficient nutrients to allow these cattle to gain to their genetic potential. In fact, performance would indicate that the quantity and quality of grass available to these animals was sufficient to support the animals maintenance needs and to allow for a daily gain of only 0.91 kg d^{-1}. There was insufficient energy available from the pasture to allow for any fat deposition (Table 5.2). The NAS-NCR (1984) in fact recommend that

medium frame 300 kg cattle, consuming 7.2 kg of DM and gaining 1.0 kg d^{-1} consume 10.1 and 6 Mcal of NE_m and NE_g, respectively. The NE_m and NE_g values for CWG in the early vegetative stage are 1.79 and 1.16 Mcal kg^{-1} DM, respectively. For full bloom and post ripe CWG the respective values are 1.34 and 0.77 and 0.93 and 0.39 Mcal kg^{-1} DM (NAS-NCR 1984). Animals consuming early vegetative CWG could get sufficient energy to gain in excess of 1.0 kg d^{-1}. Animals consuming CWG that has reached full bloom would barely be able to meet maintenance needs and that for 1 kg per day gain. Cattle grazing CWG that had nutritional characteristics similar to post ripe values would not meet maintenance and production needs. Similar gains for cattle grazing CWG to that observed in this study have been noted by other workers who have grazed cattle on CWG pasture. McCaughey (1989) reported an ADG of 0.96 kg d^{-1} which is close to that observed in the present study. Wright (1986) reported lower ADG (0.58-0.78 kg d^{-1}) for cattle grazed CWG pasture than those observed in the present study. These workers found that management of CWG pastures by N fertilization improved quality of the pasture and cattle performance. McCaughey (1989) found a 43% increase in productivity for animals grazing CWG N fertilized pastures than those grazing the control pastures. Similarly Wright (1986) reported a positive relationship between N fertilizer application and higher CP content of CWG than control pastures. This high CP content improved the performance of animals.

The cattle with access to thin stillage in this trial consumed 3.58 kg d^{-1} of DM on average from thin stillage in addition to the DM intake from pasture. This would supply an additional 3.96 Mcal kg^{-1} d^{-1} DE. Furthermore, the high crude protein content

(48.5%) of this product (Table 5.1) would indicate that the animals would consume an average of 1.92 kg d^{-1} of CP. The supplemental energy and protein from thin stillage would be used for maintenance and productive functions and can explain the extra 0.4 kg per d^{-1} daily gain observed over the course of the trial by stillage fed cattle. The fact that stillage supplemented the nutrient intake from CWG is supported by the bi-weekly daily gains shown in Figure 5.2. There were no significant differences in average daily gain until day 42. As seen from Figure 5.3, this period was when differences in fluid intake were readily apparent between the two groups of cattle and was also a period when the CWG was at its lowest (Figure 5.1) nutritional quality (low protein, high fiber). The most likely explanation for the improved performance is that thin stillage supplemented the nutrient intake of the cattle, allowing for greater weight gains and in fact, for fat deposition (Table 5.2).

An alternative explanation that may also explain part of the improvement in performance may be related to alterations in rumen pH due to stillage consumption. Reduced rumen pH has been documented to induce changes in the type of rumen microbes that dominate the fermentation process (Kaufmann et al. 1980; Mackie et al. 1978). Low rumen pH will induce an increase in the number of amylolytic and acid tolerant bacteria and decrease the number of the cellulolytic bacteria. This change in microbial population alters the fermentation pattern of VFA's such that propionate is the dominant VFA (Kaufmann et al. 1980; Mackie et al. 1978). Higher propionate production in the rumen would result in more efficient utilization of energy for gain. Several workers have reported lower rumen pH values and higher propionate in ruminal

fluids after infusion of stillage into the rumen (Ham et al. 1994; Huhtanen and Miettinen 1992). Ham et al. (1994) associated the low rumen pH and altered VFA concentration to thin stillage. In this study the average pH of stillage was 4.5. The cattle drank on average, 44.8 L d^{-1}. This level of intake may have reduced rumen pH and altered the production of VFA in the rumen. Higher ruminal propionate production would increase the supply of glucose precursors to the liver and thus for hepatic gluconeogenesis (Brockman and Laarveld 1986). Glucose is the basic energy unit required by animals for energy metabolism. The availability of glucose precursors for gluconeogenesis would improve energy status and reduce the need for amino acids as sources of energy. The improved energy status and the fact that more amino acids are available for tissue development could help explain the higher growth rates for stillage supplemented cattle. This hypothesis is supported to some extent by plasma glucose levels (Table 5.3). Although not significantly different, stillage supplemented cattle had numerically higher blood glucose levels at the end of the trial (3.75 versus 3.35 mmol L^{-1}).

The results of this trial indicate that thin stillage from wheat based ethanol production is an excellent source of energy and protein which may be successfully utilized to improve the nutritional status of grazing cattle. Supplementation will lead to improved energy and protein intake for cattle grazing crested wheatgrass pastures and therefore to improved growth.

5.4 Conclusion

Thin stillage from wheat-based ethanol production is an excellent source of protein and energy for growing cattle grazing on crested wheatgrass pastures. Performance assessed through daily gains, fat deposition and plasma metabolites improved when supplemented with thin stillage. It would appear that nutrients from thin stillage supplemented the intake of nutrients from the crested wheatgrass. This supplementation was particularly important during the latter half of the grazing season as pasture quality declined. However, due to the high moisture content, thin stillage feeding of cattle on pasture is only feasible for producers located near ethanol distillation plants. Proximity to ethanol plants would make it possible to feed stillage and cut down on the costs of transportation.

6.0 General Discussion and Conclusions.

Wet distillers grains and thin stillage are by-products of ethanol production from cereal grains. Steps involved in the process include enzymatic hydrolysis, fermentation and distillation. The main effect of fermentation is breakdown and conversion of starch to sugars and eventual conversion to alcohol. This results in a concentration of the remaining nutrients in the solids. This process converts the cereal grain from a high energy feed to a high protein byproduct relatively high in fiber (Berger 1981). Distillers grains are high in protein, fat (energy), minerals and vitamins (Hatch 1993a). The distillation process also concentrates yeast hence increasing the quantity of vitamins, particularly the B-complex (Hatch 1993a). The high energy content of distillers by-products results from its digestible fiber and high fat content. Distillers grains are separated from whole stillage through screens or centrifugation.

Thin stillage is the term used to define the liquid recovered following removal of the distillers grains. It contains 4 to 10% DM in the form of highly digestible small, suspended and dissolved particles of grain, yeast cells and other soluble nutrients (Aines et al. 1986; Hanke and Lindor 1982; Ham et al. 1994). When fed together they referred to as distillers grains with solubles. Numerous trials have shown that distillers dried grains with or without solubles can replace conventional protein sources such as soybean meal in rations of dairy and beef cattle (Distillers Feed Research Council 1982). Early use of distillers grains or thin stillage mainly involved the dry product derived from corn grain. In diets containing a combination of rumen degradable and non-degradable protein sources such as urea and distillers grains, it has been reported that the additive nature of

these two protein sources led to improved performance of cattle. Waller et al. (1980) reported improved efficiency of protein utilization for cattle fed a combination of urea and milo DDG. The improved protein utilization was reflected in higher weight gains for steers fed the combination of milo DDG-urea compared to SBM-urea control cattle (Waller et al. 1980). Recent studies indicate that feeding the wet products was cheaper and as effective (Abrams et al. 1983; Ham et al. 1994). Corn wet distillers grains have been reported to provide cattle with higher weight gains, better protein efficiencies and improved feed conversions relative to the dried products (DeHaan et al. 1982).

Research to determine the feeding value of distillers by-products for ruminants has been conducted for several decades, however, most of the research work has involved the use of corn or sorghum distillers feeds. Limited research carried out on the value of wheat distillers by-products suggests that they have similar feeding values to corn or sorghum (Heinemann 1986; Boila and Ingalls 1994). Distillers grains used in high roughage diets for growing calves, can help meet protein and energy requirements for these animals (Abrams et al. 1983; Muntifering et al. 1985).

Brewers grains have also been utilized as feed ingredients in ruminant diets. Brewers grains are by-products of fermentation of barley malt, corn grits or rice for the production of beer. Brewers dried grains are palatable and high in protein. They have been successfully incorporated into dairy and beef cattle rations (Bath et al. 1986). Brewers grains deliver more protein and DM to the duodenum than isonitrogenous amounts of SBM (Armentano et al. 1986). Armentano et al. (1986) also reported WBG as intermediate (when fed at 16% of the ration for lactating dairy cattle) to brewers dried

grains and SBM. Brewers grains may be used to substitute part of the concentrate mixture in the ration due to available energy of this byproduct (Bath et al. 1986). They may be used as 25% of the total DM of a dairy and 15 to 20% of DM of a feedlot ration (Bath et al. 1986). This may be attributed to the high protein and energy content of brewers grains which contain about 80% of the energy value in barley grain and 20 to 25% crude protein (Bath et al. 1986).

In situ dry matter disappearance from wet brewers grains used in the present study was lower ($P<0.05$) than from WDG (47% versus 53% respectively). Unpublished data collected after this trial in this Department shows similar dry matter disappearance values to that reported in this study (Mustafa et al. unpublished data). The values for DMD reported in the present study are comparable to values reported elsewhere for canola meal and SMB (Deacon et al. 1988; McKinnon et al. 1991; Ham et al. 1994). These workers reported DMD highest for SBM and lowest for CGM with canola meal intermediate to the two feeds. Armentano et al. (1986) reported similar DMD values for WBG to those observed in the present study, however, examining RUP flow to the duodenum (Armentano et al. 1986) indicated higher values for WBG compared to SBM.

The results of the present trial indicate that wheat based wet distillers grains (WDG) have similar effective crude protein degradability (ECPD) as soybean meal and canola meal. The ECPD in the present trial was 67%. This is in the same range as 68% and 71% reported for canola meal and SBM, respectively (Santos et al. 1984; Abrams et al. 1983; Ham et al. 1994; Mustafa et al. unpublished data). This implies that the feeding

of WDG to feedlot cattle would supply equivalent RUP to canola meal or SBM. Wet brewers grains provided slightly higher RUP than the values observed for WDG. The effective crude protein degradability value for WBG (61%) while not statistically different was 9% lower than WDG (67%).

Examination of the data collected during the feedlot trial indicates that feed conversions during the growing period were not different across treatments, however, WBG fed cattle had good conversions ($P<0.10$) compared to the WDG and the control fed cattle. Cumulative bi-weekly weight gains showed superior performance for the WDG fed cattle relative to control cattle for days 1 to 56 through 1 to 70. A possible explanation to the superior performance during this period may be due to the higher EDMD of WDG compared to WBG reported in Chapter 4 (Table 4.3). Dry matter intake during this period although not statistically significant ($P<0.05$) appeared lower for WBG compared to WDG and control diets.

During the finishing period the control fed cattle gained faster ($P<0.05$) than the WBG fed cattle. Wet distillers grains fed cattle were intermediate. It was found that weight gains of the control fed cattle ($P<0.03$) from day 85 to 113 and WDG fed cattle from day 85 to 127 onward ($P<0.08$) gained faster than the WBG fed cattle. This was compounded by the low EDMD of WBG (47%) which may have contributed less available energy for the animals (Table 4.3). Control fed cattle may have benefited from compensatory growth having performed relatively poor compared to WBG and WDG fed cattle during the growing period. The level of WBG grains used in this trial was

within the recommended range of 30 to 40% of the ration for lactating dairy cattle diets (Davis et al. 1983). Corn wet distillers grains have been included in lactating dairy cattle diets at 22% of the ration DM (Schingoethe et al. 1983). Ham et al. (1994) used corn wet distillers grains at 40% of the ration DM in a steer metabolism trial. Results of the present trial show that inclusion of WBG at 44% and WDG at 32% (as fed) during the growing period were equally successful compared to other standard feedlot ingredients and they may be used to replace other conventional supplements used in feedlot rations during the growing period.

The results of the present study indicated that thin stillage from wheat based ethanol production improved performance of growing cattle grazing crested wheat grass. When compared to water fed cattle the stillage fed cattle in the present trial benefited from increased nutrient intake through the consumption of thin stillage. The improved performance was reflected in a faster ($P<0.05$) rate of gain and more fat deposition at the end of test. Analysis of thin stillage used in the present trial indicates high protein (48%) and fat (9.6%) levels (Table 5.1). These high values make the byproduct a useful source of nutrients for growing cattle. The energy value in thin stillage estimated at 3.96 Mcal kg^{-1}, provided stillage fed cattle with additional energy to sustain a higher level of performance throughout the trial. The additional energy from thin stillage consumption was estimated as 14.2 Mcal d^{-1} for cattle that consumed an average of 44.5 L d^{-1}. Additional energy may have been derived from the highly digestible fiber available in stillage. The improvement in performance was reflected in higher ($P<0.05$) ADG and fat deposition throughout the course of the trial for stillage fed cattle. The extra 0.4 kg d^{-1}

gain for cattle fed thin stillage over those on water is an indication that this byproduct provided cattle with additional nutrients. Fat deposition was also higher for stillage fed cattle (2.5 versus 0.6 mm d^{-1}) compared to the water group. Another explanation for the higher performance for stillage fed cattle is the high rumen outflow rate associated with liquid feeds. The high rumen outflow rate may have reduced rumen microbial degradation of the nutrients in stillage and made them available for post ruminal digestion. Stillage also provided cattle with essential minerals such as calcium, phosphorus and magnesium. The analyzed value for magnesium (0.66%) in thin stillage (Table 5.1) was within the recommended range (0.05 to 0.25%) for medium framed steers gaining 1.0 kg d^{-1} (NAS-NCR 1984). Previous work has indicated that thin stillage from corn based ethanol production can be successfully used to improve performance of growing and finishing cattle (Berger 1981; Hanke et al. 1982 and Ham et al. 1994). In the present study, declining nutritional status of CWG pastures was evident. These included a reduced crude protein content (15% to 9%) and increases in both ADF (31 to 38%) and NDF (57 to 67%). The apparent decline in nutrient quality may have contributed to the poorer performance of the water fed cattle.

Feeding of wet distillers by-products and WBG to growing cattle has shown that both by-products are palatable and that carcasses from these cattle meet acceptable carcass classification characteristics. In this study these treatments compared favorably with the control diet. This is an indication that no detrimental effects result from feeding WBG or WDG supplements in feedlot cattle diets. Wet distillers grains and WBG can be used to replace part of the concentrate portion of the ration in growing and finishing

cattle. Due to the high moisture content, WBG and WDG should be fed in diets at levels that do not result in a reduction in dry matter intake. No health problems were encountered in animals fed WBG or WDG diets. Whenever it is feasible, thin stillage can be utilized as a source of nutrients for growing cattle. The limitation to the widespread use of these products may be their high water content.

7.0. Literature cited

Abrams, S.M., Klopfenstein, T.J. Stock, R.A., Britton, R.A. and Nelson, M.L. 1983 Preservation of wet distillers grains and its value as a protein source for growing ruminants. J. Anim. Sci. 57(3):729-738.

ARC 1984. Report of the protein group of the agricultural research council working party on the nutritional requirements of ruminants. Commonwealth Agric. Bur. Slough, England.

Aines, G., Klopfenstein, T. and Stock, R. 1986. Distillers grains. The Agricultural Research Division, Institute of Agricultural and National Resources University of Nebraska Lincoln.

Anderson, S.J., Klopfenstein, T. J. and Wilkerson, V.A. 1988. Escape protein supplementation of yearling steers grazing smooth brome pastures. J. Anim. Sci. 66:237-242.

Armentano, J.H., Herrington, R.A., Polan, C.E., Moe, A.J., Herbein, J.H. and Umstadt, P. 1986. Ruminal degradation of dried brewers grains, wet brewers grains and soybean meal. J. Dairy. Sci. 69:2124-2133.

Armstrong, D.G. and Hutton, K. 1975. Digestion and metabolism in the rumen. In: The ruminant animal, Digestive physiology and nutrition D.C. Church ed. Prentice Hall, Englewood Cliffs, New Jersey 1988.

Association of Official Analytical Chemists. 1984. Official methods of analysis A.O.A.C. Washington, D.C.

Barton R.K., Krysl, L.J., Judkins M.B., Holcombe, D.W., Gunter, S.A. and Beam, S.W. 1992. Time of daily supplementation for steers grazing dormant intermediate wheat grass pasture. J. Anim. Sci. 70:547-558.

Bath, D., Dunbur, J., King, J. Steven, B., Leonard, R.O. and Olbrich, S. 1986. composition of unusual feeds. Feedstuff July 23 58:32.

Beeson, W.M. 1975. Evaluation of condensed distillers solubles for liquid cattle supplements. Distillers. Conf. Proc. 30:14

Beyla, R.L., Steevens, B.J., Restrepo, R.J. and Clubb A.P. 1989. Variation in composition of byproduct feeds. J Anim Sci. 2339-2345.

Bergen, W.G., Purser, B.D. and Cline, J.H. 1967. Enzymatic determination of the protein quality of individual rumen bacteria. J. Nutr. 92:357-364.

Bergen, W.G., Purser, B.D. and Cline, J.H. 1968. Effect of ration on the nutritive quality of rumen bacterial protein. J. Anim. Sci. 27:1497-1501.

Berger, L.L. 1981. Nutritional value of distillers feeds for livestock. Dept. of Animal Science, University of Illinois, Urbana 61801. (Unpublished data).

Blood, D.C., Henderson J.A., Radostist, O.M., Arundel, J.H. and Gray C.C. 1980. Veterinary Medicine: A text book of diseases of cattle sheep pigs and horses. 35 Red Lion Square London WCIR 45G.

Boila, R.J. and Ingalls, J.R. 1994. The ruminal degradation of dry matter, nitrogen and amino acids in wheat-based distillers dried grains *in sacco*. Anim. Feed Sci. Tech. 48:57-72.

Borroughs, W., Nelson, D.K. and Mertens, D.R. 1974. Evaluation of protein nutrition by metabolizable protein and urea fermentation potential. J. Dairy. Sci. 58(4): 611-619.

Borroughs, W., Nelson, D.K. and Mertens, D.R. 1975. Protein physiology and its application in the lactating cow: metabolizable protein feeding standard. J. Dairy. Sci. 41(3):933-944.

Botts, R.L., Hemken, R.W. and Bull, L.S. 1979. Protein reserves in the lactating dairy cow. J. Dairy. Sci. 62:433-440.

Brockman, R.P. and Laarveld, B. 1986. Hormonal regulation of metabolism in ruminants: a review. Livest. Prod. Sci. 14(4):313-334.

Broderick, G.A. 1978. *In vitro* procedures of estimating rates of ruminal protein degradation and proportions of protein escaping the rumen undegraded. J. Nutr. 108(2):181-190.

Broster, W.H. 1972. Protein-energy interrelationships in growth and lactation of cattle and sheep. Proc. Nutr. Soc. 32:115.

Brown , W.F. 1983. Computer simulations of animal and plant growth and their interactions in a grazing situation. Ph. D. dissertation University of Nebraska, Lincoln Nebraska, USA.

Bryant, M.P. and Robinson, I.M. 1962. Some nutritional characteristics of predominant cultureable ruminal bacteria. J. Bacteriol. 84:605.

Campling, R.C. 1991. Processing cereal grains for cattle: a review. Livest. Prod. Sci. 28:223-234.

Cecava, M.J., Merchen, N.R., Berger, L.L. and Fahey, G.C. Jr. 1990. Intestinal supply of amino acids in sheep fed alkaline hydrogen peroxide-treated wheat straw-based diets supplemented with soybean meal or combinations of corn gluten meal and blood meal. J Anim Sci. 68:467-477.

Cecava, M.J., Merchen, N.R., Berger, L.L Mackie, R.I. and Fahey, G.C Jr. 1991. Effects of dietary energy level and protein source on nutrient digestion and ruminal nitrogen metabolism in steers. J. Anim. Sci. 69:2230-2243.

Cerneau, P. and Michalet-Doreau 1991. *In situ* starch degradation of different feeds in the rumen. Reprod. Nutr. Devel. 31:65-72.

Chalupa, W. 1972. Metabolic aspects of non-protein nitrogen utilization in ruminant animals. Fed. Proc. 31:1152 (as quoted by Chalupa 1974)

Chalupa, W. 1974. Rumen bypass and protection of protein and amino acids. J. Dairy. Sci. 58(8):1198-1218.

Chalupa, W. 1984. Discussion of protein symposium. J. Dairy. Sci. 67:1134-1146.

Chandler, P. 1989. Achievement of optimum amino acid balance possible. Feedstuffs June 26 pp 13-14.

Chen, M.C., Beeson, W.M., Perry, T.W. and Mohler, M.T. 1977. Effects of varying levels of processed distillers solubles and distillers dried grains on nitrogen and energy metabolism of beef steers. J. Anim. Sci. 44:859-866.

Christensen, D.A. and McKinnon, J.J. 1993. Canola meal for beef and dairy cattle. In Canola meal: Feed Industry Guide pages 21-27 ed. D. Hickling for Canola Council of Canada.

Clark, J.H. 1974. Lactational responses to postruminal administration of proteins and amino acids. J. Dairy. Sci. 58(8):1178-1197.

Clark, J.H., Klusmeyer, T.H. and Cameron, M.R. 1992. Symposium: Nitrogen metabolism and amino acid nutrition in dairy cattle. Microbial protein synthesis and flows of nitrogen fractions to the duodenum of dairy cows. J. Dairy. Sci. 75:2304-2323.

Cleale, R.M. IV, Klopfenstein, T.J., Britton, R.A., Satterlee, L.D. and Lowry, S.R. 1987a. Induced non-enzymatic browning of SBM. I. Effects of factors controlling non-enzymatic browning on *in vitro* ammonia release. J. Anim. Sci. 65:1312-1318.

Cleale, R.M. IV, Britton, R.A., Klopfenstein, T.J., Bauer, M.L., Harmon, D.L. and Satterlee, L.D. 1987b. Induced non-enzymatic browning of SBM. II. Ruminal escape and net portal absorption of SBM treated with xylose. J. Anim. Sci. 65:1319-1326.

Coleman, G.S. 1980. Rumen ciliate protozoa. Adv. Parasitol. 18:121.

Coleman, G.S. 1975. Page 149. *in* Digestion and metabolism in the ruminant. The interrelationship between rumen ciliate protozoa and bacteria. I.W. McDonald and A.I.C. Warner, ed. Univ New England Pub Unit, Armidale, Australia.

Cozzi, G. and Polan, C.E. 1994. Corn gluten meal or brewers dried grains as partial replacement for soybean meal in the diet of Holstein cows. J. Dairy Sci. 77:825-834.

Czerkawski, J.W. and Breckenridge, G. 1977. Design and development of a long-term rumen simulation technique. Br. J. Nutr. 38(3):371-384.

Davis, C.L., Grenawalt, D.A., and McCoy, G.C. 1983. Feeding value of pressed brewers grains for lactating dairy cows. J Dairy Sci 66:73-79.

Deacon, M.A., De Boer, G. and Kennelly, J.J. 1988. Influence of Jet-sploding and extrusion on ruminal and intestinal disappearance of canola and soybeans. J. Dairy Sci. 66: 492-504.

DeHaan, K., Klopfenstein, T.J., Stock, R., Abrams, S and Britton, R.A. 1982. Wet distillers by-products for growing ruminants. Beef cattle report pp 33-35. Nebraska Agricultural Experimental Station University of Nebraska, Lincoln, NE.

Delcurtoo, T., Cochran, R.C., Harmon, D.L., Beharka. A.A., Jaques, K.A., Towne, G. and Vanzant, E.S. 1990. Supplementation of dormant, tall-prairie forage: Influence of varying supplemental protein and (or) energy levels on forage utilization characteristics of beef steers in confinement. J. Anim. Sci. 68:515-531.

Distillers Feed Research Council 1982. Distillers feeds research. Cincinnati, Ohio.

Donaldson, R.S., McCann, M.A., Amos, H.E. and Hoveland, C.S. 1991. Protein and fiber digestion by steers grazing winter annuals and supplemented with ruminal escape protein. J. Anim. Sci. 69:3067-3071.

Egan, A.R. 1980. Host animal-rumen relationships. Proc. Nutr. Soc. 39:79.

Egan, A.R. and Doyle, P.T. 1985. Effects of intraruminal infusion of urea on the response in voluntary food intake by sheep. Aust. J. Agric. Res. 36:483-495.

Ensminger, M.E., Oldfield, J.E. and Heinemann, W.W. 1990. Feeds and nutrition digest. Ensminger Pub. Co. Covis California, USA.

Erdman, R.A., Vandersall, J.H., Russek-Cohen, E. And Switalski, G. 1987. Simultaneous measures of rates of ruminal digestion and passage for prediction of ruminal nitrogen and dry matter digestion in lactating dairy cows. J. Anim. Sci. 64:565-577.

Farlin, S.D. 1981. Wet distillers grains for finishing cattle. Anim Nutr. Health 36:35.

Firkins, J.L., Berger, L.L., Fahey, G.C. Jr. and Merchen, N.R. 1984. Ruminal nitrogen degradability and escape of wet and dry distillers grains and wet and dry corn gluten feeds. J. Dairy Sci. 67:1936-1944.

Firkins, J.L., Berger, L.L. and Fahey, G.C. Jr. 1985. Evaluation of wet and dry distillers grains and wet and dry corn gluten feeds for ruminants. J. Anim. Sci. 60(3):847-860.

Firkins, J.L., Berger, L.L., Merchen, N.R. and Fahey, G.C. Jr. 1986 Effects of particle size, level of feed intake and supplemental protein degradability on microbial protein synthesis and site of nutrient digestion in steers. J. Anim. Sci. 62:1081-1094.

Fox, D.G. and Barry, M.C. 1994. Predicting cattle net energy and protein requirements and supply under widely varying conditions. In Livestock production for the 21st century: Priorities and research needs. ed. P.A. Thacker. 1994.

Fox, D.G., Sniffen, C.J. O'Connor, J.D., Russell, J.B. and Van Soest, P.J. 1992. A net carbohydrate and protein system for evaluating cattle diets: III. Cattle requirements and diet adequacy. J. Anim. Sci. 70:3578-3596.

Gibb, D.J., Klopfenstein, T.J., Britton, R.A. and Lewis, A.J. 1992 Plasma amino acid response to graded levels of escape protein. J. Anim. Sci. 70:2885-2892.

Goering, H.K. and Van Soest, P.J. 1970. Forage fiber analysis. Agricultural handbook No.379. USDA.

Grenawalt, D.A., McCoy, G.C. and Davis, C.L. 1981. Performance of lactating dairy cows fed rations containing varying amounts of pressed brewers grains. J. Dairy Sci. 64 (suppl. 1): 116 (abstract).

Ha, J.K., Kennelly, J.J and Berzins, R. 1986. Effect of dietary nitrogen source on microbial protein synthesis, dietary protein degradation and nutrient digestion in steers. Anim. Feed. Sci. Tech. 14:117-126.

Hale, W.H., 1973. Influence of processing on the utilization of grains (starch) by ruminants. J. Anim. Sci. 37(4):1075-81.

Ham, G.A, Stock, R.A., Klopfenstein, T.J, Larson, E.M., Shain, D.H. and Huffman, R.P., 1994. Wet corn distillers by-products compared with dried corn distillers grains with solubles as a source of protein and energy for ruminants. J. Anim. Sci. 72:3246-3257.

Hannah, S.M., Cochran, R.C., Vanzant, E.S. and Harmon, D.L. 1991. Influence of protein supplementation on site and extend of digestion, forage intake and nutrient flow characteristics in steers consuming dormant bluestem-range forage. J. Anim. Sci. 69:2624-2633.

Hanke, H.E., Lindor, L.K. and Smith R.E. 1982. Influence of feeding thin stillage as a replacement for water on feedlot performance of yearling steers. Minnesota Beef Report. B-288:23-27.

Hanke, H.E. and Lindor, L.K. 1982. Pressed distillers grains in diets of finishing yearling steers. Minnesota Beef Report. B-289:28-35.

Hatch, R.H. 1993a. Use of distillers grain, like any feed, requires understanding. May 17 Feedstuffs-17.

Hatch, R.H. 1993b. Distillers feeds and grains are good sources of feed, protein Feedstuffs August, 16 vol. 14.

Heinemann, W.W. 1986. Dried distillers grains of hard spring wheat in finishing diet for steers. Research Bulletin XB. 0975, Agriculture Research Center, Washington State University.

Hennessy, D.W. 1983. Improved production from grazing cattle when given protein. S. Afr. J. Anim. Sci. 13(1):9-11.

Hennessy, D.W. and Nolan J.V. 1988. Nitrogen kinetics in cattle fed a mature subtropical grass hay with and without protein supplementation. Aust. J. Agric. Res. 39: 1135-50.

Hennessy, D.W. and Williamson, P.J. 1990. Feed intake and live weight of cattle on subtropical native pasture hays. II. The effect of urea and maize flour or protected-casein. Aust. J. Agric. Res. 41:1197-85

Hennessy, D.W., Lee, G.T. and Williamson P.J. 1983. Nitrogen loss from protein meals held in terylene bags in the rumen of cattle and the nutritive value of the residues Aust. J. Agric. Res. 34:453-671.

Hespell, R.B. and Bryant, M.P. 1979. Efficiency of rumen microbial growth: influence of some theoretical and experimental factors on Y_{ATP} . J. Anim. Sci. 49:1640-1659.

Hoover, W.H. and Stokes, S.R. 1991. Balancing carbohydrates and proteins for optimum rumen microbial yield. J. Dairy Sci. 74:3630-3644.

Huber, J.T. and Kung, L. Jr. 1981. Protein and non protein nitrogen in dairy cattle. J. Dairy Sci. 64:1170-1195.

Huber, J.T. and Thomas, J.W. 1971. Urea treated corn silage in low protein rations for lactating cows. J. Dairy Sci. 54:224-230.

Huhtanen, P. and Miettinen, H. 1992. Milk production and concentration of blood metabolites as influenced by the level of wet distillers solubles in dairy cows receiving grass silage-based diet. Agric. Sci. Finl. 1:279-290.

Hungate 1966. The rumen and its microbes. Acad. Press New York, NY USA.

Jacobson, D.R., Barnett, J.W., Carr, S.B. and Hatton, H. 1967. Voluntary feed intake , milk production, rumen content, and plasma-free amino acid levels of lactating cows on low sulfur and sulfur supplemented diets. J. Dairy Sci. 50:1248-1254.

Johnson B.C., Hamiliton, T.S., Robinson W.B. and Gavey, J.C. 1944. On the mechanism of non-protein nitrogen utilization by ruminants. J. Anim. Sci. 3:287-298

Kaufmann, W., Hagemeister, H. and Dirksen, G. 1980. Adaptation to changes in dietary composition, level and frequency of feeding. Pages 587-602 In Y. Ruchebusch and P Thivend ed. Digestive physiology and metabolism in ruminants. MTP Press Falcon House, Lancaster, England.

Kennelly, J.J. and De Boer, G. 1986. Ruminal and Intestinal disappearance of whole canola seed as influenced by Jet sploding temperature. Page 82 in 65th Annual Feeders' Day Report Univ. Alberta Edmonton, AB, Canada.

Kennelly, J.J. and Khorasani, G.R. 1993. Enhancement of the nutritive value of canola protein by acid treatment. 10th Project report Research on canola meal pp 101-129.

Kennelly, J.J., Khorasani, G.R., Robinson, P.H. and de Boer, G. 1993. Effect of Jet-sploding and extrusion on the nutritive value of canola meal and whole canola seed for dairy cattle. 10th Project report Research on canola meal pp 130-140.

Khorasani, G.R., Robinson, P.H. and Kennelly, J.J. 1989. Effect of chemical treatment on *in vitro* and *in situ* degradation of canola meal protein. J. Dairy Sci. 72:2074-2080

Khorasani, G.R., Robinson, P.H., De Boer, G. and Kennelly, J.J. 1991. Influence of canola fat on yield, fat percentage, fatty acid profile and nitrogen fraction in Holstein milk. J. Dairy Sci. 74: 1904-1911.

Larson, D.A., Diallo, M, Goodrich, R.D. and Meiske, J.C. 1982a. Chemical analysis of ethanol plant by-products. Minnesota Beef Research report B289.

Larson, D.A., Diallo, M, Goodrich, R.D. and Meiske, J.C. 1982b. Chemical preservation of wet distillers pressed grains. Minnesota Beef Research report B-290.

Lee, W.J., Sosulski, F.W. and Sokhansanj, S. 1991. Yield and composition of soluble and insoluble fractions from corn and wheat stillages. Cereal Chem. 68(5): 559-562.

Leibholz, J. and Kellaway, R.C. 1979. Amino acid requirements for microbial protein synthesis. Ann. Rech. Vet 10:274.

Leng, R.A. and Nolan, J.V. 1984. Symposium: Protein nutrition of the lactating dairy cow. Nitrogen metabolism in the rumen. J. Dairy Sci. 67:1072-1089.

Lewis D. 1958. Blood-Urea concentration in relation to protein utilization in the ruminant. J. Agric. Sci. 48:438-446.

Little, C.O., Mitchell, G.E., Jr. and Bradley, N.W. 1964. Rumen stimulatory factors in corn distillers dried solubles. Dist. Feed Res. Conf. Proc. 19:43

Little, C.O., Mitchell, G.E. Jr. and Potter, G.D. 1968. Nitrogen in the abomasum of wethers fed different protein sources. J. Anim. Sci. 27:1722. (As quoted by Aines et al. 1986)

Little, C.O., Potter, G.D. and Amos, H.E. 1970. Distillers feeds - Stimulants of rumen digestion. Dist. Feed. Conf. Proc. 25:41.

Loosli, J.K. and Warner, G.R. 1958. Distillers grains, brewers grains and urea as protein supplements for dairy rations. J. Dairy. Sci. 41:1446.

Loosli, J.K., Elliot, J.M. and Warner, G.R. 1960. Comparative value of corn distillers dried grains with solubles, soybean oil meal and linseed oil meal as for milk production. J. Dairy. Sci. 43:816-820.

Loosli, J.K., Warner, G.R. and Hintz, H.F. 1961. Value of corn distillers dried grains , soybean oil meal, heated soybeans and soybean oil meal plus starch for milk production. J. Dairy. Sci. 43:1910-1914.

Mackie, R.J., Gilchrist, M.C., Roberts, A.M., Hannah, P.E. and Swartz, H.M. 1978. Microbiological and chemical changes in the rumen during a stepwise adaptation of sheep to high concentrate diets. J. Agric. Sci. Camb. 90:124-254.

Mantysaari, P.E., Sniffen, C.J. and Muscato, T.V. 1989. Performance of cows in early lactation fed isonitrogenous diets containing soybean meal or animal by-product meals. J. Dairy. Sci. 72(2):2958-2967.

McAllister, T.A., Rode, L.M., Major, D.J., Cheng, K.J. and Buchnan-Smith, J.G. 1990. Effect of ruminal microbial colonization on cereal grain digestion. Can. J. Anim. Sci. 70:571-579.

McCarthy, R.D. Jr., Klusmeyer, T.H., Vicini, J.L., Clark, J. H. and Nelson, D.R. 1989 Effects of source of protein and carbohydrate on ruminal fermentation and passage of nutrients to the small intestines of lactating dairy cows. J. Dairy. Sci. 72:2002-2016.

McCaughey, W.P. 1989. Management of pastures using plant growth regulators and nitrogen fertilizer. Ph.D. Dissertation.

McKinnon, J.J., 1992. Protein requirements of feedlot cattle that differ in mature body size. Ph.D. Dissertation. Univ. of Saskatchewan, Saskatoon, SK.

McKinnon, J.J., Cohen, R.D.H., Jones, S.D.M., Laarveld, B. and Christensen, D.A. 1993. The effects of dietary energy and crude protein concentration on growth and serum insulin-like growth factor-1 levels of cattle that differ in mature body size. Can. J. Anim. Sci. 73: 303-313.

McKinnon, J.J., Olubobokun, J.A., Christensen, D.A. and Cohen, R.D.H. 1991. The influence of heat and chemical treatment on ruminal disappearance of canola meal. Can. J. Anim. Sci. 71:773-780.

McNaught, M.L., Smith, J.A.B., Henry, K.M. and Kon, S.K. 1950. The utilization of non-protein nitrogen in the bovine rumen: 5. The isolation and nutritive value of a preparation of dried rumen bacteria. Biochem. J. 46:32-36.

McNaught, M.L., Owen, E.C., Henry, K.M. and Kon, S.K. 1954. The utilization of non-protein nitrogen in the bovine rumen :8. The nutritive value of the proteins of preparations of dried rumen bacteria, rumen protozoa and brewers yeast for rats. Biochem. J. 56:151-156.

Michalet-Doreau, B. and Ould-Bah, M Y. 1992. *In vitro* and *in sacco* methods for estimation of dietary nitrogen degradability in the rumen: a review. Anim. Feed Sci. Tech. 40:57-86.

Moran, J.B. 1986. Cereal grains in complete diets of dairy cows: A comparison of rolled barley, wheat and oats and of three methods of processing oats. Anim. Prod. 43: 27-36.

Muntifering, R.B., Burch, T.J. Miller, B.G. and Ely, D.G. 1983. Digestibility and metabolism of mature tall fescue hay reconstituted and ensiled with whole stillage. J. Anim. Sci. 57:1286-1293.

Muntifering, R.B., Wedekind, K.J., Knifley, T. and Ely, D.G. 1985. Effects of processing on the supplemental value of distillers by-products in forage diets. J. Anim. Sci. 61(3):647-653.

Murdock, F.R., Hodgson, A.S. and Riley, R.E., Jr. 1981. Nutritive value of wet brewers grains for lactating dairy cows. J. Dairy Sci. 64:1826-1832.

Mustafa, F.A., McKinnon, J.J. and Christensen, D.A. (unpublished data).

Nakamura, T. Klopfenstaein T.J. and Britton R.A. 1994. Evaluation of acid detergent nitrogen as an indicator of protein quality in non forage proteins J. Anim. Sci. 72:1043-1048.

NAS-NCR 1976. Nutrient requirements of beef cattle. National Academy Press Washington, D.C.

NAS-NCR 1981. Feeding value of ethanol by-products. Committee on Animal Nutrition, Board on Agriculture and Renewable Resources. National Academy Press Washington, D.C.

NAS-NCR 1984. Nutrient requirements of beef cattle. National Academic Press 6th ed. Washington, D.C.

NAS-NCR 1985. Ruminant nitrogen usage National Academic Press Washington, D.C.

NAS-NCR 1989 Nutrient requirements for dairy cattle. National Academic Press Washington, D.C.

Nocek, J.C. 1988. *In situ* and other methods to estimate ruminal energy and protein digestibility: a review. J. Dairy Sci. 71:2051-2069

Nordin, M. and Campling, R.C. 1976. Digestibility studies with cows given whole and rolled cereal grains. Anim. Prod. 23: 305-313.

Nugent, J.H.A., Jones, W.T., Jordan, D.J. and Mangan, J.L., 1983. Rates of proteolysis in the rumen of soluble protein casein, Fraction 1(18S) leaf protein , bovine serum albumin and bovine submaxillary mucoprotein. Br. J. Nutr. 50 (2):357-368.

Offer, J.E. and Offer, N.W. 1992a. Calcium hydroxide treatment of malt distillers grains. 1. Effects on chemical composition and digestibility measured *in vitro* and *in sacco.* Anim. Prod. 55:203-208.

Offer, J.E. and Offer, N.W. 1992b Calcium hydroxide treatment of malt distillers grains. 2. Effects on apparent digestibility *in vivo*, intake and performance in sheep. Anim. Prod. 55:209-218

Oldham, J.D. 1993. Recent progress towards matching feed quality to the amino acid needs of ruminants. Anim. Feed Sci. Tech. 45:19-34.

Olfert, E.D. Brenda, M.C. and McWilliam, A.A. 1992. Guide to the care and use of experimental animals. Bradda Prin. Inc. Ottawa, Ontario, Canada.

Ørskov, E.R. 1976. Manipulation of protein nutrition for production in young animals. Page 123 in Reviews in rural science II University of New England publishers Unit Armidale, Australia.

Ørskov, E.R. and McDonald, I. 1979. The estimation of protein degradability in the rumen from incubation measurements weighted according to rate of passage. J. Agric. Sci. Camb. 92:499-503.

Ørskov, E.R. 1982. Protein nutrition in ruminants. Academic Press New York. NY.

Ørskov, E.R. 1992. Protein nutrition in ruminants 2nd edition. Academic Press, London, England. pp 175.

Ørskov, E.R., Hughes-Jones, M. and McDonald I. 1980. Degradability of protein supplements and utilization of undegradaded protein by high producing dairy cows. Page 85, In recent advances in Animal nutrition. W. Haresign ed. Butterworths, London, Engl.

Palmquist, D.L. 1988. The feeding value of fats. Pages 293-311 in Ørskov ed. Feed Science, World Animal Science, B4. Elsevier Science Publisher B.V. Amsterdam, Holland.

Paquay, R. DeBaere, R and Lousse, A. 1972. The capacity of the mature cow to lose and recover nitrogen and the significance of protein reserves. Br. J. Nutr. 27:27-37.

Perkins, T.L., Green, R.D., Hamlin, K.E., Shepard, H.H. and Miller, M F 1992. Ultrasonic prediction of carcass merit in beef cattle: Evaluation of technician effects on ultrasonic estimates of carcass fat thickness and longissimus muscle area. J. Anim. Sci. 70:2758-2765

Pitts, S.J., McCollum, F.T. and Britton M.C. 1992 Protein supplementation of steers grazing tobosa grass in spring and summer. J. Range Mana. 45:226-231.

Polan, C.E., 1988. Dietary protein and microbial contribution. J. Nutr. 118(2):242-248.

Polan, C.E., Herrington, R.A., Wark, W.A. and Armentano, L.E. 1985. Milk production response to diets supplemented with dried brewers grains, wet brewers grains or soybean meal. J. Dairy. Sci. 68:2016-2026.

Porter, R.M. and Conrad, H.R. 1975. Comparative nutritive value of wet and dry brewers grains. J. Dairy Sci. 58:747 P32 (abstract), Ohio Agric. Res. and Dev. center Wooster, USA.

Purser, D.B. and Buechler, S.M. 1966. Amino acid composition of rumen organisms. J. Dairy. Sci. 49:81-84.

Risk, J.E., Hendrix, K.S., Perry, T.W. and Lemenager, R.P. 1982. Distillers and brewers wet grains feeding. Indiana Beef Cattle Day Report, Purdue University.

Roe, M.B. and Sniffen, C.J. 1990. Techniques for measuring protein fractions in feedstuffs. Cornell Nutr. Conf.

Rooke, J.A. and Armstrong, D.G. 1989 The importance of the form of nitrogen on microbial protein synthesis in the rumen of cattle receiving grass silage and continuous intrarumen rumen infusions of sucrose. Br. J. Nutr. 61:113-121.

Rounds, 1975. Slowly degraded protein sources in ruminant rations. Ph. D. Dissertation University of Nebraska Lincoln, Nebraska.

Rouse, G. and Trenkle, G. 1980. Stillage from grain alcohol as a feed source for cattle. Iowa State University. A.S. Leaflet R307.

Russell, J.B., O'Connor, J.D., Fox, D.G., Van Soest, P.J. and Sniffen, C.J. 1992. A net carbohydrate and protein system for evaluating cattle diets: I. Ruminal fermentation. J. Anim. Sci. 70:3551-3561.

Santos, K.A., Stern, M.D. and Satter , L.D. 1984. Protein degradation in the rumen and amino acid absorption in the small intestine of lactating dairy cattle fed various protein sources. J. Anim. Sci. 58:244-255.

Saskatchewan Feed Testing Laboratory, Department of Animal and Poultry Science University of Saskatchewan, Saskatoon (Personal communication V.J. Racz).

Satter, L.D. and Roffler, R.E. 1975a. Relationship between ruminal ammonia and non protein nitrogen utilization by cattle. 1 Development of a model for predicting non protein nitrogen utilization by cattle. J. Dairy Sci. Ed. 264.

Satter, L.D and Roffler, R.E. 1975b. Relationship between ruminal ammonia and non protein nitrogen utilization by cattle. 11 Application of published evidence to the development of a theoretical model for predicting non protein nitrogen utilization . J. Dairy Sci. Ed. 265.

Satter, L.D. and Stehr, D.B. 1984. Feeding resistant protein to dairy cows. Distillers feed conference Proc. 39-59.

Satter, L.D., and Roffler, R.E. 1974. Nitrogen requirement and utilization in dairy cattle. J. Dairy Sci. 58:8:1219-1236.

Satter, L.D., and Slyter, L.L., 1974. Effect of ammonia concentration on rumen microbial protein production *in vitro.* Br. J. Nutr. 32:199-217.

Shaver R.D., 1991. Feeding the high producing dairy cow: carbohydrate, protein and fat. Dist. Feed Conf. Proc. Vol. 46: April 2, Syracuse, New York, USA.

Schingoethe, D.J. Clark, A.K. and Voelker, H.H. 1983. Wet corn distillers grains in lactating dairy cattle. J. Dairy Sci. 66:345-349.

Shelford, J.A. and Tait R.M. 1986. Comparison of distillers grains with solubles from rye and corn in production and digestibility trials with lactating cows and sheep. Can. J. Anim. Sci. 66:1003-1008.

Smith, R.H. 1979. Synthesis of microbial nitrogen compounds in the rumen and their subsequent digestion. J. Anim. Sci. 49:1604-1614.

Sniffen, C.J. O'Connor, J.D., Van Soest, P.J. Fox, D.G. and Russell, J.B., 1992. A net carbohydrate and protein system for evaluating cattle diets: II. Carbohydrate and protein availability. J. Anim. Sci. 70:3562-3577.

Sosulski, F.W., Lee, W.J. and Sokhansanj, S. 1991 Wet milling and separation of wheat distillers grains with solubles into dietary fiber and protein fractions. Cereal Chem. 68(6):562-565.

Statistical Analysis System (SAS) Institute, Inc., 1990. SAS User's guide: Statistics. Version 6. Third edition.

Statistics Canada 1993 Cereals and oil seeds review December cat No. 22-007 Page 14-15.

Steel, R.G.D. and Torrie, J.H. 1980. Principle and procedures of statistics. McGraw-Hill Book Co., New York, N.Y.

Stern, M.D. and Satter, L.D. 1984. Evaluation of nitrogen solubility and the dracon bag technique as methods for estimating protein degradation in the rumen. J. Anim. Sci. 58(3):714-724.

Stern, M.D. and Hoover, W.H. 1979. Methods for determining and factors affecting rumen microbial protein synthesis. J. Anim. Sci. 49:1590.

Stokes, SR., Hoover, W.H., Miller, T.K. and Blauweikel, R. 1991. Ruminal digestion and microbial utilization of diets varying in type of carbohydrate and protein. J. Dairy. Sci. 74:871-881.

Storm, E.R. and Ørskov, E.R. 1977. Utilization of rumen bacteria by ruminants. Ann. Rech. Vet. 10:294.

Storm, E.R. and Ørskov, E.R. 1983. The nutritive value of rumen micro-organisms in ruminants 1. Large-scale isolation and chemical composition of rumen micro-organisms. Br. J Nutr. 50:463-470.

Storm, E.R., Ørskov, E.R. and Smart, R. 1983a The nutritive value of rumen micro-organisms in ruminants. 2 The apparent digestibility and net utilization of microbial nitrogen for growing lambs. Br. J Nutr. 50:471-478.

Storm, E.R., Brown, D.S. and Ørskov, E.R. 1983b The nutritive value of rumen micro-organisms in ruminants. 3 The digestion of microbial amino and nucleic acids in, and losses of endogenous nitrogen from, the small intestine of sheep. Br. J Nutr. 50:479-485.

Strobel, H.J. and Russell, J.B. 1986 Effect of pH and energy spilling on bacterial protein synthesis by carbohydrate limited cultures of mixed rumen bacteria. J. Dairy Sci. 69:2941-2947.

Swanson, E.W. 1982. In Protein requirements of cattle: Symposium, pp 183-197. F.N. Owens ed. Oklahoma State University Press, Still Water, OK.

Syvaoja, E.L. and Kreula, M. 1979. The *in vitro* determination of the protein quality of rumen microorganisms of cows on urea rich feed. J. Sci. Agric. Soc. Finland. 51:68.

Tamminga, S. 1979. Protein degradation in the fore stomach of ruminants. J. Anim. Sci. 49:1615-1629.

Theurer, C.B. 1986. Grain processing effects on starch utilization by ruminants. J. Anim Sci. 63:1649-1662.

Van Soest, P.J. 1982. Nitrogen metabolism. In Nutritional ecology of the ruminant ed Van Soest, Peter. J. Page 230-248, Cornell University Press, Ithaca New York.

Waller, J., Klopfenstein, T. and Poos, M. 1980. Distillers grains as a protein source for growing ruminants. J. Anim. Sci. 51(5):1154-1167.

Waller, J.C. 1978. Slowly degraded protein sources for ruminants. Ph. D. dissertation University of Nebraska, Lincoln Nebraska.

Weiss, W.P., Erickson, D.O., Erickson, G.M. and Fisher G.R. 1989. Barley distillers grains as a protein supplement for dairy cows. J Dairy Sci. 72:980-987.

Windschitl, P.M. and Stern, M.D. 1988. Evaluation of calcium lignosulfonate-treated soybean meal as a source of rumen protected protein for dairy cattle J. Dairy Sci. 71:3310-3322.

Wright, S.B.M. 1986. A study of nitrogen fertilization of grazed pasture in Saskatchewan. M.Sc. Thesis. Dept. of Anim. and Py. Sci. University of Saskatchewan, Saskatoon.

Yu, Y. and Thomas, J.L. 1976. Estimation of heat damage in alfalfa haylage by laboratory measurement. J. Anim. Sci. 43:(3):766-744.

Zasoski, R.J. and Burau, R.G. 1977. A rapid nitric-perchloric acid digestion method for multi-element tissue analysis. Commun. Soil Sci. Plant Anal. 8:425-436.