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EFFECT OF TYPE OF BARLEY GRAIN ON RATE OF DEGRADATION, DIGESTIBILITY AND FEEDLOT PERFORMANCE OF STEERS

BY

PATRICK BRUCE RAMSEY

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A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

IN

ANIMAL NUTRITION

DEPARTMENT OF ANIMAL SCIENCE

EDMONTON, ALBERTA

FALL 1994

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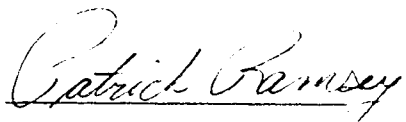

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SUCCESS

To laugh often and love much; to win the respect of intelligent people and the affection of children; to earn the approbation of honest critics and endure the betrayal of false friends; to appreciate beauty; to find the best in others; to give one's self; to leave the world a bit better, whether by a healthy child, a garden patch, or redeemed social condition; to have played and laughed with enthusiasm and sung with exultation; to know even one life has breathed easier because you have lived. This is to have succeeded.

Ralph Waldo Emerson

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommended to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled EFFECT OF TYPE OF BARLEY GRAIN ON RATE OF DEGRADATION, DIGESTIBILITY AND FEEDLOT PERFORMANCE OF STEERS submitted by PATRICK BRUCE RAMSEY in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE in ANIMAL NUTRITION.

Dr. G.W. Mathison, Supervisor

Dr. F.X. Aherne

Dr. F.S. Novak

October 4, 1994

DEDICATION

I dedicate this thesis to my wife Trudy, and to my children Michael, Brian, and Daniel. Their love, support and personal sacrifice made it possible for me to complete this task.

ABSTRACT

The effects of barley grain (two-row vs. six-row, hulless vs. hulled, malting vs. feed type) on rate of in situ degradation, in vivo digestibility and rate and efficiency of gain of steers (365 ± 27 kg) were determined using ten lots of barley grain. The barley samples varied with respect to volume weight (VW; 55-67 kg hL^{-1}), crude protein (CP; 10.3-14.8%), acid detergent fibre (ADF; 5.2-8.0%), kernel hardness (KH; 46.7-77.7 seconds in grinding time with shorter times being associated with harder grain), and in situ dry matter (DM) degradability after 0, 4, 8, 12, and 24 h (P=0.0006). There were differences in total tract organic matter digestibility between barley samples (82.4%-88.7%, P=0.04) and between two-row and six-row barley (86.8% and 85.1% respectively, P=0.03). The digestible energy (DE) content also varied between barley samples (14.5-16.0 MJ kg^{-1} diet, P=0.03) and between two-row and six-row barley (15.5 vs. 15.2 MJ kg^{-1}, respectively, P=0.04). No differences in DM intake (9.7-10.9 kg d^{-1}, P=0.73), average daily gain (ADG) (1.5-1.6 kg d^{-1}, P=0.20), feed DM:gain ratio (6.4-6.9, P=0.96), or carcass characteristics (P>0.20) were detected between steers fed these ten different samples of barley in diets containing 85.5% barley grain. Similarly, no differences (P>0.12) in these parameters were detected between steers fed two-row, six-row or hulless barley, or between steers fed malting or feed barley. Feed

ratios were related to 24 hour in situ degradability of ground (3 mm screen) grain DM (r=0.68, P=0.03) and to 24 hour in situ degradability of rolled (cracked) grain DM (r=-0.71, P=0.02). Significant relationships were detected between the percentage of animals which bloated (14%) and CP (r=0.68, P=0.02), ADF (r=-0.73, P=0.02), VW (r=0.67, P=0.04), and in situ DM degradability after 12 h (r=0.74, P=0.01). There were no significant relationships between any of the measured parameters and the percentage of animals which developed abscessed livers (16%). It was concluded that large differences in the feeding value of two-row vs. six-row, or malting vs. feed barley grains of similar volume weight are not to be expected when the grains are included in feedlot diets containing adequate protein and other nutrients. Further, we were unable to confirm or refute our hypotheses that barley grain which is degraded more rapidly in the rumen is undesirable.

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Agriculture Canada personnel provided carcass measurements.

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1.0 INTRODUCTION

Barley is the major cereal grain for feeding beef cattle in Alberta. Of the 5.9 million tonnes of barley produced in Alberta in 1991, 2.6 million tonnes were fed to livestock and poultry. Beef cattle consumed over 65% or 1.7 million tonnes of this barley (Statistics Canada 1992). In spite of this, the emphasis in barley breeding has been for malting barley production, and only relatively recently has emphasis been placed on the development of feed cultivars (Bhatty 1980; Newman et al. 1981). Froseth and Miller (1992) suggested that in the future barley breeding programs should consider nutritional quality to a greater extent than in the past. Much of the development in feed barley has been aimed at improving the protein and lysine content, which can greatly decrease the use of protein supplements in monogastric diets (Bhatty 1980; Newman et al. 1981). More work needs to be done in selecting and developing suitable feed barleys for ruminants.

Large differences between barley genotypes in terms of morphological, physiological and chemical characteristics have been reported (Bhatty 1980; Newman and McGuire 1985; Froseth and Miller 1992). According to Froseth and Miller (1992) head morphology (two-row, six-row), growth habit, and intended end-use (malting, feed) are probably the most useful indicators of barley nutritional quality, but these

can be affected by climatic changes such as high rainfall or drought in some growing seasons and in certain geographic locations. Moreover, there appears to be large differences in the feeding value of barley cultivars for steers. Males and Fong (1987) reported differences between cultivars for ruminants amounting to 10% for average daily gain (ADG), 5% for feed DM:gain ratio, and 10% for digestible energy (DE). They also indicated that the reasons for these differences have not yet been identified. In spite of the potential differences between feed barleys, limited research work has been conducted on the factors affecting the feeding value of barley for beef cattle in Alberta (Grimson et al. 1987; Mathison et al. 1991; Engstrom et al. 1992).

The primary value of barley and other cereals in animal feeds is as a source of highly available energy which is primarily derived from starch (Newman et al. 1981). For most grain, except corn and sorghum, 90% or more of starch is degraded in the rumen (Ørskov 1986; McAllister et al. 1990). Rapid starch degradation in the rumen is believed to be undesirable since it lowers rumen pH, depresses fibre digestion, and causes digestive disturbances such as acidosis, rumenitis, liver abscess and bloat (Ørskov 1986; Robinson 1989; McAllister et al. 1990; Cone and Vlot 1990). Clark et al. (1987) reported differences between in vitro dry matter (DM) and neutral detergent fibre (NDF) degradation rates between barley varieties and suggested

that it may be possible to select barleys with slower rates of degradation for use as a ruminant feed grain. Givens et al. (1993), in a summary of recommendations for research in cereal grains for ruminants, identified the following areas as the top three priorities: 1) factors influencing the measurement of DM, starch and protein degradation in the rumen using the nylon bag method, 2) influence of factors such as protein content and processing or treatment methods on rate of cereal protein and starch degradation in the rumen, and 3) influence of variety within cereal species on the rate and extent of starch and protein degradation in the rumen. Thus more work on the differences in rumen degradation rates between samples of barley and the effect on feedlot performance is warranted.

Considerable amounts of both two-row and six-row barley are grown in Alberta. Improvements in feed efficiency have been noted in some experiments when two-row barley grain has been compared with six-row barley in monogastric diets (Newman and McGuire 1985) however in other experiments no improvements have been observed (Newman and Eslick 1970; Castell and Bowren 1980). There is limited information concerning the comparable nutritive value of two-row vs. six-row barley in cattle diets (Hinman 1979; Bradshaw et al. 1992; Ovenell and Nelson 1992; Ovenell et al. 1993). Further studies on the relative feeding value of two- and six-row barley for ruminants are warranted.

Differences in feed DM:gain ratios between corn and barley fed cattle are often about 10% (Neumann 1977) which is similar to the difference in digestibilities between the two grains. Bhatty (1980) indicated that removal of the hull increased DE content of barley so that it was equal or superior to that of corn for monogastric animals, and that hulless barley has the same fibre content as corn. Based upon several experiments with monogastric animals (Newman and Eslick 1970; Bhatty et al. 1979; Spicer and Aherne 1990) it might be expected that hulless barley would be superior to hulled barley for cattle. There are reports in the literature however, in which the feeding value of hulless barley was not greater than that of hulled barley for swine (Newman and McGuire 1985) and poultry (Sibbald 1982; Classen et al. 1985; Bhatty 1986). The poorer feeding value of hulless barley for poultry may be related to the higher β-glucan content of hulless barley (Classen et al. 1985; Bhatty 1986; Newman and Newman 1990). β-glucans are however, believed to be highly degradable in the rumen (Engstrom et al. 1992). Since hulless barley is becoming increasingly important in Alberta and its feeding value for ruminants cannot be completely predicted from composition and feeding experiments with other animals, studies on its usefulness in ruminant diets are warranted.

Many of the feed varieties released have resulted from malting barley breeding programs (Canada Grains Council

1982). There is evidence that malting varieties provide better feed value than feed varieties in monogastric diets (Froseth 1977). There is limited data in which malting and feed barley have been compared in ruminant diets (Hinman 1979; Bradshaw et al. 1992) and thus more work is required in this area.

The objectives of this research were to test the hypotheses that rate of degradation varies between samples of barley and that this characteristic influences feedlot performance of steers. Additionally, objectives were to test the hypotheses that feedlot performance is enhanced by feeding two-row vs. six-row barley, or malting vs. feed barley.

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2.0 LITERATURE REVIEW

2.1 Chemical Composition, Physical Characteristics and Digestible Energy Content of Barley Grain

Barley grain differs greatly in morphological, physiological, and chemical characteristics due to genotype and environment and their interaction (Hoppner et al. 1968, as cited by Newman and McGuire 1985). Bhatty et al. (1974) found ranges in the content of protein (12.5-17.2%), starch (44-56%), amylose (23.5-33.0%), and gross energy (4032-4415 kcal kg^{-1}), ether extract (1.4-2.7%), fibre (2.3-6.2%), ash (2.0-5.0%) and β-glucan (1.2-3.3%) among 29 barley cultivars. Barley cultivars also ranged in VW (62.3-73.6 kg hL^{-1}), thousand kernel weight (TKW; 34.5-57.0 g), and plumpness (17-99%). Doornbos and Newman (1989) found significant differences between 12 barley varieties and nine locations in northcentral Montana, in terms of chemical and physical characteristics. A wide range in quality existed for Kjeldahl protein (10.3-21.7%), acid detergent fibre (ADF; 5.8-16.7%), soluble carbohydrates (26.0-52.5%), ash (2.1-5.4%), in vitro DM degradability (60.8-84.4%), metabolizable energy (ME; 2.3-3.1 kcal g^{-1}), and total digestible nutrient content (63.2-86.5%). Wide ranges were also reported in the physical properties of the barleys for volume weight (VW; 32.8-61.0 kg hL^{-1}), plump kernels (0-

77.8%), and thin kernels (5.3-98.3%). Similarly, chemical and physical composition of Pacific Northwest barley were variable as reported by Froseth and Miller (1992). In their study of 556 barley samples representing 52 varieties, wide variations were noted in VW (45.6-79.6 kg hL^{-1}), DM (87.6-97.5%), CP (7.3-18.1%), ether extract (1.3-3.3%), ash (2.0-3.6%), ADF (2.4-12.5%), starch (40.8-67.1%), β-glucans (3.2-7.4%), and calculated ruminant digestible energy (DE) content (15.34-15.99 MJ kg^{-1}). They concluded that high variability in VW, CP and lysine are probably the most important from a practical point of view.

Although differences between physical and chemical composition of barley samples were found, VW had no significant effect on CP, soluble carbohydrate, or ADF content and swine performance did not support the theory that barley feeding quality is highly related to VW (Doornbos and Newman 1989). Froseth and Miller (1992) reported that VW was not highly correlated with most other measures of quality including ADF ($r=-0.37$), β-glucan ($r=0.21$), starch ($r=0.46$), swine DE ($r=-0.12$), CP content ($r=-0.19$) or most of the essential amino acids ($r=-0.21$ to 0.53). The only exemption was a high correlation between VW and poultry total ME ($r=0.94$). Low correlations between VW and most other measures of nutritional quality together with the high variability of Pacific Northwest barley suggested that the use of VW as the only or primary measure of quality

when purchasing barley could not be recommended or defended (Froseth and Miller 1992).

Commercial feedlots and feedmills commonly purchase barley under the quality criteria of VW, moisture content and dockage (Grimson et al. 1987). However, a limited number of trials examining the effects of VW of barley on feeding value for ruminants have been conducted resulting in conflicting conclusions about the usefulness of this quality criteria. Hanke and Jordan (1963) found that VW had no effect on ADG or feed efficiency in lambs fed pelleted barley. However, when fed as whole barley the heavy-weight barley resulted in significantly ($P<0.01$) greater gains than the light-weight barley. Feed efficiency declined as the VW declined when the barley was fed whole. Thomas et al. (1963) conducted two trials to determine the feeding value of light and heavy barley in cattle fattening diets. In trial 1, steers were fed either light (54.4 kg hL^{-1}) or heavy barley (60.4 kg hL^{-1}) with, and without, additional protein. The steers fed additional protein gained slightly faster with less feed required than those fed light or heavy barley without the supplement. In trial 2, steers fed heavy barley (62.8 kg hL^{-1}) gained slightly faster on less feed than those fed the light barley (50.8 kg hL^{-1}). However, there were no statistical differences in gains of steers in either trial.

Hinman (1978) found a trend for ADG to decrease from

1.29 to 1.14 kg d^{-1} as barley VW decreased from 61.6 to 50.7 kg hL^{-1}. There were no differences in daily feed consumption or feed DM:gain ratio, although feed DM:gain ratio increased from 7.08 to 7.74 as barley VW decreased. The overall effect was an increase in the feed cost per pound of gain when lightweight barley was fed.

Grimson et al. (1987) fed barley weighing 47.8, 55.6 and 66.6 kg hL^{-1} to steers (332 kg), and reported that feed DM:gain was 9.0% lower ($P<0.05$) for the steers fed medium barley and 10.3% lower ($P<0.05$) for the steers fed heavy barley than for those fed the light barley. Dry matter per unit gain was similar for cattle fed medium and heavy barley (55.6 and 66.6 kg hL^{-1}). However, VW had no effect on ADG, or DM intake. Overall, DM:gain decreased an average 1.2% for each unit (kg hL^{-1}) increase in VW from 47.8 to 55.6 kg hL^{-1}.

Mathison et al. (1991) fed barley weighing 43, 59 and 64 kg hL^{-1} to steers and reported that steers fed the light barley had a 6% increase ($P=0.27$) in feed DM:gain requirements compared to steers fed the two heavier barley grains. Mathison et al. (1991) found that the organic matter in light barley (43 kg hL^{-1}) was 2% less digestible than organic matter in heavier barley (59, 64, and 66 kg hL^{-1}). No differences in methane production due to barley volume-weight were detected. Rates of gain (1.63-1.67 kg d^{-1}) and DM intake (9.8-10.2 kg d^{-1}) of steers were not

affected by VW.

Engstrom et al. (1992) fed six lots of barley with VW varying from 56.9 to 70.5 kg hL^{-1} to feedlot steers and found no difference in DM intake (9.09-9.72 kg d^{-1}), ADG (1.49-1.57 kg), feed DM:gain (5.85-6.35, P=0.17) or carcass characteristics.

Although a technical committee on feed grain utilization (Canada Grains Council 1972) suggested that VW was the most practical measure of the DE content of feed grains, a relationship between VW and DE or metabolizable energy (ME) has not always been demonstrated for cereals (Christison and Bell 1975). Sibbald and Slinger (1963) measured the ME content for chicks in three samples each of wheat, barley and oats. Oats alone demonstrated a consistent change in ME content associated with changes in VW. However, the VW of the grains, including oats, had no significant effects upon the chick weight gains or feed efficiency. Sibbald and Slinger (1963) concluded that VW are of little use in estimating the nutritive worth of either wheat or barley, but may serve as a useful guide to the ME content of oats in chick diets. Schumaier and McGinnis (1967) found that the ME for chicks of samples of wheats grown in two different locations were similar. There was some variability in the results for different varieties of wheat, however, composition of the wheats as determined by proximate analysis did not reveal any differences that

would greatly affect ME for chicks (Schumaier and McGinnis 1967).

Bhatty et al. (1974) examined the relationships of various physical and chemical characters to digestible energy (DE) for mice in 29 cultivars of two row and six row barley. The six-row cultivars had a larger proportion of small seeds than the two-row barley. Two-row barley had, on the average, 4.1 kg hL^{-1} higher VW, 5 g higher kernel weight and 30% more plump kernels, 3% more amylose in the starch and a higher β-glucan content (2.1 vs. 1.8%) than six-row barley. However, except for plumpness, there were no major differences between two- and six-row barley. In barley, DE was positively correlated to protein and gross energy, and the digestion coefficient was positively correlated to VW, plumpness, ether extract and negatively correlated to fibre. Bhatty et al. (1974) concluded that for use as selection criteria, the most significant correlations were between DE and gross energy in barley and that physical characters of the feed grain were of little or no value in predicting DE of a feed grain. However, they noted that VW, kernel weight and plumpness add market value to feed grains and could be selected for without affecting DE in barley.

Bhatty et al. (1975) determined the digestibility of energy and DE content of 16 cultivars and lines of barley by mouse feeding and related these to kernel weight, plumpness, hull, protein, lysine, starch, amylose and gross energy of

the cultivars. Their experimental design allowed paired comparisons of digestibility of energy and DE content between hulled vs. hulless types, small vs. large-seeded, normal vs. high lysine, low vs. high amylose, and good vs. poor malting quality of the cultivars. The authors concluded that kernel weight, plumpness and lysine contents of barley had little effect on digestibility of energy and DE content.

Christison and Bell (1975), did an assessment of VW and other simple criteria for predicting the DE values of feed grains, using mice. For barley, both gross energy and crude fibre determinations were needed to permit a reliable estimation of DE. In earlier experiments that showed VW effects Christison and Bell (1975) noted that low VW was often confounded with differences due to dockage, maturity, weather damage, or to other non specific results of adverse climatic conditions. In their study, Christison and Bell (1975) concluded that VW was of limited merit in predicting the energy content of wheat and barley but was useful for predicting the energy content of oats. They also reported that within each grain the gross energy values displayed a relatively small range of variation; there was no clear indication of increasing fibre content being associated with decreasing grades of wheat, barley or oats. Kernel weight or plumpness were also not highly correlated to available energy.

Bhatty (1979) indicated that hull content was the only component of barley that had a major influence on its DE content for mice and that the physical characters of kernel weight and VW were of little or no value in predicting the DE content of barley.

2.2 Effects of Variety on Feeding Value

Major differences among samples of barley have been attributed to variety, head morphology (two-row vs. six-row), intended end-use (feed vs. malting), growth habit (spring vs winter), geographical location grown, and year of production (Froseth and Miller 1992; Ovenell et al. 1993a).

Research with ruminants in which the feeding value of barley varieties has been compared are limited. However, results with swine suggest that there might be differences. Newman and Eslick (1970) compared five commercial barley varieties, grown under irrigation and dryland conditions, in feed value for swine. Differences in rates of gain due to the commercial barley varieties studied were not significant and gains were not different from the gains made by animals fed corn diets. However, barleys produced under dryland conditions resulted in a 6.8% higher ($P<0.05$) ADG than barley grown under irrigation. Anderson et al. (1984) compared the total and digestible yield of nutrients for swine in seven barley cultivars (Bonanza, Galt, Gateway,

Klondike, Betzes, Fairfield and Klages) grown under similar environmental and soil conditions. There were significant differences among the barley cultivars for digestibilities of DM, energy, protein and availabilities of indispensable amino acids. It was suggested that in addition to yield, the nutritive value of a barley, should be considered when selecting a barley cultivar to grow for pig diets. Honeyfield et al. (1987) showed that the chemical composition of five barley cultivars was variable and the feeding value for pigs was dependent upon the cultivar and growing conditions for the barley. Barley cultivar affected feed intake ($P<0.05$) which ranged from 1.36-1.57 kg day^{-1} for dryland vs. 1.26-1.43 kg day^{-1} for irrigated. There was a cultivar by growing condition interaction for ADG ($P<0.01$) which ranged from 0.53-0.62 kg day^{-1} for dryland vs. 0.52-0.61 kg day^{-1} for irrigated. There was also a cultivar by growing condition interaction for feed DM:gain ($P<0.01$) which ranged from 2.20-2.73 for dryland vs. 2.21-2.47 for irrigated barley. Middaugh et al. (1989) found that barley cultivar affected feed DM:gain slightly ($P<0.11$) in pigs. Pigs fed Gus and Steptoe were 7.4% more efficient in conversion of feed to weight gain than those fed Gusto.

Similarly, differences in feeding value of different barley varieties have been detected in cattle. Preston and Herlugson (1980) indicated a 10-12% advantage in rate of gain ($P=0.17$) and feed efficiency ($P=0.07$) for Boyer vs.

Steptoe barley when fed as whole barley to yearling steers, whereas cattle performed similarly on both barleys when they were rolled. Taylor et al. (1985) found that there were differences ($P<0.05$) in feed DM:gain of different barley cultivars for finishing cattle (7.2 for Andre vs. 6.5 for Steptoe barley and 6.6 for Klages). They indicated that VW and CP content did not appear to be related to the utilization of barley by the animal. Males and Fong (1987) compared the feeding value of three barley cultivars, grown in two locations, under irrigation or dryland conditions, for steers. The irrigated cultivars were higher in CP and VW than the dryland cultivars. Through the first 91 days of the trial, cattle fed Piston gained faster ($P<0.05$) than cattle fed Andre or Steptoe and cattle fed irrigated cultivars used their feed more efficiently than those fed dryland cultivars. Growing location did not affect ADG. By the end of the trial, the cattle fed Piston were growing more slowly and this resulted in a lower ($P<0.05$) ADG for the Piston fed cattle over the whole trial. Over the whole trial, cattle fed Andre and Steptoe barley were more efficient ($P<0.05$) than cattle fed Piston barley. However, this difference in feed efficiency between barley cultivars wasn't apparent until after 120 days on feed.

Ovenell and Nelson (1992) examined the feedlot performance, carcass characteristics of steers, and digestibility of diets containing different barley

cultivars. They found differences ($p<0.05$) in DM intake, ADG, feed DM:gain, hot carcass weight, backfat, rib eye area (REA), kidney, pelvic and heart fat, organic matter intake, and total tract (NDF) digestibility between six barley cultivars. The range in NDF digestibility among cultivars was approximately 24% and appeared to be the biggest factor contributing to differences among cultivars. They concluded that there are variations in animal performance, carcass characteristics, and diet digestibility among barley cultivars.

Ovenell et al. (1993a) comparing the effects of six different barley cultivars fed to steers, found that Hesk-fed steers had the poorest ($P<0.10$) feed DM:gain ratio. Their results suggested that Camelot (two-row spring feed) and Harrington (two-row spring malting) had superior feeding value for ruminants compared to Hesk and Steptoe (six-row spring feed). They noted that DM intake, ADG, and feed DM:gain were all improved over performance in a previous trial (Ovenell and Nelson 1992), suggesting year-to-year variation among those cultivars fed in both years. Steers fed Camelot barley had greater ($P<0.05$) ruminal and greater ($P<0.10$) total tract NDF digestibility than steers fed Hesk or Steptoe. It was observed that chemical composition of barley cultivars was not useful in predicting animal performance and diet digestibility, and that there were other reasons for the observed variability. It was

concluded that NDF digestibility appeared to be the major factor contributing to variability among barley cultivars and that methane production may be involved.

Ovenell et al. (1993b) comparing six different barley cultivars fed to lambs, found that OM intake was greater ($P<0.10$) for lambs fed 1991 Boyer (six-row winter feed) than 1990 Camelot-fed lambs. The authors suggested that 1991 Boyer had a slower rate of degradation than 1990 Camelot, increasing residence time in the rumen, and leading to increased fibre digestion and methane production. Digestibility of NDF varied ($P<0.10$) between cultivars (46.8% for 1990 Camelot to 53.2% for 1990 Steptoe). Methane (CH_4) production also varied ($P<0.10$) between cultivars (23.84 L d^{-1} for 1990 Steptoe to 37.76 L d^{-1} for 1991 Boyer) and significantly contributed to differences ($P<0.10$) in the ME content of the six different barley cultivars (2.84 Mcal kg^{-1} for 1990 Cougbar to 3.13 Mcal kg^{-1} for 1991 Camelot). They concluded that digestibility of NDF, methane (CH_4) production, and nitrogen metabolism were major factors contributing to barley cultivar variability within and among years. The authors noted that NDF content of the barley cultivars ranged from 19.9% for 1990 Camelot to 25.3% for 1991 Steptoe, and that CP ranged from 9.9% for 1991 Boyer to 13.7% for 1991 Camelot.

Cultivars effects were also demonstrated in ewes fed high concentrate barley-based diets by Kemalyan et al.

(1990). Their work showed duodenal starch flow differed among barley cultivars, with values ranging from 5.9 to 9.5 g d^{-1} which was lower than 14.6 g d^{-1} for corn. Crude protein flow in the duodenum tended to differ with values ranging from 88.3 to 128.7 g d^{-1}. There were also significant differences in dietary escape protein between barley cultivars and between barley and corn (0-11.6 for barley and 24.9 g d^{-1} for corn), microbial nitrogen flow to the duodenum (14.8-18.9 g d^{-1}), and microbial efficiency (13.3-21.7 g microbial protein per 100 g OM digested). However, Hatfield et al. (1991), using two different varieties, found that starch and organic matter (OM) digestibility, duodenal flow of OM and ruminal pH were not affected by variety or level of feed intake of wethers.

2.3 Two-row vs. Six-row Barley

Hanson (1942) found that in most cases a two-row variety of barley (Spartan) contained more protein and less fibre and had a considerably higher VW than the prominent six-rowed varieties. In a feeding trial pigs fed Spartan barley gained more rapidly than those fed a six-row cultivar, however, the two-row barley had higher volume weight and protein content. When the diets were mixed to contain the same protein content the pigs fed the six-row cultivar gained more rapidly, however, the pigs fed the two-

row barley may have lacked carotene since they didn't get as much supplement. Newman and Eslick (1970) found that growth rate and feed efficiency were similar for pigs fed two-rowed (Betzes, Compana, Dekap) or six-rowed (Unitan, Vantage) cultivars. Froseth (1977) compared Vanguard (two-row malting) and Steptoe (six-row feed) barley in swine diets. Pigs fed Vanguard barley required less feed per pound of gain ($P<0.05$) and tended ($P<0.24$) to grow faster than those fed Steptoe barley. Newman and McGuire (1985) cite Bouard et al. (1980) as finding that pigs gained at similar rates when fed diets containing two- or six-rowed barleys, although pigs fed the six-rowed barley consumed greater amounts of diet and were less efficient. Castell and Bowren (1980) found a trend in swine diets for feed DM:gain in two-row cultivars to be lower than six-row cultivars, as supported by their higher apparent digestibilities of energy (80.8 vs. 71.8%) and nitrogen (73.5 vs. 65.7%). A palatability study using these diets indicated the pigs had a preference for two-row over six-row barleys, although differences in intake were small. Newman et al. (1982) compared the feeding value of two-row and six-row isotypes of Titan barley in pig diets. The two-row barleys produced the fastest ($P<0.10$) gain and best ($P<0.10$) feed conversion in the grower and overall feeding periods. Anderson et al. (1984) indicated that in growing swine that apparent DM digestibilities ranged from 82.9% for Galt (six-row), to

85.7% for Klages (two-row) barley. Protein digestibility ranged from 65.2% for Galt to 69.4% for Betzes (two-row) barley. Gross energy digestibility ranged from 81.2% for Galt to 84.2% for Klages. Lysine digestibility ranged from 48.1% for Galt to 61.7% for Bonanza (six-row) barley. Middaugh et al. (1989) found that in gerneral two-row barleys tended to have a higher VW, contained more CP and lysine, and had a lower ADF content than six-row barleys. Middaugh et al. (1989) found statistical differences in feed efficiency among pigs fed two-row vs. six-row barleys, but felt that since these were less than 1% they were probably not biologically important. The literature seems to indicate that two-row cultivars are superior to six-row cultivars in monogastric diets.

In ruminant diets, Hinman (1979) found that feed efficiency was about 6% better ($P>0.10$) in yearling steers fed Klages, a two-row spring malting barley, compared to Steptoe, a six-row feed barley. This difference was attributed to Klages having a higher VW (70 vs. 63 kg hL^{-1}). A higher VW in barley suggests a greater percentage of starch in the kernel and thus a higher productive energy value (Newman and McGuire 1985). Moreover, Bradshaw et al. (1992) observed no difference in performance, digestibility or carcass characteristics between Steptoe and Klages fed steers when VW was equal. However, Ovenell and Nelson (1992) found that feed:gain, ADG, backfat, kidney, pelvic

and heart fat were was greater when Clark, a two-row malting barley was fed than when Cougbar, a six-row malting barley was fed to steers. Similarly, Ovenell et al. (1993) found that Camelot and Harrington (two-row cultivars) had superior feeding value for ruminants compared to Hesk and Steptoe (six-row cultivars). More research is required to determine the comparative feed value of two-rowed vs. six-rowed barleys in steer rations.

2.4 Hulless vs. Hulled Barley

Hulless barley has been compared to hulled barley in a number of trials in monogastric diets with mixed results (see review by Aherne 1990). However, no comparisons could be found for ruminants.

Joseph (1924) found that hulless barley was equal to wheat for fattening 45 kg swine. Good quality hulled barley was found to be equivalent to hulless barley when both were fed with good quality supplements. However, when fed with no supplements or with poor quality supplements, hulless barley was used 8-15% more efficiently by the pigs. This is understandable since hulless barley contains more protein and substantially more lysine than hulled barley (Aherne 1990).

When comparing hulless barley with other grains in rations for growing chicks, Anderson et al. (1961) found

that rations based on hulless barley were not superior to rations based on regular barley.

Gill et al. (1966) found that pigs preferred hulless barley. Those receiving hulless barley gorged themselves the first time this feed was offered and subsequently exhibited vomiting and diarrhoea, which cleared up within 2 days without treatment. Pigs receiving the hulled barley wasted large amounts of feed late in the experiment, apparently in an attempt to discard the hull fraction (Gill et al. 1966). Pigs fed hulless barley had a 10.6% advantage ($P<0.05$) in daily gain and required 20.7% less ($P<0.05$) feed per unit gain compared to those fed hulled barley, although feed efficiency of the hulled barley was influenced by feed wastage (Gill et al. 1966).

Newman et al. (1968) suggested that differences may exist in the nutritive value of hulless barley other than a lower crude fibre content. Rate and efficiency of gains of pigs fed hulless Compana barley were superior to those fed covered Compana barley, while hulless Glacier and covered Glacier performed similarly in diets for young pigs (Newman et al. 1968). The authors suggested that the method of development of the Compana isogenes would indicate that the superiority of the hulless genotype could be transferred to any other variety lacking the genes involved.

Newman and Eslick (1970) found significantly greater ($P<0.05$) rate and efficiency of gain when pigs were fed

finishing diets containing hulless barley (Nupana) and corn than when they received a diet of hulled barley (Compana). Pigs fed hulless barley had a 11.6% higher ADG than those fed hulled barley. Pigs fed hulled barley required 9.3% more feed per unit gain than those fed hulless barley.

Bhatty et al. (1974, 1975) investigated the digestibility of gross energy and DE content of 45 cultivars and lines of hulled and hulless barley by mouse-feeding. They found that of the number of physical and chemical characters of grain examined, hull content had a major influence on its digestibility of gross energy and DE content. On average, the hulless barley cultivars had 8.2% greater digestibility of gross energy (85.7 vs. 79.2%) as well as a higher DE content (16.39 vs. 15.18 MJ kg^{-1}) than the hulled barley. Bhatty et al. (1979), investigated the digestibility of gross energy and DE content of four near-isogenic hulled and hulless two-row and six-row barley for swine feeding. Hulless barley had an 11.1% greater energy digestibility (81.8 vs. 73.6%) as well as 14.7% more DE (14.22 vs. 12.39 MJ kg^{-1}) than hulled barley. The digestibility of protein from hulless barley was superior to that from hulled barley (65.8 vs. 58.6%) in the two-row cultivars. Removal of the hull increased the DE content of barley to an amount equal or superior to that of corn (Bhatty et al 1979). Hulless barley contained more protein of superior quality than hulled barley or corn (Bhatty et

al. 1979).

Sibbald (1982) found no difference in the true ME content of hulless vs. hulled barley fed to chickens. However, Classen et al. (1985) found the true ME value of hulless barley was significantly higher than for hulled barley and similar to that of wheat for adult roosters. However, substitution of hulless barley for wheat in broiler chick diets resulted in a significant linear depression in performance.

Classen et al. (1988) substituted hulless or conventional barley for wheat in laying hen diets. Hens fed hulless barley, at 35.7% of the diet, layed more eggs with higher specific gravity than did hens fed the same level of conventional barley. When barley was fed at 71.4% of the diet, hens fed hulless barley were heavier and produced larger eggs than hens fed the conventional barley. It was concluded that hulless barley was at least equivalent to wheat and surpassed conventional barley as a cereal grain for laying hens.

Thacker et al. (1986) compared Scout, a hulless feed variety, to Harrington, a two-row malting barley commonly used for feed, in swine diets. Their results indicated that the digestibility of CP may be lower (75 vs.78%) in hulless barley compared with hulled barley. Pigs fed diets based on hulless barley gained at approximately the same rate as those fed the hulled barley (0.74 vs 0.75 kg d^{-1}). However,

the feed intake of pigs fed the diets based on hulless barley was lower than that of pigs fed the hulled barley diet (2.32 vs 2.46 kg d^{-1}). As a consequence, feed conversion was significantly better for pigs fed the hulless barley compared with the hulled barley (3.13 vs 3.3). Based on this result, it was estimated that pigs fed Scout barley would require approximately 13 kg less feed to reach market weight than pigs fed hulled barley.

Spicer and Aherne (1988), evaluated a new variety of hulless barley (TR607) in comparison to control diets of barley and wheat, regular barley, and Scout (a hulless barley) in diets for young pigs. Pigs fed the Scout barley had poorer ADG and feed DM:gain than pigs fed the other three diets. However, the diet containing the regular barley also contained more soybean meal (SBM) which was added to keep the diets isonitrogenous. TR607 replaced all the wheat and about 8% of the SBM in the control diet, yet pigs fed this diet performed as well as those fed the control diet. It was concluded that on a cost per unit gain basis, the most cost-effective grain would be the TR607 barley. In a second experiment using Samson as the regular barley, with or without wheat, and two lots of TR607 barley, there were no significant differences in ADG or feed DM:gain. However, it was observed that pigs fed the Samson barley with wheat tended to gain faster than those fed Samson barley without wheat or the TR607 barley diets.

Condor, a hulless barley, was evaluated by Spicer and Aherne (1990) and compared to Samson (hulled) with or without wheat and BT536 (a hulled barley), in diets for starter and grower pigs. The ADG of pigs fed Condor barley was not significantly different from that of pigs fed Samson barley or wheat plus Samson barley. There were no differences in feed intakes ADG, or feed DM:gain ratio between pigs fed the Samson-based diet compared to that of pigs fed the Condor or BT536 barley diets. In these trials, however, Condor hulless barley replaced all of the wheat and up to 21% of the SBM in pig diets with no reduction in performance. It was concluded that substantial savings in feed costs could be obtained by incorporating Condor hulless barley into swine diets.

Newman and Newman (1990) indicated that on average, hulled barley contains 18-20% total dietary fibre (lignin, pentosans, cellulose, β-glucans), compared to hulless barley which contains 11-13%. They stated that the fibre in the hull is mainly cellulose and lignin which are considered to be insoluble fibre, therefore, hulless barley should be more desirable than hulled barley for monogastric animals. However, Newman and Newman (1990), citing Newman and McGuire (1985), indicated that the majority of research reports showed no major nutritional advantage for hulless over hulled barley in swine or broiler chick rations. Classen et al. (1985) indicated that the depression in performance when

hulless barley was substituted for wheat in broiler chick diets may have been due to the higher β-glucan content of hulless barley. β-glucans increase the viscosity of intestinal fluids, thereby impairing nutrient absorbtion and water relationships in the digestive tracts of young chicks (Classen et al. 1985 as cited by Bhatty 1986). Classen et al. (1985) suggested that β-glucan, primarily found in endosperm cell walls, may directly limit access to intracellular starch granules, thereby depressing starch absorbtion. While this was not a major effect in their study, starch absorbtion was lower with hulless barley in the diet. Addition of cellulase, antibiotic or irradiation of the grain increased the growth rate of the chicks receiving the hulless barley (Classen et al. 1985). Autoclaving the hulless barley significantly reduced 3-wk weight and increased feed DM:gain ratio for the birds. Gamma irradiation or cellulase addition reduced the viscosity of the β-glucan solution indicating that these treatments may have increased the nutritional value of the hulless barley by depolymerization of the β-glucan (Classen et al. 1985). Newman and Newman (1987) compared covered and hulless barley diets with and without β-glucanase in broiler chick diets and found no difference ($P>0.10$) between the two types for final body weight, body weight gain, or feed:gain ratio. However, β-glucanase treatment significantly increased ($P<0.001$) body weight, gain and feed efficiency

for both covered and hulless types. This effect was more pronounced in the hulless barleys for both chick weights and feed efficiency suggesting a greater concentration of β-glucans or related endosperm cell wall components in the hulless types (Newman and Newman 1987). The higher relative viscosity measurements in the hulless types within starch type supported this conclusion (Newman and Newman 1987). Newman and Newman (1990) found that waxy (96-100% amylopectin) hulless barleys contained a greater percentage of β-glucans and other components of soluble dietary fibre than non-waxy (75% amylopectin and 25% amylose) hulless or covered barleys. β-glucan contents were 6.4, 5.8, 5.0 and 4.6 per cent for waxy hulless, waxy covered, hulless and covered barley respectively. This makes the waxy hulless types of barleys undesirable as feed barleys, especially for poultry. However, Newman and Newman (1990) indicated that these barleys are highly desirable for human food products where soluble dietary fibre has distinct health advantages.

2.5 Malting vs. Feed Barley

For malting barley the major quality factors are: high extractability in the malting process, a reflection of a high starch content, and the presence of adequate levels of a number of enzyme systems which are required in the malting and brewing processes (Canada Grains Council 1982). A high

starch content is of value for both malting and feeding purposes (Canada Grains Council 1982). Substantial quantities of barley for malting are selected regularly by the maltsters from the "feed" grades, and many of the feed varieties released have resulted from malting barley breeding programs (Canada Grains Council 1982).

Bhatty et al. (1975) suggested that good malting quality in barley is not incompatible with high digestibility of energy and DE content as determined by mouse feeding. Froseth (1977), compared Steptoe (six-row feed) barley with Vanguard (two-row malting) barley in swine diets. Pigs fed Vanguard barley had lower feed DM:gain (3.60 vs. 3.79) and tended to have higher ADG than those fed Steptoe barley. Rations containing Steptoe barley appeared to require higher levels of protein supplementation than Vanguard barley. Froseth (1977) concluded that the lower relative feeding value of Steptoe compared to Vanguard was probably due to the differences in protein and amino acid contents. Froseth (1977) felt that this confirmed the suggestion of Kringes (1976) that in general, malting cultivars of barley have higher feeding value than those developed as feed barleys. Moreover, Coon et al. (1979) reported considerable differences in nutritional value between malting and feed barley in chick feeding trials (see Froseth and Miller 1992).

There is a limited data in which malting and feed

barley have been compared in ruminant diets. As discussed previously Hinman (1979) found no differences (P>0.10) in the ADG between steers fed Klages (two-row, malting) or Steptoe (six-row, rough awned feed) barley. Daily feed consumption was slightly lower for steers fed the Klages dryland barley compared to those fed the other treatments. The steers fed the Klages barley tended (P>0.10) to be 6% more feed efficient. However, this difference was attributed to the heavier VW of Klages compared to Steptoe (70 vs. 63 kg hL^{-1}). There were no differences (P>0.10) in the carcass characteristics between treatments. Bradshaw et al. (1992), observed no difference in performance, digestibility or carcass characteristics between steers fed Steptoe and Klages when VW was equal. Froseth and Miller (1992) suggested that in the future barley breeding programs should consider the nutritional quality to a greater extent than in the past. It appears that more work is also needed in qualifying the performance of existing malting vs. feed barley varieties in steer rations.

2.6 Starch Degradation Rate

For most grain, except corn and sorghum, 90% or more of the starch is normally degraded in the rumen (Waldo 1973; Ørskov 1986; McAllister et al. 1990a). About 78% of corn starch and 76% of sorghum starch is degraded in the rumen

(Waldo 1973). Rapid starch degradation in the rumen may be undesirable since it lowers rumen pH, depresses fibre digestion, and causes digestive disturbances such as acidosis, rumenitis, liver abscess and bloat (Ørskov 1986; Clark et al. 1987; Robinson 1989; McAllister et al. 1990a; Cone and Vlot 1990).

2.6.1 Amylose and Amylopectin

Barley is composed of 50-70% starch in granules (Rooney and Pflugfelder 1986). Cereal starches contain 20-30% amylose (linear D-glucose units, linked by α-1,4 bonds), with the remaining fraction consisting of the more branched (α-1,4 chains branched with α-1,6 glucosidic linkages) and therefore more easily digested amylopectin (French 1973; Moss et al. 1980; Rooney and Pflugfelder 1986). Waxy grains are characterized by a large percentage of amylopectin with little or no amylose in their starch (French 1973; Moss et al. 1980; Rooney and Pflugfelder 1986). Both the starch granules and the protein matrix around them are more digestible in waxy grain (Rooney and Pflugfelder 1986). The amylose content of cereal starches is under genetic control and high amylose varieties of peas, corn (70% amylose) and barley (44-52% amylose) have been discovered (French 1973; Merritt 1967; Newman et al. 1978). Some published reports have suggested that the starch composition of grain (ratio

of amylose to amylopectin) affects its digestibility (Bhatty et al. 1975). Standstedt et al. (1962) and Borchers (1962) found that digestibility of high amylose corn was lower than that of normal amylose corn with in vitro analysis as well as in feeding studies with rats and chicks. Similarly, Moss et al. (1980) quoted several in vitro studies which indicated that high amylopectin starch tends to be more digestible than normal starch but indicated that performance studies comparing waxy to normal starches in ruminant and swine diets have been inconsistent. Hironaka (see Bhatty 1975) found high amylopectin barley to be superior to normal barley in a digestibility trial with lambs. Sullins and Rooney (1974) reported more rapid in vitro hydrolysis and improved feed efficiency in ruminants fed waxy (low amylose) lines of sorghum compared with lines containing normal levels of amylose. However, Sandstedt et al. (1962) found that, on arranging maize starches in the order of increasing amylose content, degradability with pancreatic α-amylase was not directly related to amylose content and that the genes involved in producing high-amylose starch in corn are apparently also associated with digestibility.

Pomeranz et al. (1972) found that high-amylose barley had a much lower susceptibility to amylolytic action due to the tightly packed and bonded amylose fraction. Calvert (see Bhatty 1975) indicated that the purified amylose starch of Glacier barley was the least digestible to rats compared

to starches of three other cultivars of barley containing either no amylose or starch with normal amylose:amylopectin ratio. Calvert et al. (1976) fed purified starch from high-amylose Glacier, Glacier, waxy Compana and Compana barleys to rats. They found that average gain in the growth trial was higher ($P<0.10$) in rats fed the normal Glacier starch diet as compared to rats fed the normal Compana or high-amylose Glacier starch diets, although there were no differences in feed consumption or feed efficiency. Daily gain and protein efficiency ratio were not different in rats fed waxy Compana or the other starches.

Newman and McGuire (1985) cite Calvert et al. (1977) and Newman et al. (1978) as concluding that the major nutritional differences in the feeding value of waxy and high amylose barleys compared to the normal isotypes were due to protein and amino acid differences rather than starch differences. Calvert et al. (1977) suggested that the increased rate of gain and improved feed efficiency of pigs fed waxy Compana barley as compared to pigs fed the normal Compana barley was probably due to the higher protein and lysine content of the waxy isogene. Calvert et al. (1977) concluded that the waxy barley appeared to be of the same feed quality as normal barley when fed to rats in isonitrogenous diets and to pigs when fed in complete protein supplemented diets. Newman et al. (1978) found that rats fed high amylose Glacier diets gained faster ($P<0.01$),

consumed more feed ($P<0.05$), were more efficient ($P<0.01$) and had a higher protein efficiency ratio ($P<0.01$) than rats fed Glacier diets. The high amylose Glacier barley contained more albumin and globulin, which they indicate, are less digestible than the endosperm proteins, and more of the amino acids lysine and threonine. The normal Glacier barley contained more of the endosperm proteins hordein and glutelin which are very digestible (see Newman et al. 1978).

The foregoing studies suggest that barleys high in amylose starch may have lowered digestibility and that high amylopectin is a desirable characteristic (Bhatty 1975). Most of the foregoing studies, however, have been on nonruminant animals or young lambs. Higher amylose barleys may in fact be beneficial in feedlot steer rations in slowing down the rate of degradation and preventing acidosis and bloat.

2.6.2 Processing Method and Grain Type

Non-damaged starch has low susceptibility to enzyme attack (Rooney and Pflugfelder 1986; McAllister et al. 1990a). Grain processing methods can influence starch degradation rates in the rumen. McAllister et al. (1989) found that the in situ DM degradability of whole grain (barley, corn and wheat) was lower ($P<0.05$) than for halved or quartered grain. Quartered barley had increased ($P<0.01$)

in situ DM degradability compared to halved barley between 8 and 12 h of incubation. However, there was no difference between in situ DM degradability of quartered and halved grain after 48 h incubation. Wheat was the most susceptible to microbial degradation followed by barley and corn, respectively (McAllister et al. 1989). Microbial colonization of whole grain was minimal after 48 h incubation. It was concluded that fracturing of the outer husk of cereal grain is necessary to allow rumen bacteria to gain access to the readily degradable nutrients of the inner husk and endosperm. However, further fractioning did not substantially increase in situ DM degradability. McAllister et al. (1990b) found that the degradability of protein, starch and DM increased ($P<0.001$) with increased physical processing.

Dry grinding, and rolling produce varying amounts of damaged starch depending on the grain, moisture content, and grinding conditions (Rooney and Plugfelder 1986). Steam flaking involves movement of water and heat into the kernel, causing some swelling of starch. Rolling the hot moist grain tears apart some of the swollen granules, forming a paste that binds the other material into a strong flake. The surface area and enzyme susceptibility of the starch are greatly increased with steam flaking (Rooney and Pflugfelder 1986; Mathison et al. 1991).

Some of the problems of rapid starch degradation can be

overcome by reducing the extent of cereal processing and other methods that prevent low rumen pH (Ørskov 1986). Robertson and Kennelly (1988) reduced the in situ rate of DM degradation in high moisture barley with increasing levels of ammoniation. They found that cows tended to eat diets more rapidly as ammoniation level of substituted high moisture barley increased, although total DM intake was not influenced. Rate of decline of rumen pH, and accumulation of butyrate post-feeding was less pronounced as level of ammoniation of substituted high moisture barley increased.

McAllister et al. (1990a) controlled the rate of barley starch degradation in vitro by reducing the susceptibility of the protein matrix encasing the starch granules to microbial degradation using formaldehyde. This method is impractical however, because chewing action disrupts the formaldehyde coating (McAllister et al. 1992).

2.6.3 Barley variety

Clark et al. (1987), in an evaluation of barley varieties for ruminants, found that DM and NDF degradation rates in rumen fluid in vitro were different ($P<0.05$) between cultivars. Dry matter rates ranged from 6.81 to 12.09% h^{-1} and NDF degradation rates ranged from 4.39 to 43.69% h^{-1}. Clark et al. (1987) also found a variation in the purine accumulation (an estimate of microbial yield) in

the in vitro tubes suggesting that the rumen microbial response to barley cultivars may differ. They suggested that barley degradation characteristics can vary, and that the in vitro technique provides the ability to identify barley cultivars that exhibit slower rumen degradation rates.

2.6.4 Proanthocyanidins

Many plants, including barley, contain phenolic compounds which inhibit microbial activity (Theodorou et al. 1987 as cited by Kemalyan et al. 1989). Proanthocyanidins, which belong to a class of phenolic compounds called flavenoids, are known to form a precipitate with proteins in beer forming an insoluble complex (von Wettstein 1980 as cited by Kemalyan et al. 1989). Protein digestibility of proanthocyanidin-free cultivars is higher than normal cultivars when fed to chicks (Newman et al. 1984 as cited by Kemalyan 1989). Kemalyan et al. (1989) compared the DM disappearance rate and purine accumulation between one normal, five proanthocyanidin-free mutants lines, and two cross-line barley cultivars. In vitro DM degradation rates ranged from 8.47 to 10.14% h^{-1} ($P<0.05$), and purine accumulation ranged from 8.2 to 10.93 mg g^{-1} DM ($P<0.05$). Negative relationships ($P<0.05$) were found between DM disappearance rate and starch ($r=-0.66$), flavenoid compounds

(r=-0.55), and phenolic compounds (r=-0.56). Purine accumulation was positively related ($P<0.05$) to protein content (r=0.55) and NDF (r=0.68) and negatively related to starch content (r=-0.62), flavenoid compounds (r=-0.57) and phenolic compounds (r=-0.61). It was concluded that DM degradation rates and purine yields differ between barley cultivars. These factors were related in a nonlinear fashion, with faster degrading cultivars supporting lower microbial yields than moderate degrading cultivars.

In a metabolism trial using ewes, Kemalyan (1991) found differences in the flow of DM ($P<0.05$) and organic matter ($P<0.01$) to the small intestine between four barley cultivars. A proanthocyanidin-free mutant of the variety Gunhild (ANT 246) was found to have a low ruminal starch degradation (87.0%) and a high duodenal flow of starch (9.5 g d^{-1}), while Klages barley was found to have a high ruminal starch degradation (92.9%) and a low duodenal flow of starch (5.9 g d^{-1}). Rumen pH was not effected by barley genotype or by corn in this study. There was no significant correlation between in vitro DM degradation rate and ruminal starch degradation (r=0.62, P=0.38), or between in vitro purine accumulation and duodenal microbial nitrogen (r=0.53, P=0.46).

2.6.5 Animal performance

Fulton et al. (1979) observed an increased incidence of acidosis in steers fed high concentrate diets of wheat, which is degraded rapidly in the rumen, compared to corn which is degraded more slowly by the rumen flora, as substantiated by the lower ruminal pH values and DM intake for cattle fed wheat diets.

Bock et al. (1991) evaluated feedlot performance of steers fed mixtures of wheat and high moisture corn in finishing rations. As the percentage of wheat in the diet increased through 25%, 50%, 75% and 100%, gain/feed ratios did not differ ($P>0.10$); however, final weight, hot carcass weight, and ADG decreased linearly ($P<0.05$) and DM intake exhibited a cubic response ($P<0.05$). Rate of starch degradation did not differ significantly between grains or mixtures, but was inversely related to DM intake ($r=-0.78$, $P=0.21$), ADG ($r=-0.83$, $P=0.17$), and gain/feed ($r=-0.85$, $P=0.15$). It was suggested that slower ruminal degradation rates may imply a reduction in the incidence of subacute acidosis and that increased performance may be associated with a decreased rate of ruminal starch degradation.

Gramlich et al. (1989) noted varietal differences ($P<0.10$) in rates of starch degradation in situ among three corn hybrids and suggested that this may have contributed to varietal differences ($P<0.10$) in feed:gain ratio in steers.

However, in this trial the variety with the lowest in situ rate of starch degradation had the highest feed:gain ratio. In a similar trial, Ladley et al. (1991) selected three corn hybrids and evaluated the effect of corn hybrids (fed as dry rolled or high moisture corn) on finishing cattle performance. It was observed that cattle fed dry rolled hybrid B were more efficient and had faster daily gains than cattle fed hybrid A ($P<0.05$) or C ($P<0.10$). In vitro rate of starch disappearance of dry rolled hybrid B was 13% faster than hybrid A and 4.9% faster than hybrid C. There were no differences in DM intake, quality grade or fat thickness among the corn hybrids fed. Hybrid C tended to have the highest incidence of liver abscesses ($P<0.10$). In a second trial, there were no differences in DM intake, daily gain, feed efficiency, or carcass measurements between corn hybrids fed. However, differences in rate of starch disappearance were much smaller in 1988 compared to 1987 grown corn hybrids.

Stock et al. (1987) reported that steers fed a mixture of high moisture corn and dry-rolled grain sorghum were 4.2% more efficient in feed conversion and had improved ruminal starch degradation (14%) and total tract starch digestion (2%) in comparison with steers fed either 100% high moisture corn or 100% dry-rolled grain sorghum. It was shown that nearly all the high moisture corn starch was degraded in the rumen (89.9%), with only half of the dry-rolled grain

sorghum starch degraded in the rumen (45.7%). It was concluded that replacing 33% of the high moisture corn with dry-rolled grain sorghum maintained ruminal starch degradation, and increased the degradation of dry-rolled grain sorghum resulting in the positive associative effects observed for gain:feed in four trials. The rate of ruminal starch degradation is probably slowed due to the addition of dry-rolled grain sorghum, and thus the incidence of acidosis may be reduced (Stock et al. 1987).

Wester et al. (1992) observed that steers fed a sorghum hybrid selected for a faster (7.0%) in vitro rate of starch disappearance gained 9.0% faster than steers fed a hybrid with a slower in vitro rate of starch disappearance (1.33 vs. 1.22 kg d^{-1}, P=0.06). Gain:feed ratio was positively correlated with in vitro starch disappearance across all treatments (R^2=0.94). In another trial sheep fed a sorghum hybrid with the fastest in vitro starch disappearance were similar in finishing performance to those fed a sorghum hybrid with the lowest in vitro starch disappearance, suggesting that factors other than in vitro starch disappearance affected lamb performance (Wester et al. 1992).

Boss et al. (1994) evaluated three barley cultivars selected for high by-pass starch value (Gunhilde), low by-pass starch value (Harrington), and high yield (Medallion), and compared these with corn for finishing beef cattle over

a 168 d feeding trial. In vivo DM and starch digestibilities were found to be 11.2 and 8.8% lower, respectively, for corn compared to the three barley diets ($P<0.01$). It was noted that the in situ DM degradability of the individual grains followed the same trend as in vivo DM digestibility of the entire diets, with corn having 8.1% lower ($P<0.05$) degradability compared with the three barleys. Harrington's rate of degradation in situ was found to be 71.4% faster ($P<0.01$) than Medallion or Gunhilde barleys, and was 254.3% faster than corn, while Medallion and Gunhilde barleys degraded 106.6% faster ($P<0.01$) than corn. It was observed that cattle fed the corn diet gained 9.8% faster (1.4 kg d^{-1}) than those fed Harrington barley (1.3 kg d^{-1}), which gained 8.0% faster than those fed Medallion (1.2 kg d^{-1}) or Gunhild barley (1.2 kg d^{-1}) diets. The ADG rankings corresponded to the total amount of starch in the diets. Feed DM:gain ratio did not vary significantly between steers fed the three barley varieties (Medallion 6.3, Harrington 6.6, Gunhilde 6.8). Steers fed Medallion and Harrington barleys had lower feed DM:gain ratios than those fed corn (7.4). However, hot carcass weights were 14.9 kg heavier for cattle fed corn (318.5 kg) compared to those fed Harrington barley (303.6 kg) which were 14.1 kg heavier than those fed Gunhilde (289.6 kg) or Medallion (289.4 kg) barleys. Backfat thickness was greater for corn and Harrington barley carcasses (10.7 and 9.4 mm,

respectively) compared to Gunhilde and Medallion carcasses (6.4 and 6.1 mm, respectively), indicating that cattle were not fed to a constant degree of finish. It was concluded that despite an extremely rapid rate of ruminal degradation Harrington barley provided superior feedlot performance compared with Medallion or Gunhilde barleys. This contradicts the view that rapid ruminal starch degradation negatively influences feedlot performance (Fulton 1979; Clark et al. 1987; Robinson and Kennelly 1988; Bock et al. 1991), but agrees with the work of Ladley et al. (1991) with corn hybrids and Wester et al. (1992) with sorghum hybrids indicating that more rapid rates of starch degradation in the rumen may be beneficial.

In light of the conflicting reports on the importance of rate of degradation in the rumen among different types of grain and grain mixtures, and the minimal amount of work on barley degradation rates in the rumen, more research is warranted in this area.

2.6.6 Measurements of degradation rates

Starch degradation has been measured in vitro using pancreatic enzymes (Frederick et al. 1973), α-amylases (Cone 1991) and amyloglucosidases (Herrera-Saldana 1990, Mathison et al. 1991), or rumen fluid (McAllister et al. 1990a), and in vivo using the nylon bag technique (De Boer 1987).

Rooney and Pflugfelder (1986) explain that α-amylases randomly hydrolyse α-1,4 glucosidic bonds within starch molecules, generating maltose and branched and linear dextrins (endo-amylase activity), while amyloglucosidases, such as β-amylases and glucoamylases, attack terminal glucose residues to yield maltose and glucose, respectively (exo-amylase activity). The problem with the nylon bag procedure besides being labour intensive and cumbersome is that 50% of the barley in the bag is lost in the wash (De Boer 1987).

Cone (1991) compared the degradation of starch in feed concentrates by α-amylase enzymes, rumen fluid and cell-free preparation of rumen fluid. The degree of starch degradation varied widely for the 21 feedstuffs investigated. Sorghum, maize and millet starch degraded slowly whereas tapioca starch degraded rapidly. Processed feedstuffs were degraded more rapidly than non-processed feedstuffs. It was found that the use of enzymes did not allow an accurate prediction of rate of starch degradation by rumen fluid. However, the use of a freeze dried, cell-free preparation of rumen fluid did allow an accurate prediction of starch degradation by rumen fluid, indicating that additional enzymes present in rumen fluid are necessary (Cone 1991). Addition of non-amylolytic enzymes, such as cellulase, protease, lipase, xylanase, lysozyme and pectinase, did not enhance starch degradation by

amyloglucosidase (Cone and Vlot 1990). However, Holm et al. (1987), indicated that an improved correlation between in vitro and in vivo results was obtained when both pepsin and α-amylase were used in the in vitro assay instead of α-amylase alone, suggesting starch-protein interactions occur. This agrees with the work of Sullins and Rooney (1974) and McAllister et al. (1990a), who suggested that the protein matrix appears to be responsible for differences in the ruminal degradation of ground corn and barley.

Home et al. (1987) also discussed amylose-lipid complexes. These complexes are degraded slower than free amylose in vitro. It was suggested that this slower degradation rate was one plausible explanation for the lower glucose and insulin response in man after ingestion of high-amylose rice compared to rice with all amylopectin.

If a reliable laboratory method that predicts the in vitro degradation of starch by rumen fluid could be developed, it could be used by feed manufactures to prepare concentrates that result in a high total dry matter intake and stable rumen fermentation (Cone 1991).

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3.0 EFFECT OF TYPE OF BARLEY GRAIN ON RATE OF DEGRADATION, DIGESTIBILITY AND FEEDLOT PERFORMANCE OF STEERS

3.1 Introduction

Large differences between barley genotypes in terms of morphological, physiological and chemical characteristics have been reported (Bhatty 1980; Newman and McGuire 1985; Froseth and Miller 1992). According to Froseth and Miller (1992) head morphology (two-row, six-row), growth habit, and intended end-use (malting, feed) are probably the most useful indicators of barley nutritional quality. Males and Fong (1987) reported differences in feed value between cultivars amounting to 10% for average daily gain (ADG), 5% for feed DM:gain ratio, and 10% for digestible energy (DE). They indicated that the reasons for these differences have not been determined.

Limited research work has been conducted on the factors affecting the feeding value of barley for beef cattle in Alberta (Grimson et al. 1987; Mathison et al. 1991; Engstrom et al. 1992). Rapid starch degradation in the rumen is believed to be undesirable since it lowers rumen pH, depresses fibre digestion, and causes digestive disturbances such as acidosis, rumenitis, liver abscess and bloat (Ørskov 1986; Clark et al. 1987; Robinson and Kennelly 1988; McAllister et al. 1990a). Clark et al. (1987) reported

differences between in vitro dry matter (DM) and neutral detergent fibre (NDF) degradation rates between barley varieties and suggested that it may be possible to select barleys with slower rates of degradation for use as a ruminant feed grain.

Improvements in feed efficiency have been noted in some experiments when two-row barley grain has been compared with six-row barley in monogastric diets (Newman and McGuire 1985) however in other experiments no improvements have been observed (Newman and Eslick 1970, Castell and Bowren 1980). There is limited information concerning the comparable nutritive value of two-row vs. six-row barley in cattle diets (Hinman 1979; Bradshaw et al. 1992; Ovenell and Nelson 1992; Ovenell et al. 1993).

Based upon several experiments with monogastric animals (Newman and Eslick 1970; Bhatty et al. 1979; Spicer and Aherne 1988 and 1990) it might be expected that hulless barley would be superior to hulled barley for cattle.

Work with monogastrics (Froseth 1977) suggests that malting barley is used more efficiently than feed barley. Research with ruminants comparing the feeding value of malting vs. feed barley is limited (Hinman 1979; Bradshaw 1992).

The objectives of this research were to test the hypotheses that rate of degradation varies between samples of barley and that this characteristic influences feedlot

performance of steers. Additionally, objectives were to test the hypotheses that feedlot performance is enhanced by feeding two-row vs. six-row barley, or malting barley vs. feed barley.

3.2 MATERIALS AND METHODS

Ten of 22 lots of barley (Hordeum Distichum and H. Vulgare) grown in the Edmonton area were selected on the basis of variety, volume weight, row and hull (two-row or six-row or hulless), feed or malting type, and rate of in situ degradation for this experiment. The varieties selected included Abee (two-row feed), Ellice (two-row malting), two lots of Harrington (two-row malting), two lots of Duke (six-row feed), Leduc (six-row feed), Virden (six-row feed), Bonanza (six-row malting), and Condor (hulless). The chemical composition of the barleys are presented in Table 1.

3.2.1 Feeding Trial

Two hundred crossbred steers (365 ± 27 kg bodyweight) were purchased between October 12 and 25, 1991 for this experiment, which was conducted at the Beef Cattle Test Unit at the Ellerslie Research Station.

During the startup period the steers were ear-tagged,

dehorned, and injected intramuscularly with 5 mL of vitamin A and D (500,000 IU vitamin A and 75,000 IU vitamin D_3 mL^{-1}, Pfizer Canada Inc., Agriculture Division, Montreal). Upon arrival, steers were fed 1 kg $head^{-1}$ day^{-1} of grain mix (60% oats and 40% barley grain) and 6.14 kg of chopped alfalfa-grass hay. After 5 days the grain mix was increased to 2 kg $head^{-1}$ day^{-1}, split between morning and evening feedings. Later arriving cattle were offered 2 kg $head^{-1}$ day^{-1} of grain mix and hay. After one week the oats was reduced to 50% of the grain mix and the grain mix fed was increased by 0.2 kg hd^{-1} d^{-1}. Also, every 2 days the percentage oats in the grain mix was reduced by 10%. This continued until the oats were phased out of the ration and the cattle were adapted to a 90% concentrate (Table 2) and 10% alfalfa-grass hay diet. Once-daily feeding commenced 60 days after the arrival of the first lot of calves. Two weeks after the last steers arrived all were vaccinated for blackleg, malignant edema and hemophillus somnus with Ultrabac 7 with Somubac™ (SmithKline Beecham, Missasauga, Ontario), treated for warbles and lice with Ivomec™ pour-on (Merck Agvet, Merck Frosst Canada Inc. Kirkland, Quebec), and injected with another 3 mL. of vitamin A and D (500,000 IU vitamin A and 75,000 IU vitamin D_3 mL^{-1}, Pfizer Canada Inc., Agriculture Division, Montreal), and implanted with the growth promotant Ralgro™ (Coopers Agropharm Inc, Ajax, Ontario). Lighter weight steers were re-implanted after 103 days.

It took longer than anticipated to get the calves on full feed due to the high number of bloats (54) with four calves dying of bloat in the startup period. Similar sized replacement calves that were already started on grain rations were purchased from neighbouring farms to replace those that died from bloat during this time.

Steers were weighed on 3 consecutive days at the start (November 27) and end of the trial and biweekly throughout, after water had been withheld for approximately 16 h. Based on the first two weights steers were blocked by weight into a high and low weight group with 100 steers and 20 pens per block. Animals were randomly allocated within block to 20 partially covered pens (five animals per pen) and pens (4 X 8 m) were randomly allocated to the ten grain treatments. Cattle were fed one of ten experimental diets utilizing the ten barley lots, with the concentrate mixture (Table 2) being formulated according to National Research Council (1984) guidelines. Dry rolled barley was prepared with a Peerless Model 235 roller mill (Ketchum Manufacturing Sales Ltd., Ottawa). Hay was ground using a Sperry New Holland Model 390 tubgrinder (Farmhand, Pa., U.S.A.).

The steers were fed to finish (approximately 540 kg) and slaughtered when they had enough finish to grade. Carcass measurements including, warm carcass weight, fat cover, average fat, grade fat, ribeye area (REA), marbling, quality grade, and cutability estimate, were made by

Agriculture Canada personnel, and the number of liver abscesses determined. Carcasses graded under the new grading system (Canada Gazette 1992) were converted back to the old grading system (Canada Gazette 1983) based on the backfat at the minimum point of thickness (grade fat) for a standard comparison. Dressing percentages were calculated from warm carcass and final feedlot weights. Feed refusals were weighed and sampled for analysis when they accumulated.

3.2.2 Digestibility Trial

During the feedlot trial, a digestibility trial was conducted concurrently at the Ruminant Feed Evaluation Unit in a manner similar to that described by Mathison et al. (1991). The ten lots of barley were fed at maintenance levels in all-concentrate diets containing 95% barley grain (Table 2) to 20 Hereford steers (235 ± 17 kg bodyweight). The experiment was conducted over two periods with each concentrate being fed to two steers in each period. Each period consisted of a 14 d adaptation to the feed followed by 8 d of total collection of the urine and faeces. Urine was collected in 400 mL of 6 N HCL.

3.2.3 In situ Degradability Trial

To determine the in situ rate of dry matter (DM) and

starch degradation of the barley, the nylon bag technique was used for both ground barley (3 mm screen, Christy Mill, Bentall Simplex Industries Ltd, South Humberside, England), and coarse rolled barley samples. For the ground barley the nylon bag procedure involved placing 1-g samples of each of the ten barley cultivars into each of 18 separate tared 3.5 by 5.5 cm Nitex bags (50 u mesh size; Thompson, Scarborough, Ontario). These small bags were sewn on three sides with polyester thread, and heat sealed at the top after adding the barley. One sample of each barley was incubated in the rumen of each of three yearling rumen fistulated steers for incubation times of 0, 2, 4, 8, 12, and 24 h. The bags were held in the ventral sac by placing them in a polyester mesh lingerie bag which was anchored with a plastic bottle filled with sand. Each steer received two lingerie bags containing 30 nylon bags as described by De Boer (1987). After removal from the rumen the bags were mechanically washed using a mechanical washer as described in De Boer (1987), and dried for 12 hours at 60°C, and another 12 h at 105°C. Starch degradability was calculated by determining the amount of starch remaining in the ground barley residues after in situ incubation for different lengths of time and subtracting this amount from the starch in the sample of barley added to the bags. The same procedures were used for the rolled barley except that larger 10 X 12 cm Nitex bags were used. These larger bags were heat sealed on three sides and

cinched-closed 2 cm from the top with a plastic tie after adding about 5 g of sample. Since the rolled barley breaks down more slowly than ground barley in the rumen, one additional observation time was included at 48 h. These bags were dried at 60°C for 2 days then for 4 h at 105°C before weighing.

3.2.4 Chemical and physical analysis of barely

Concentrates were stored in 1.2 X 1.2 m wooden boxes in the barns prior to feeding. Chopped hay was stored in large piles. Random samples of the concentrate and hay were collected every 2 weeks and analyzed for DM content. Every month, biweekly concentrate samples were combined and analyzed for crude protein (CP), calcium, phosphorus, acid detergent fibre (ADF), and trace mineral content (Tables 3 and 4). The alfalfa-grass hay contained 86.2% DM, 16.4% crude protein, 1.19% calcium, 0.24% phosphorus, and 36.9% ADF. Samples were also collected monthly from the whole barley lots, and analyzed for volume weight, crude protein, phosphorus, and acid detergent fibre content. Composite samples of each lot of barley were sent to the Canadian Grain Commission (1992) to determine dockage content.

Feed and faeces analysis were conducted at Alberta Agriculture's Soil and Animal Nutrition Laboratory, according to procedures described by Engstrom et al. (1992)

as follows. Dry matter was determined as the residual remaining after drying at 100°C according to Association of Official Analytical Chemists (AOAC; 1984) procedures. Acid detergent fibre (ADF) was determined by the method of Goering and Van Soest (1970). Volume weight (kg hL^{-1}) was calculated by multiplying the weight (g) of whole grain in a 302 mL container (Ohaus 86, Seedburo Equipment Co., Chicago, IL.) by 0.33113. Nitrogen and phosphorus content of samples were measured using a Technicon Auto Analyzer II (Technicon Industrial Systems, Tarry Town, NY)(method 7.025, AOAC 1984) in extracts of a Kjeldahl digest (method 7.021, AOAC 1984). For other major and trace element analysis, samples were digested in a nitric-perchloric acid mixture (4:1, v/v). Selenium was determined on a Kontron Spectrofluorometer Model SFM23/B (Research Instrument International, San Diago, CA) according to AOAC (1984) method 3.107. Sulphur was determined by infrared analysis of sulphur dioxide released on total ignition of the sample using a LECO Model SC-132 (LECO Corp., St. Joseph, MI). Calcium, magnesium, potassium, copper, manganese, and zinc were determined by emission spectroscopy using an Inductively Coupled Plasma (ICP) Spectrometer (Applied Research Laboratories Inc., Sunland, CA).

Gross energy in feed, urine and faeces was measured with a Parr adiabatic bomb calorimeter (Parr Instrument Co. Inc., Moline IL). Replicate urine subsamples (10 mL) from

each steer in the digestibility trial were freeze dried (The Virtus Co., Model 50-SRC, Gardiner, NY) for this procedure and faeces samples from these steers were dried and ground through a 1 mm screen using a Christy Mill (Bentall Simplex Industries Ltd., South Humberside, England) before gross energy determinations were made. Nitrogen content of urine samples were determined by the Kjeldahl method (Labconco, Labconco Corporation, Kansas City, Missouri).

Starch composition of barley samples and of samples incubated in the rumen for up to 8 h were determined with a procedure adapted from Aman and Hesselman (1984).

Thousand kernel weight was determined with a Count-A-Pak Seed Counter (Seedburo Equipment Co., Chicago, IL.). Kernel hardness (KH) was determined using a Brabender Hardness Tester (C.W. Brabender Instruments Inc., South Hackensack, NJ). This machine was developed to automate a process reported by Kosmolak (1978) who used the principle that hard and soft wheats, with differences in endosperm particle size and resultant differences in physical properties, take different times to grind. The machine measured the amount of time it took to grind a 4 g sample, with shorter grinding times being associated with harder grains.

Geometric mean particle size and DM passing a 0.85 mm screen were determined after screening the rolled rations through a progressive series of Tyler (W.S. Tyler Co. of

Canada, Ltd., a subsidiary of Combustion Engineering, Inc., St. Catharines, Ontario) and Endecotts (Endocotts (test sieves) Ltd., London, England) sieves (1.700, 0.850, 0.595, 0.297, 0.180, and 0.149 mm) using a Cenco-Meinzer Sieve Shaker (Catalog No. 18480, Central Scientific Company) as reported by Wilcox et al. (1970). The screens used were similar to those used by Hironaka et al. (1973, 1979). Approximately 100 g of each rolled ration was added to the 1.700 mm screen and the sieves were agitated for 5 minutes.

Ration density on a dry matter basis was determined by measuring the weight (g) of 302 mL (Ohaus 86, Seedburo Equipment Co., Chicago, IL.) of the experimental diets and multiplying by the percentage DM and a conversion factor.

3.2.5 Statistical Analyses

Differences in chemical composition and physical characteristics of whole barley, and composition of concentrates, were analyzed using a one way analysis of variance using SAS (Statistical Analysis Systems Institute, Inc., 1990). The first analysis used barley variety (n=10), the second row type (two-row, six-row and hulless), and the third feed type (malting vs. feed) as main effects. The Student-Newman Keul's test was used to separate means (Steel and Torrie 1980).

Dry matter degradability of ground barley, rolled

barley and starch, and digestibility data were analyzed by a one way analysis of variance procedure. The main effects for each analysis were variety, row type or feed type. Least square means derived in each analysis were separated by Student-Newman Keul's test (Steel and Torrie 1980). Analysis of covariance (SAS 1990) was conducted for DM, organic matter, and nitrogen digestibility and DE of concentrates by variety, row-type and feed-type after adjusting for differences in volume weight (covariate).

The feedlot trial was analyzed as a multiway analysis of variance using the General Linear Models Procedure (GLM) of SAS (Statistical Analysis Systems Institute, Inc., 1990). The main effects included in the model were variety (n=10), barn group (n=2), variety x barn group, and pen within variety x barn group. The dependent variables were body weight, average daily gain (ADG), carcass weight, dressing percentage, average fat, rib eye area, marbling score, grade and cutability. A similar analysis was done when the barley varieties were regrouped as either row or feed types. Feed intake and feed:gain ratios were analyzed on a pen basis using a reduced model. Three periods 1-28, 29-69, 70-111 days and overall were identified and analyses for body weight, DM intake, ADG and feed:gain were done within period and overall. Least square means were used to calculate the standard error of the mean except for feed efficiency, in the row and feed type comparison in period 3 and overall,

where a harmonic mean was used. A Student Newman Keul's test was used to separate means (Steel and Torrie 1980). Carcass grade, percentage of animals that bloated, and liver abscess occurrence were analyzed using the CATMOD Procedure of SAS (Statistical Analysis Systems Institute, Inc., 1990). The relationship between density of diets and the percentage of animals that bloated was determined by Chi square analysis (SAS 1990) after density of diets were classified into high, medium and low ranges.

Simple correlations were done between starch, crude protein, acid detergent fibre, volume weight, total tract DM digestibilities, in situ DM degradability (after 0, 4, 8, 12 and 24 h), DM degradation rate, starch degradability (after 0, 2, 4, and 8 h), starch degradation rate, thousand kernel weight, kernel hardness, percentage of animals that bloated, liver abscess occurrence, DM intake, ADG and feed:gain ratios. Correlations that were significant were subjected to regression analysis, and stepwise regression was done to determine the main factors affecting feed efficiency (SAS 1990).

3.3 RESULTS

3.3.1 Chemical and Physical Characteristics of the Barley and Concentrates

Dockage was not removed from the barley prior to feeding or analysis. However, it was low in all samples and ranged from 0.5% to 2.5% (Canadian Grain Commission 1992). Barley varieties (Table 1) varied (P=0.0001) with respect to VW (55-67 kg hL^{-1}), CP (10.3-14.8%), ADF (5.2-8.0%), and KH (46.7-77.7 seconds in grinding time with shorter times being associated with harder grain).

Volume weight was 6% higher (P=0.0001) for hulless barley (67 kg hL^{-1}) than for two-row barley (63 kg hL^{-1}), which had a 5% higher VW than six-row barley (60 kg hL^{-1}). Hulless barley had a 17% higher (P=0.0001) crude protein content (14.8%) than two-row barley (12.7%) which had a similar CP content to six-row barley (12.1%). The ADF content varied for barley type and was 21% lower (P=0.0001) for hulless (5.2%) than for two-row barley (6.3%) which had a similar ADF content as six-row barley (6.8%). Hulless barley had harder (P=0.0001) kernels (48.8 seconds) than two-row barley (63.8 seconds) or six-row barley (71.2 seconds), as demonstrated by the shorter time to grind a 4 g sample.

Differences (P<0.001) between samples of barley in the

composition of concentrates were detected in CP (10.8-15.3%), ADF (5.6-7.9%), density (0.42-0.55 kg L^{-1}) and in contents of selenium, iron and aluminum (Tables 3 and 4). Composition of concentrates containing two-row and six-row barley were similar and varied ($P<0.03$) from hulless barley in CP, ADF, density and in contents of copper and manganese. Hulless barley had twice the copper content, and 1.5 times the manganese content of two- and six-row barley. Feed and malting barley diets had similar composition, except for potassium ($P=0.005$) and selenium content ($P=0.004$). There were no differences in mean particle size ($P=0.97$), or percent DM passing an 85 mm screen ($P=0.97$) between cultivars, row type or malting vs. feed type.

3.3.2 In situ Degradability of Barley

Percent DM degradability of ground (3 mm screen) barley in situ (Table 5) varied ($P<0.004$) for variety, and between two-row, six-row and hulless type after 0, 4, 8, 12 and 24 h incubation in the rumen. Malting barley tended ($P<0.09$) to have a 6% higher DM degradability after 0 h incubation than feed barleys (53.0 vs. 50.1%).

Dry matter degradability after 4 and 8 h in situ was correlated (Table 6) to starch content ($r=0.76$, $P=0.01$ and $r=0.66$, $P=0.07$ respectively). Dry matter degradability after 12 h in situ tended to be correlated with protein

content (r=0.60, P=0.07). Dry matter degradability after 8, 12, and 24 h in situ were correlated (P=0.05) with ADF content (r=-0.78, r=-0.86, and r=-0.64, respectively). Dry matter degradability after 12 h in situ was highly correlated with VW (r=0.70, P=0.03).

There were differences in the amount of soluble and potentially degradable fractions between varieties and type of barley (Table 5). The soluble fraction varied (P=0.0005) between 45.4% for Duke (Lot No. 1) and 46.1% for Virden to 57.7% for Harrington (Lot No. 4). The slowly degradable fraction varied (P=0.006) between 30.3% for Harrington (Lot No. 4) to 39.9% for Duke (Lot No. 1). Two-row barley had a 3% higher (P>0.05) soluble fraction (54.4%) than hulless (52.8%) and an 11% higher (P=0.003) soluble fraction than six-row barley (48.9%). Malting barley tended (P=0.08) to have a 6% higher soluble fraction than feed barley (53.2 vs. 50.3%) which was expected. Malting barley had an 8% lower (P=0.046) slowly degradable fraction than feed barley (33.4 vs. 36.2%).

There was no difference in rate of in situ DM degradation of the potentially degradable fraction between cultivars (33 to 58% h^{-1}, P=0.21). Six-row barley tended to have a 19% faster (P=0.14) rate of in situ DM degradation (47.9% h^{-1}) than two-row barley (40.3% h^{-1}), which was degraded at a 12% faster rate than hulless barley (36% h^{-1}). Feed and malting barley were degraded at similar (P=0.51)

rates (45 vs. 42% h^{-1}, respectively). In situ rate of DM degradation tended (P=0.11) to be correlated with DM content of the barley (r=0.54). In situ DM degradation rate was correlated (P<.04) to crude protein content (r=-0.84; Fig. 1), ADF content (r=0.74; Fig. 2), DM degradability after 12 h in situ (r=-0.63), soluble fraction (r=-0.74) and to DE content (r=-0.65; Fig. 3).

Percent starch degradability from ground barley (Table 7) in situ varied (P<0.04) for variety after 0 h, 2 h and 8 h incubation in the rumen. After 2 h incubation there was about a 10% difference in the amount of starch degraded between samples of barley. Two-row barley had a 13% higher (P=0.025) starch degradability (59.5%) than six-row or hulless barley (both 52.8%) after 0 h. Hulless barley had about a 6% lower (P=0.017) starch degradability (81.1%) after 2 h incubation than two-row (87.1%) or six-row barley (85.7%). Malting barley had a 10% higher (P=0.02) starch degradability (58.8%) than feed barley (53.3%) after 0 h. Malting barley tended (P=0.09) to have a 3% higher starch degradability than feed barley after 2 h (87.2 vs. 84.9%) and 1% higher starch degradability after 4 h (96.1 vs. 95.0) incubation.

The soluble starch fraction varied (P=0.006) between varieties and was lowest for Duke (Lot No. 1; 41.2%) and highest for Abee (63.4%; Table 7). The slowly degradable starch fraction varied (P=0.006) between varieties and was

lowest for Abee (35.5%) and highest for Duke (Lot No. 1; 59.0%). The soluble and slowly degradable starch fractions were similar (P>0.05) between row type and malting and feed barley. Starch degradability from ground barley after 8 h in situ tended to be correlated to DM (r=-0.56, P=0.09) and gross energy content of barleys (r=0.60, P=0.07).

The rate of starch degradation from ground barley was not significantly different (P=0.17) between varieties. The rate of starch degradation from ground barley was about 32% slower (P=0.06) for hulless barley (49% h^{-1}) than for two-row and six-row barley (63 and 66% h^{-1}). There was no difference (P=0.43) in rate of starch degradation from ground barley between malting vs. feed barley.

Percent DM degradability of rolled barley (Table 8) varied significantly (P<0.03) for variety after rumen incubation for 0, 2, 4, 8, 12, 24, and 48 h. There were, however, no differences (P>0.05) in rolled barley DM degradability between two-row, six-row and hulless barley or between malting and feed barley.

The soluble fraction varied (P=0.02) for variety and was lowest for Abee (3.1%) and highest for Harrington (Lot No. 4; 10.7%). The slowly degradable fraction varied (P=0.02) from 43.2 and 44.3% for Bonanza and Virden to 69.3% for Duke (Lot No. 1). There were no differences (P>0.57) in the amount of soluble or potentially degradable fractions between the different types of rolled barley.

The rate of DM degradation of rolled barley from nylon bags tended (P=0.07) to differ between varieties and was 67% slower for Duke (Lot No. 1) at 6% h^{-1} than for Virden and Leduc, both at 16% h^{-1}. There were no differences (P>0.45) in the rate of degradation between the different types of rolled barley. There was a negative correlation between rolled barley DM degradability after 2 h in situ and crude protein content (r=-0.64, P=0.047). Rolled barley DM degradability at 4 h was correlated to ADF content (r=0.65, P=0.04). There tended to be a correlation between rolled barley DM degradability after 12 and 24 h in situ and thousand kernel weight (r=0.56, P=0.09 and r=0.55, P=0.10 respectively).

3.3.3 In vivo Digestibility

By design, DM intake (33.8-38.8 g $kg^{-0.75}$) between varieties , two-row and six-row, or malting and feed type barley, were similar (P>0.38) as seen in Table 9.

Total tract dry matter digestibility varied (P=0.05) between 80.5% for Virden to 87.4% for Condor (Table 9). Two-row barley tended (P=0.056) to have a 2% higher total tract DM digestibility than six-row barley (85.1 vs. 83.5%). There were no differences (P=0.24) between malting and feed barley in DM digestibility.

Similar results were seen with OM digestibility with

two-row barley having a 2% higher (P=0.03) OM digestibility than six-row barley (86.8 vs. 85.1%). There was a trend (P=0.07) for differences in total tract energy digestibility between Virden (79.7%) and Condor (87.0%) with the other varieties intermediate between these. Two-row barley tended (P=0.058) to have a 2% higher energy digestibility than six-row barley (84.8 vs. 83.1%). There were no differences (P=0.20) between malting and feed barley in energy digestibility.

Virden had about an 11% lower (P=0.003) total tract nitrogen digestibility than did the other varieties, but it also had about a 20% lower crude protein content. Two-row barley tended (P=0.09) to have a 3% higher nitrogen digestibility than six-row barley (81.6 vs. 79.5%).

The digestible energy content differed (P=0.03) by 10% between varieties (14.5 vs. 16.0 MJ kg^{-1} diet for Virden and Condor respectively). The DE content was 2% higher (P=0.04) for two-row than six-row barley (15.5 vs. 15.2 MJ kg^{-1} diet). Malting barley and feed barley had similar (P=0.20) DE contents.

Total tract DM digestibility tended (P<0.10) to be correlated to starch (r=0.58), protein (r=0.58), phosphorus (r=-0.58), soluble fraction (r=0.58), DM degradation rate (r=-0.56), and DM degradability after 24 hours (r=0.57) in situ. Total tract DM digestibility was correlated (P<0.02) to ADF (r=-0.85), ash (r=-0.73), volume weight (r=0.78) and

in situ DM degradability after 4 h (r=0.76; Fig. 4), 8 h (r=0.80; Fig. 5), and 12 h (r=0.79; Fig. 6). Digestible energy content was correlated (P<0.04) to protein (r=0.71), ADF (r=-0.83), ash (r=-0.81), volume weight (r=0.83), DM degradability after 4, 8 and 12 h in situ (r=0.65, r=0.72, r=0.75 respectively), DM degradation rate (r=-0.65; Fig. 3), and total tract DM digestibility (r=0.98). Digestible energy content tended (P<0.08) to be correlated to phosphorus content (r=-0.59), DM degradability at 0 h (r=0.58) and the soluble fraction (r=0.57).

3.3.4 Performance in the Feedlot

Data from the first 2 weeks of the trial was eliminated from the analysis because of bloat problems, thus shifting the startup date to December 11. Another animal died of bloat during this time (December 1). Two more animals died of bloat during the trial (January 24 and April 7) and one chronic bloating animal was shipped January 27. These animals were all on different treatments and were not replaced.

No significant differences (P>0.20) in DM intake (9.72-10.87 kg d^{-1}), average daily gain (1.46-1.61 kg d^{-1}), feed DM:gain ratio (6.38-6.85) or carcass characteristics and grade were detected between steers fed the ten different lots of barley (Tables 10 and 11). Similarly, no

differences (P>0.12) in these parameters were observed between steers fed two-row, six-row or hulless, and malting or feed barley. As expected steers with higher ADG tended to be more feed efficient (r=-0.57, P=0.08).

There were no differences (P>0.27) in the percentage of animals that bloated (Table 10; overall average of 14% of the steers bloated at least once in the trial) or the occurrence of liver abscesses (P>0.25, Table 11; overall average 16%) between varieties, two-row vs. six-row vs. hulless, or malting vs. feed barley.

Feed DM:gain ratios were correlated to DM degradability of ground barley after 24 h in situ (r=0.68, P=0.03; Fig. 7). Feed DM:gain ratios were also correlated to 24 h in situ DM degradability of rolled barley (r=-0.71, P=0.02) and tended to be correlated to rolled barley in situ DM degradability after 8 h (r=-0.62, P=0.06) and to ADG (r=-0.57, P=0.08). The variations in DM:gain were explained in the stepwise regression by in situ rolled barley DM degradation in the following order 24 h (R^2=0.51, P=0.02), 0 h (R^2=0.75, P=0.03) and 2 h (R^2=0.95, P=0.003). However, feed DM:gain ratios were not correlated to starch (r=-0.08, P=0.83), gross energy (r=-0.41, P=0.25), CP (r=-0.14, P=0.69), ADF (r=-0.31, P=0.39), VW (r=-0.21, P=0.56), TKW (r=-0.45, P=0.19), KH (r=-0.08, P=0.82), DM degradation rate (r=-0.09, P=0.81), total tract DM digestibility (r=0.14, P=0.69), DE content (r=-0.002, P=0.99), the percentage of

animals that bloated (r=0.23, P=0.52), or the percentage of liver abscesses (r=0.05, P=0.88). There were no significant correlations between starch degradability and feed DM:gain ratios. Starch degradability from ground barley after 8 h in situ was correlated to ADG (r=0.81, P=0.005; Fig. 8). Significant correlations were detected between the percentage of animals that bloated and CP (r=0.68, P=0.02; Fig. 9), ADF (r=-0.73, P=0.016; Fig. 10), VW (r=0.67, P=0.04), DM digestibility (r=0.67, P=0.03), DE content (r=0.72, P=0.02), DM degradability in situ after 12 h (r=0.72, P=0.02; Fig. 11), and DM degradation rate (r=-0.74, P=0.01; Fig. 12) as seen in Table 6. The soluble fraction of ground barley tended to be correlated to the percentage of animals that bloated (r=0.57, P=0.09) and was correlated to the DM degradation rate (r=-0.74, P=0.015). There was a trend (P=0.09) for density of diets to affect the percentage of animals that bloated. Diets in the high density range resulted in 22.5% bloated animals, while those in the medium and low ranges resulted in 12.7 and 8.5% bloated animals respectively. After classifying the data into high and low ranges, Chi Square analysis revealed that only crude protein affected (P=0.05), and DM degradation rate tended (P=0.11) to affect, the percentage of animals that bloated.

There were no significant relationships between any of the measured parameters and the percentage of animals which developed abscessed livers.

3.4 DISCUSSION

3.4.1 Chemical Composition

The barley varieties and types tested had chemical and physical characteristics within the ranges seen for these varieties and types grown in Alberta (Suleiman 1992). The average starch content (60%) of the barleys (Table 1) were close to those reported by Engstrom et al. (1988) for six lots of barley (62%), and Sibbald and Price (1976) for 40 lots of barley (62%) representing 17 varieties.

3.4.2 Effect of Barley Variety on Nutritive Value

There were no significant differences between samples of barley in terms of steer performance or carcass characteristics in this trial (Tables 10 and 11). Indeed there is as much variation in steer performance within samples of the same barley as between samples as seen in the two lots of Duke and Harrington. Thus differences in ADG and DM:gain ratios of approximately 9 and 12% respectively would have been necessary before differences between varieties reached significance. This is a very high detection limit for this facility and was related to health problems as well as to low numbers of steers per treatment. However, the experiment was designed primarily for use of

regression analyses rather than analyses of variance procedures. A 10% difference (P=0.03) was detected in DE content between samples of barley.

In contrast, Taylor et al. (1985) found that there were differences (P<0.05) in feed DM:gain of different barley cultivars for finishing cattle (7.2 for Andre vs. 6.5 for Steptoe barley and 6.6 for Klages). Males and Fong (1987) also indicated large differences exist in the feeding value of barley cultivars for ruminants, amounting to differences of 10% in ADG, 5% in feed DM:gain and 10% in DE content of the grain. Similarly, Ovenell and Nelson (1992) found differences (p<0.05) in DM intake, ADG, feed DM:gain, hot carcass weight, backfat, rib eye area (REA), kidney, pelvic and heart fat, organic matter intake, and total tract neutral detergent fibre (NDF) digestibility between six barley cultivars fed to steers. There is, however, not a large difference in feed efficiencies between barley varieties with monogastrics which agrees with our results. Danielson and Newman (1991) in a three year study evaluating swine growth response to four commercial barleys found that there was no significant (P>0.10) differences in performance of swine due to barley cultivar, year, or barley by year interaction even though chemical and physical analysis of barley varied by year.

Although Ellice had the lowest numerical feed DM:gain ratio (6.38) it is not widely grown because of its

susceptibility to barley diseases (Treffry 1993).

3.4.3 Two-row vs. Six-row Barley

No significant differences were seen in steer DM intake, ADG or feed DM:gain or carcass characteristics between two-row and six-row barley was detected (Tables 10 and 11). This is contrary to the work of Ovenell and Nelson (1992) indicating that steer performance, carcass parameters, and diet digestibility was greater when Clark, a tow-row malting barley was fed than when Cougbar, a six-row malting barley was fed. Ovenell et al. (1993) found that Camelot and Harrington (two-row cultivars) had superior feeding value for ruminants compared to Hesk and Steptoe (six-row cultivars). Our results are also contrary to the work of Newman et al. (1982) and Middaugh et al. (1989) with swine. However, our results agree with the work of Hinman (1979) and Bradshaw et al. (1992) with steers.

The increased levels of digestibility for two-row vs. six-row barley are in agreement with the results of Castell and Bowren (1980) and Anderson et al. (1984) with swine. Any advantage two-row barley may have over six-row barley appears to be related to plumper kernels, and VW of the two-row barley (Table 1; Newman and McGuire 1985; Kemalyan 1991). Bhatty et al. (1974) found that two-row barley had, on the average, 4.1 kg hL^{-1} higher bulk weight, 5 g higher

kernel weight, and 30% more plump kernels than six-row barley. Froseth and Miller (1992) found that head morphology (two-row vs. six-row) had the most influence on nutrient composition and concluded that in most cases the composition of two-row barley is superior to six-row barley and were higher in energy, CP, all amino acids, starch, calcium, and phosphorus and lower in ADF than six-row barley. No difference in chemical composition between two-row and six-row barley was detected in this experiment.

3.4.4 Hulless vs. Hulled Barley

The presence or absence of hulls have been related to the nutritional quality of barley (Bhatty 1979; Newman and McQuire 1985; Aherne 1990). Newman et al. (1968) indicated that the hull and fibre content of barley are major factors which cause inferior performance of swine fed barley in comparison to those fed grains low in fibre.

Condor had higher ($P<0.004$) in situ DM degradability after 8, 12, and 24 h in situ compared to most of the other barleys (Table 5). This was supported by higher ($P<0.05$) in vivo digestibilities of DM and OM and higher ($P=0.03$) DE content in Condor relative to Virden (Table 9), and can be explained by the absence of hull in Condor and the higher ADF content of Virden. Aherne and Darroch (1993) found that the addition of hulls (0, 5, 10, 15, 20%) to hulless barley

(Condor) led to a linear decrease in digestible energy ($P=0.01$) and a curvilinear decline in protein digestibility ($P=0.01$) in swine. Since the ruminant animal is highly adapted to digest fibrous materials it is reasonable to expect that there would not be as great an advantage to feeding hulless barley to steers as to swine. While Classen et al. (1985) found the true metabolizable energy level in hulless barley was higher than hulled barley fed to adult roosters, substitution of hulless barley for wheat in broiler chick diets resulted in a significant linear depression in performance. He indicated that this may have been due to the higher β-glucan content of hulless barley, resulting in depressed starch absorption. Engstrom et al. (1992) however, indicated that β-glucans are highly digestible (98.6%) in ruminant diets.

The presence or absence of hulls did not significantly influence feedlot performance or carcass characteristics in this trial (Tables 10 and 11), contrary to performance trials in swine by various researchers (Joseph 1924; Gill et al. 1966; Newman and Eslick 1970; Bhatty et al. 1979; Thacker et al. 1986). Our results are however, similar to the results of Anderson et al. (1961) and Sibbald (1982) with chickens, and Spicer and Aherne (1988 and 1990) with pigs. The hulless barley used in this trial was not a true representative of hulless barley since it had a lighter than acceptable VW (67 vs. an acceptable weight of 75 kg hL^{-1})

and had twice the acid detergent fibre level reported by Aherne (1990). This was likely due to the presence of loose hulls that were not separated from the grain during combining. It should be noted however, that the hulless barley (Condor) was purchased from a seed grower.

3.4.5 Malting vs. Feed Barley

No significant differences between malting and feed barley on feedlot performance or carcass characteristics could be detected in this experiment (Table 10 and 11). There was no advantage (P=0.38) in feed DM:gain for malting barley versus feed barley. These results are supported by those of Hinman (1979) and Bradshaw et al. (1992) who found no difference in feedlot performance, digestibility, or carcass characteristics of steers fed malting or feed barley. Our results disagree with the suggestion of Froseth and Miller (1992) that intended end use (malting vs. feed) is one of the most useful indicators of barley nutritional quality. They found that feed barleys contained higher ADF, and lower DE, CP, and phosphorus than malting barleys although no such differences were detected in this experiment (Table 1).

3.4.6 Relationship between Barley Chemical Characteristics and Nutritive Value

Crude protein and ADF content of the barley did not affect DM intake, ADG, feed DM:gain ratio or carcass characteristics in this trial (Table 1, 10 and 11). This was probably because canola meal was added to the rations to ensure protein levels were above NRC (1984) recommendations. The results showing no relationship between CP and ADF content of the barley and feedlot performance are contrary to the findings of Froseth and Miller (1992) that barley varies more in crude protein and fibre content than other components, suggesting that these may be useful as quality criteria when selecting a feed barley. Our results however, are supported by those of Taylor et al. (1985) who found that barley CP content did not appear to be related to barley utilization by the animal. Ovenell et al. (1993) observed that chemical composition of barley cultivars was not useful in predicting animal performance and diet digestibility, and that there were other reasons for the observed variability. Neutral detergent fibre digestibility and methane production appeared to be the major factors contributing to variability among barley cultivars and subsequent feeding value for cattle. Results indicating that barleys with higher CP contents had slower rates of in situ DM degradation (Table 6; Fig. 1) agrees with the work

of Sullins and Rooney (1974) and with suggestions of McAllister et al. (1990a) that the protein matrix surrounding the starch granules appears to be responsible for differences in the ruminal degradation of ground corn and barley. Thus there is some reason to believe a negative relationship should exist between protein content and rate of degradation. Kemalyan (1991), however, found no correlation between in vitro DM disappearance rate and crude protein or neutral detergent fibre content of barley.

A positive relationship was observed between barley protein and the percentage of steers which bloated (Table 6; Fig. 11). Soluble feed proteins have been linked to foam stability in bloated cattle in the work of many groups as discussed by Engstrom (1988). Gutierrez et al. (1961) isolated an ethanol insoluble slime from the rumen fluid of bloating cattle which increased the viscosity of rumen fluid during the onset of bloat. The slime contained 33 to 35% protein and was suggested to be of microbial origin. However, in view of its composition the possibility of feed or animal origin should also be considered (Howarth 1975). Higher protein rations may contribute to the development of this slime. Howarth et al. (1984) found that soluble protein is not responsible for the immediate onset of frothiness in rumen fluid, but does contribute to frothiness as part of a complex with other substances. They indicated that although both nitrogen content and initial rate of

degradation (of legumes) are related to the day-to-day occurrence of bloat, the predictive value of both parameters is low compared to the measures of animal predisposition, including rumen fluid volume and composition of the ruminal contents. A predisposed rumen was characterized by an excess of dispersed particulate matter with adherent microorganisms, which provide an active inoculum for the fermentation of incoming feedstuffs. Kemalyan (1991) found a positive correlation ($r=0.30$, $P<0.01$) between protein content of barley and purine yield indicating greater in vitro microbial activity with higher protein barley.

Engstrom et al. (1992) indicated that ADF content was significantly correlated to DM feed:gain ratio ($R^2=0.90$, $P=0.04$) when six different barleys were fed to steers and suggested ADF would be useful in predicting nutritive value of barley. There was no such significant correlation in this trial (Table 6) even though the ADF content of the barleys ranged from 5.2 to 8% (Table 1). However, there was a correlation between ADF content and VW ($r=-0.76$, $P=0.01$) which was expected.

Similar to the results of Christison and Bell (1975), we found a very narrow range in the gross energy content of the barleys (Table 1).

3.4.7 Relationship Between Barley Physical Characteristics and Nutritive Value

Kernel weight, VW and plumpness have been related to the nutritional quality of barley (Newman and McQuire 1985).

Kernel hardness was not correlated to steer growth or efficiency (Table 6). This is in agreement with Classen et al. (1985) who found that KH of hulless barley did not influence chick growth or efficiency.

Hironaka et al. (1973) showed that fine particle sizes in barley increased the rate of gas production ($P<0.05$) 1 h after feeding compared to coarse particle sizes. They concluded that fine particle-feed produces a bloat condition more readily than coarse particle-feed. There were no differences in mean particle size or DM passing a .85 mm screen between the rations used in this trial. This is not surprising since the roller mill was adjusted for each barley as necessary, allowing for differences in moisture content and plumpness, to ensure that the kernels were cracked in a consistent manner.

A technical committee on feed grain utilization (Canada Grains Council 1972) suggested that VW was the most practical measure of the energy content of feed grains. However, in earlier experiments that showed VW effects Christison and Bell (1975) noted that low VW was often confounded with differences due to dockage, maturity,

weather damage, or to other non specific results of adverse climatic conditions. There was a significant correlation between DE and VW (Table 6; r=0.83, P=0.003) but there was no correlation between DE and thousand kernel weight (r=0.18, P=0.62) which is in agreement with Christison and Bell (1975). Mathison et al. (1991) could not measure any statistical difference in DE content between barley weighing 43 to 66 kg hL^{-1}. Volume weight was also related to CP, ADF, DM degradability after 12 h in situ, total tract DM digestibility, and the percentage of animals that bloated. The inclusion of the hulless variety Condor in the present trial was probably the reason why the relationship between VW and digestibility reached significance. Low correlations between VW and most other measures of nutritional quality, along with the high variability of Pacific Northwest barley, suggested that the use of VW as the only or primary measure of quality when purchasing barley could not be recommended or defended (Froseth and Miller 1992).

Volume weight was not related to rate of gain, feed intake, or feed DM:gain ratio (Table 6). This may be because the range in VW was small (55-67 kg hL^{-1}) and because VW was above 53.6 kg hL^{-1}, below which there is a greater change in crude fibre per unit change in test weight (Canada Grains Council 1982). Similarly, no effect of VW on feedlot performance was noted by Engstrom et al. (1992) with six lots of barley weighing from 57 to 70 kg hL^{-1}. Mathison

et al. (1991) reported a non significant increase of 6% in feed:gain ratios when steers were fed barley weighing 43 versus 59 and 64 kg hL^{-1} and Grimson et al. (1987) reported a 9-10% decrease ($P<0.05$) in feed:gain ratios for steers fed 56 and 67 kg hL^{-1} barley in comparison with steers fed 48 kg hL^{-1} barley.

Therefore within VW normally encountered, there is no reason to discriminate against lighter barley to the extent that some purchasers of barley do (Froseth and Miller 1992; Mathison et al. 1991). Our results disagree with those of Reynolds et al. (1992) who indicated that current industry practice of barley evaluation via test weight appears to be prudent.

3.4.8 Rate and Extent of Barley Degradability and Digestion

3.4.8.1 Relationship Between Extent of Degradation and Barley Characteristics

The results indicating that DM degradability after 12 h in situ was highly correlated to VW (Table 6; $r=0.70$) are in agreement with the results of Reynolds et al. (1992), who found that 18 h in situ DM disappearance was highly correlated to test weight ($r=0.72$), and the results of Engstrom et al. (1992) who found that in situ DM disappearance after 8 and 24 h were highly correlated to VW

(r=0.91 and 0.87 respectively). Results indicating DM degradability after 8, 12, and 24 h in situ were negatively correlated to ADF content (r=-0.78, -0.86. -0.64 respectively), and that DM degradabilities after 4 and 8 h in situ were highly correlated to starch content (r=0.76 and 0.66 respectively) contrast with the work of Reynolds et al. (1992) who found low correlations between in situ DM disappearance and ADF, and starch (r=-0.44, and 0.47, respectively). However, our results agree with those of Engstrom et al. (1992) who found a high correlation between 24 h in situ DM disappearance and ADF content (r=0.93) and between DM disappearance after 8 and 24 h incubation and starch (r=0.83 and 0.96 respectively).

3.4.8.2 Rate of Degradation of the Slowly Degradable Fraction

In our study the average DM degradation rate of ground barley (43.7% h^{-1}) was nearly four times greater than that of the rolled barley (11.3% h^{-1}). Odle and Schaefer (1987) found no difference in DM degradation rates between rolled or ground barley. However, in our study the rolled barley was very coarsely rolled or cracked and this may have limited access to rumen organisms compared to the ground barley. McAllister et al. (1990b) found that in situ DM disappearance rate increased from whole to halved to

quartered barley and concluded that bacterial colonization and degradation are essential processes for the efficient utilization of cereal grains by ruminants.

In spite of a large range in degradation rate (Table 5) we could not measure any statistical difference in rate of degradation between barley samples. Our results are supported by those of Bock et al. (1991) who found no significant differences in rate of in situ starch degradability between wheat or corn or mixtures of these grains. In contrast, Clark et al. (1987) reported that the DM and NDF in vitro degradation rates were different ($P<0.05$) between barley cultivars. Kemalyan et al. (1989) also found similar results from two independently run trials demonstrating that barley cultivars differed ($P<0.05$) with respect to DM disappearance rate and purine accumulation. Similarly, Ovenell and Nelson (1992) suggested that differences in rate of degradation exist between barley cultivars. Lehman et al. (unpublished data) indicated that rate of barley DM degradation in situ varies ($P<0.05$) between barley varieties ($n=22$) and that this was independent of the location ($n=3$) where the barley was grown.

It is very interesting that barleys with higher crude protein contents had significantly lower rates of in situ DM degradation ($r=-0.84$; Table 6; Fig. 1). Boss et al. (1994) also found that barleys with higher CP contents had lower

rates of in situ DM degradability. Reynolds et al. (1992) found a low correlation between in situ DM disappearance and barley protein ($r=-0.40$) which agrees with this experiment ($r=0.19-0.60$).

We are however, concerned about the average of 51.5% of ground barley lost from the bags during the wash in the mechanical washer, leaving an average of 35.1% as the potentially degradable fraction, and about 13.4% as the undegradable fraction (Table 5). The material lost in this wash may not have been only the truly soluble fraction. Particle size of the ground material may influence the amount that is immediately soluble. In previous studies a 1 mm screen (De Boer et al. 1987) or 2 mm screen (Engstrom et al. 1992) was used to grind the barley samples. Because of this concern we used a 3 mm screen in preparing barley samples for this study. In spite of this however, the soluble fractions lost during washing the bags were similar to those of Engstrom et al. (1992), although lower than those of De Boer et al. (1987). De Boer et al. (1987) also indicated that the DM disappearance during washing is influenced by bag size, with large bags having higher DM disappearance, and by washing method, with mechanical washing having higher DM disappearance than hand washing.

Bock et al. (1991) indicated that the lack of statistical difference between in situ starch degradation rates in their trial was likely due to high variability,

which resulted from differences in solubility of starch with respect to grain form used (high moisture corn vs. dry rolled wheat), much greater particle size for the high moisture corn, and or variability within the nylon bag procedure. Bock et al. (1991) cites Frigoid et al. (1972) as observing wide variations between in situ DM degradability of sorghum and barley due to grains and grain processing as well as several other factors. It was concluded that the value of the nylon bag technique lay in its ability to rank various treatments, not in specific numeral values obtained (Bock et al (1991).

Kemalyan (1991) found in situ rate of degradation to be questionable due to extremely low values in ewes. She proposed that the thick, viscous nature of the ruminal fluid interfered with normal degradation of grain samples inside the bags, and cites Odle and Schaefer (1987) as finding that the viscous ruminal fluid of concentrate fed animals tended to plug the pores in nylon bags preventing the escape of gases. Kemalyan (1991) observed ballooning of the bags in her study in all periods and all treatments and concluded that although the nylon bag technique has been considered useful in determining degradability of concentrate feeds, it is apparently not adequate when attempting to describe a rate of degradation. Many of the problems that Kemalyan (1991) observed with sheep were not seen in this trial using fistulated steers with larger rumen volumes. No ballooning

of bags was seen in our trial. Because of these problems rate of degradation of the slowly degradable fraction of barley may be less meaningful than total degradation after specific incubation times. The following discussion therefore focuses primarily on amount degraded.

3.4.8.3 Barley Degradability and Animal Performance

Dry matter intake, digestibilities of DM, OM, energy, and nitrogen, and DE content of the barleys were similar to those of Mathison (1991). Because of the relatively small range in DE (14.5 to 16.0 MJ kg^{-1}) it is perhaps not surprising that DE content was not related to feed DM:gain ratio. Significant differences in digestibility of DM, organic matter, and nitrogen were found between barley samples. Ovenell and Nelson (1992) found significant differences in organic matter intake and digestibility of NDF between barley cultivars. Kemalyan (1991) found differences between barley varieties in the proportion of starch that is degraded in the rumen and the proportion that "by-passes" the rumen and is more efficiently degraded in the small intestine of sheep.

We observed a positive relationship (Table 6) between degradability of barley DM at all times with significance occurring at 12 h, and the percentage of animals that bloated ($r=0.72$, $P=0.02$; Fig. 11), suggesting that faster

rates of degradation are undesirable. Other researchers have suggested that barley grain may be degraded too rapidly in the rumen contributing to acidosis, rumenitis and bloat (Ørskov 1986; Clark et al. 1987; Robinson and Kennelly 1988; McAllister et al. 1990a).

There is other indirect evidence supporting the concept of fast degradability in the rumen being undesirable. Fulton et al. (1979) found an increased incidence of acidosis in steers fed high concentrate diets of wheat, which is degraded rapidly in the rumen, compared to corn which is degraded more slowly by the rumen flora. Bock et al. (1991) evaluated feedlot performance of steers fed mixtures of wheat and high moisture corn in finishing rations. As the percentage of wheat in the ration increased (25%, 50%, 75% and 100%), gain/feed did not differ ($P>0.10$); however, final weight, hot carcass weight, and ADG decreased linearly ($P<0.05$) and DM intake exhibited a cubic response ($P<0.05$) with increased wheat in the diet. The rate of starch degradation did not differ significantly between grains or mixtures, but was inversely related to DM intake ($r=-0.78$, $P=0.21$), ADG ($r=-0.83$, $P=0.17$), and gain:feed ($r=-0.85$, $P=0.15$). It was concluded that increased performance may be associated with a decreased rate of ruminal starch degradation, and that slower ruminal degradation rates may imply a reduction in the incidence of subacute acidosis.

In contrast with the above results, there is also

evidence that cereal grain may be degraded too slowly in the rumen. Ladley et al. (1991) selected three corn hybrids and evaluated the effect of corn hybrids (fed as dry rolled or high moisture corn) on finishing cattle performance. It was found that cattle fed dry rolled hybrid B were more efficient and had faster daily gains than cattle fed hybrid A ($P<0.05$) or C ($P<0.10$). In vitro rate of starch disappearance of dry rolled hybrid B was 13% faster than hybrid A and 4.9% faster than hybrid C. There were no differences in DM intake, quality grade or fat thickness among the corn hybrids fed. Hybrid C tended to have the highest incidence of liver abscesses ($P<0.10$). Stock et al. (1987) found that steers fed a mixture of high moisture corn and dry-rolled grain sorghum were 4.2% more efficient and had improved ruminal starch degradation (14%) and total tract starch digestion (2%) than steers fed either 100% high moisture corn or 100% dry-rolled grain sorghum. It was shown that nearly all the high moisture corn starch was degraded in the rumen, and that only half of the dry-rolled grain sorghum starch degraded in the rumen. It was concluded that replacing 33% of the high moisture corn with dry-rolled grain sorghum maintained ruminal starch degradation, and increased the degradation of dry-rolled grain sorghum resulting in the positive associative effects observed for gain/feed in four trials. The rate of ruminal starch degradation was probably slowed due to the addition

of dry-rolled grain sorghum, and thus the incidence of acidosis may have been reduced (Stock et al. 1987). Wester et al. (1992) found that steers fed a sorghum hybrid selected for a faster (7.0%) in vitro rate of starch disappearance gained 9.0% faster than steers fed a hybrid with a slower in vitro rate of starch disappearance (1.33 vs. 1.22 kg d^{-1}, P=0.06). Gain:feed ratio was positively correlated with in vitro starch disappearance across all treatments (R^2=0.94). However, in another trial sheep fed a sorghum hybrid with the fastest in vitro starch disappearance were similar in finishing performance to those fed a sorghum hybrid with the lowest in vitro starch disappearance, suggesting that factors other than in vitro starch disappearance affected lamb performance (Wester et al. 1992).

Boss et al. (1994) found that Harrington's rate of degradation in situ was found to be 71.4% faster (P<0.01) than Medallion or Gunhilde barleys, and was 254.3% faster than corn, while Medallion and Gunhilde barleys degraded 106.6% faster (P<0.01) than corn. However, cattle fed the corn diet gained 9.8% faster than those fed Harrington barley which gained 8.0% faster than those fed Medallion or Gunhild barley. Feed DM:gain ratios did not vary between steers fed the three barleys (Medallion 6.3, Harrington 6.6 and Gunhild 6.8). It was concluded that despite an extremely rapid rate of ruminal degradation Harrington

barley provided superior feedlot performance compared with Medallion or Gunhilde barleys.

3.4.8.4 Prediction of In Vivo Digestibility from In Situ Degradability

Based on the significant correlations ($P<0.01$) between DM degradability in situ after 4, 8 and 12 h and DM digestibility ($r=0.76$, 0.80, and 0.79 respectively) in our trial, it appears that DM degradability in situ can be used to predict total tract DM digestibility, which agrees with the results of Boss et al. (1994). In their trial, Boss et al. (1994) noted that the in situ DM degradability of the individual grains followed the same trend as in vivo DM digestibility of the entire diets, with corn having 8.1% lower ($P<0.05$) degradability compared with the three barleys.

It was concluded that large differences in the feeding value of two-row vs. six-row, or malt vs. feed barley grains of similar volume weight are not to be expected when the grains are included in feedlot diets containing adequate protein and other nutrients. Further, we were unable to confirm or refute our hypotheses that barley grain which is degraded more rapidly in the rumen is undesirable.

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4.0 GENERAL DISCUSSION AND CONCLUSIONS

The present research attempted to address some of the factors affecting rate of barley DM and starch degradation in situ, including variety, type of barley (two-row, six-row, hulless, malting, and feed), chemical and physical composition, and the effect on feedlot performance of steers.

There was about a 7% difference in feed DM:gain between samples of barley which was below the detection limits for this experiment (Table 10), but similar to results of Males and Fong (1987). At this time no clear recommendation regarding locally grown varieties most suited for ruminants can be made. However, in time differences between barley varieties may be more important as new varieties are developed for ruminant feeds.

The literature seems to indicate that two-row barley is preferred to six-row barley for swine diets, and there is some evidence that this may also be true for cattle, although we could not detect any differences in feedlot performance or carcass characteristics in this trial (Table 10 and 11). In light of the conflicting information on feed value of two-row vs. six-row barley for cattle, more research will be needed before a clear recommendation can be made. However, commercial feedlots may be selecting more two-row barley inadvertently by purchasing heavier barleys,

which can be supported by the 2% increase in digestibilities of DM, OM and energy and DE content, and the 3% increase in nitrogen digestibility for two-row barley compared to six-row barley.

Hulless barley was more digestible in DM, OM, and N, and had a higher DE content than Virden hulled barley (Table 9) and therefore in theory cattle should be able to utilize it better than Virden hulled barley. However, we could not detect any differences in utilization. Further studies on the feed value of hulless barley for cattle should be conducted to verify these results.

Malting barley has been selected for quality factors including higher starch content and extractability in the malting process which may be as or more important than rate of degradation. There was a trend ($p=0.08$) for malting barley to have a 3% higher starch degradability after 2 h in situ than feed barley which would be expected based on selection (Table 7) however, this did not affect feedlot performance.

Volume weight, within VW normally encountered, was shown to be of no value in predicting feedlot performance of steers (Table 6 and 10). This is in general agreement with the work of Engstrom et al. (1992) for barleys in normal VW range but is in contrast to the work of Grimson et al. (1987) and Mathison et al. (1991) when very low VW barleys were compared. However, volume weight was correlated with

DM digestibility, DE content, and percentage of animals that bloated.

This is among the first data on the effect of volume weight on rate of barley DM and starch degradation. Although we did not find a correlation between VW and in situ DM or starch degradation rate, VW was positively correlated to in situ DM degradation after 12 h (Table 6). This is in agreement with the results of Engstrom et al. (1992) indicating a positive correlation between VW and in situ DM degradation after 8 h ($r=0.91$, $P<0.05$).

It appears that DM degradation in situ can be used to predict DM digestibility in vivo (Table 6), which is in agreement with Boss et al. (1994), and we agree with Engstrom (1988) that it may be a useful measurement in the development of new feed barley cultivars for cattle. Total ground barley DM degradation after 24 h in situ may be more useful than rate of degradation, since it was related to DM:gain ($r=0.68$, $P=0.03$; Table 6; Fig. 7), and due to the difficulty in measuring degradation rate using the nylon bag technique. We tried to rank barleys for degradation rate after 4 h incubation in vitro using α-amylase or pancreatin (Cone and Vlot 1990) or after predigestion with pepsin for 1 h followed by α-amylase (Holm et al. 1987), however, the results were not repeatable. The cell-free freeze dried preparation of rumen fluid discussed by Cone (1991) for predicting in vivo degradability should be examined since it

would be a convenient method for researchers and feed manufacturers who have no facilities for housing donor cows.

The correlation between DM:gain ratio and DM degradability after 24 h is completely different than that reported by Engstrom (1988) for steam rolled and dry rolled barley that was ground through a 2 mm screen ($r=-0.91$, $P=0.01$) and may be due to the bloat problems in our trial. In addition, Engstrom (1988) noted that DM degradability was reduced in steam rolled barley relative to dry rolled barley. However, since no attempt was made to separate processing effects in the above correlation we couldn't determine if this would explain the discrepancy with our results. The reason for a positive slope in the correlation of DM:gain ratio with in situ DM degradability of ground barley after 24 h and a negative slope in the correlation with in situ DM degradability of rolled barley after 24 h is likely due to an interaction between the amount degraded and the degree of processing. Rate of degradation may have been limited in the coarsely rolled barley. Zinn (1993) found that gain:feed tended ($P>0.10$) to decrease with increasing flake thickness, and indicated that the tendency for improved feed efficiency with decreased flake thickness is consistent with lower ($P<0.10$) faecal starch for steam-rolled barley thinly rolled vs. steam-rolled barley coarsely rolled. Overall steam-rolled barley thinly rolled had a 4% higher feed value compared to steam-rolled barley coarsely

rolled. Likewise, Hironaka et al. (1992) found that gain:feed was highest in steers fed thin- and medium-rolled vs. coarse-rolled barley ($P<0.05$) and lowest in steers fed whole barley ($P<0.05$). However, they also observed more cattle off feed with apparent digestive disturbance from wk 2 to wk 6 among those fed the thin- and medium-rolled barley than among those fed the coarse-rolled or whole barley. They indicated that a coarse-rolled barley is the most desirable during the period when cattle are initiated to feed, and a medium-rolled barley is most desirable after the cattle are accustomed to the grain diet. We did not detect any differences in the level of acidosis between cattle fed the different barleys in our trial.

The positive correlation between DM degradability after 12h incubation and the percentage of steers which bloated, and the 10% difference ($P=0.0001$) in the amount of starch degraded between barley samples after 2 h in situ (Table 7), may indicate that the rate of degradation is important. A positive relationship between rapid rate of degradation and DM:gain ratio has been suggested previously (Fulton et al. 1979; Clark et al. 1987; Bock et al. 1991). We had a fairly narrow range of 5.6% in amount of DM degraded after 4 h in situ (Table 5) which may explain why we did not see a significant difference in rate of in situ DM degradation between varieties. However, Lehman et al. (unpublished data) with a wider range of 17.6% in DM degraded after 4 h

in situ found a significant ($P<0.05$) difference in rate of in situ DM degradation between unselected barley varieties. The literature and these results suggests that there is likely an optimum rate of degradation, with sorghum and corn being too slow and most barleys and wheat being too fast (Boss et al. 1994; Wester et al. 1992; Ladley et al. 1991; Bock et al. 1991; Robinson 1989; Theurer 1986; Fulton et al. 1979). More research is required to determine what the optimum rate of degradation for cattle is and how to achieve this optimum rate via selection of certain varieties of barley, mixtures of different grains, degree of processing, and source and level of roughage (Owens et al. 1986). Thus rate of degradation may become a more important factor in the future as barley varieties for cattle are selected based on in situ rate of DM degradation. Dr. James Helm, Head, Crop Research Station, Field Crop Development Centre, Agriculture Food and Rural Development, Lacombe, is currently using this criteria as a selection tool in developing new varieties of feed barley for ruminants.

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Table 1. Chemical composition and physical characteristics of whole barley grain dry matter

Lot No.	Barley Variety	Type	DM[z] (%)	Starch (%)	GE[z] (MJ kg^{-1})	CP[z] (%)	P[z] (%)	ADF[z] (%)	Ash (%)	VW[z] (Kg hL^{-1})	TKW[z] (g)	KH[z] (sec)
1	Duke	6 Row-feed	87.8^{ab}	60.4	18.95	12.3^{d}	0.36^{bcd}	6.5^{b}	2.44	60^{e}	40.4^{ef}	77.7^{a}
2	Condor	Hulless-feed	88.4^{b}	60.9	18.95	14.8^{a}	0.41^{a}	5.2^{c}	2.20	67^{a}	41.1^{de}	46.7^{e}
3	Ellice	2 Row-malt	87.7^{ab}	59.3	18.91	13.7^{bc}	0.33^{d}	7.0^{b}	2.22	65^{b}	45.7^{b}	59.7^{cd}
4	Harrington	2 Row-malt	87.7^{ab}	61.9	18.70	12.0^{d}	0.39^{ab}	6.4^{b}	2.42	58^{f}	39.8^{fg}	75.1^{ab}
5	Duke	6 Row-feed	87.0^{a}	57.5	18.83	14.2^{ab}	0.33^{d}	6.2^{b}	2.30	61^{d}	41.6^{d}	75.4^{a}
6	Virden	6 Row-feed	88.3^{ab}	58.1	18.58	10.3^{e}	0.38^{bc}	8.0^{a}	2.80	55^{g}	41.6^{d}	77.5^{a}
7	Bonanza	6 Row-malt	88.2^{ab}	60.3	18.83	11.6^{d}	0.34^{d}	6.6^{b}	2.32	61^{cd}	39.4^{g}	58.4^{cd}
8	Pbee	2 Row-feed	87.9^{ab}	60.7	18.66	12.0^{d}	0.35^{cd}	5.5^{c}	2.45	66^{a}	45.0^{c}	54.9^{d}
9	Leduc	6 Row-feed	87.7^{ab}	58.6	18.74	12.1^{d}	0.34^{d}	6.9^{b}	2.38	62^{c}	46.6^{a}	69.0^{ab}
10	Harrington	2 Row-malt	87.2^{ab}	58.0	18.79	13.0^{c}	0.37^{bc}	6.2^{b}	2.55	62^{c}	46.6^{a}	65.7^{bc}
	SEM[y]		0.28	0.47	0.04	0.22	0.01	0.19	0.06	0.28	0.25	2.99
	P[x]		0.03			0.0001	0.0001	0.0001		0.0001	0.0001	0.0001
		2 Row	87.7^{a}	60.4	18.74	12.7^{b}	0.36^{b}	6.3^{a}	2.41	63^{b}	44.2^{a}	63.8^{a}
		6 Row	87.8^{a}	59.0	18.79	12.1^{b}	0.35^{b}	6.8^{a}	2.45	60^{c}	42.0^{b}	71.2^{a}
		Hulless	88.4^{b}	60.9	18.95	14.8^{a}	0.41^{a}	5.2^{b}	2.20	67^{a}	41.1^{b}	48.8^{b}
		SEM[y]	0.20	0.57	0.06	0.32	0.007	0.20	0.08	0.66	0.65	2.56
		P[x]	0.11			0.0001	0.0001	0.0001		0.0001	0.0008	0.0001
		Malting	87.7	60.3	18.83	12.6	0.36	6.6	2.38	61.5	42.8	64.9
		Feed	87.9	59.4	18.79	12.6	0.36	6.4	2.43	61.8	42.8	67.8
		SEM[y]	0.14	0.45	0.02	0.28	0.01	0.17	0.03	0.59	0.46	1.87
		P[x]	0.52			0.96	0.75	0.48		0.78	0.93	0.28

[z]DM=Dry matter, GE=gross energy, CP=crude protein, P=phosphorus, ADF=acid detergent fibre, VW=volume weight, TKW=thousand kernel weight, and KH=kernel hardness (air dry basis - longer grinding times associated with softer grain).

[y]Pooled standard error of means based on 5, 20, 25, and 30 samples for variety, two-row and malting, six-row, and feed type respectively.

[x]Probability of a significant difference.

[a,b] Means within each column and comparison not followed by the same letter differ significantly ($p<0.05$).

Table 2. Concentrate formulation (air-dry basis)

Ingredient	Percent
Barley grain (dry rolled)	95.05
Canola meal	3.00
Calcium carbonate (38% Calcium)	1.10
Fortified salt[z]	0.30
Vitamin-Bovatec premix[y]	0.35
Dynamate[x]	0.20

[z]Salt contained 27% Na, and the following in mg kg^{-1}: Co 80; Cu 4000; I 200; Mn 6000; Zn 8000; and Se 100.
[y]Premix contained 10,050 mg kg^{-1} of lasalocid sodium, 1,340,000 IU vitamin A and 134,000 IU vitamin D kg^{-1}.
[x]Dynamate contained 11% Mg, 18% K, and 22% S.

Table 3. Composition of concentrate dry matter

Lot No.	Barley Variety	Type	Dry Matter (%)	Gross energy (MJ kg^{-1})	CP (%)	Ca (%)	P (%)	ADF[w] (%)	Ash (%)	S (%)	Mg (%)	K (%)	Density (kg L^{-1})
1	Duke	6 Row-feed	87.6^{bc}	18.28	13.0^{cde}	0.51	0.38^{abc}	6.6^{bc}	3.83^{cd}	0.21	0.16	0.50^{abc}	0.47^{de}
2	Condor	Hulless-feed	89.1^{d}	18.37	15.3^{a}	0.53	0.42^{a}	5.6^{c}	3.87^{c}	0.23	0.18	0.51^{abc}	0.55^{a}
3	Ellice	2 Row-malt	87.5^{bc}	18.45	13.7^{bc}	0.45	0.35^{bc}	6.9^{b}	3.62^{de}	0.16	0.14	0.40^{c}	0.49^{dc}
4	Harrington	2 Row-malt	87.3^{bc}	18.24	12.7^{de}	0.53	0.40^{a}	6.5^{bc}	3.71^{cd}	0.21	0.15	0.50^{abc}	0.46^{e}
5	Duke	6 Row-feed	86.1^{a}	18.33	14.4^{b}	0.46	0.35^{bc}	6.4^{bc}	3.79^{cd}	0.19	0.14	0.45^{bc}	0.47^{de}
6	Virden	6 Row-feed	87.4^{bc}	18.16	10.8^{f}	0.45	0.39^{abc}	7.9^{a}	4.21^{b}	0.16	0.16	0.58^{a}	0.42^{f}
7	Bonanza	6 Row-malt	87.7^{bc}	18.20	12.0^{e}	0.44	0.35^{bc}	6.8^{b}	3.63^{de}	0.17	0.15	0.42^{bc}	0.48^{dc}
8	Abee	2 Row-feed	88.2^{c}	18.33	12.6^{de}	0.47	0.39^{abc}	6.2^{bc}	3.49^{e}	0.19	0.15	0.53^{ab}	0.54^{b}
9	Leduc	6 Row-feed	87.8^{bc}	18.33	12.1^{e}	0.45	0.34^{c}	7.4^{ab}	3.73^{cd}	0.18	0.15	0.49^{abc}	0.46^{e}
10	Harrington	2 Row-malt	87.0^{b}	18.20	13.5^{bcd}	0.44	0.39^{ab}	6.5^{bc}	4.59^{a}	0.18	0.15	0.50^{abc}	0.50^{c}
	SEM[v]		0.25	0.01	0.27	0.07	0.01	0.27	0.05	0.02	0.01	0.03	0.005
	P[x]		0.0001	0.05	0.0001	0.98	0.0001	0.0001	0.0001	0.37	0.34	0.001	0.0001
		2 Row	87.5^{a}	18.33	13.1^{b}	0.47	0.38^{b}	6.5^{a}	3.85	0.18^{b}	0.15^{b}	0.48	0.50^{b}
		6 Row	87.3^{a}	18.24	12.4^{b}	0.46	0.36^{b}	7.0^{a}	3.84	0.18^{b}	0.15^{b}	0.49	0.46^{c}
		Hulless	89.1^{b}	18.37	15.3^{a}	0.53	0.42^{a}	5.6^{b}	3.87	0.23^{a}	0.18^{a}	0.51	0.55^{a}
		SEM[v]	0.21	0.01	0.30	0.04	0.01	0.20	0.13	0.01	0.01	0.02	0.01
		P[x]	0.0001	0.23	0.0001	0.63	0.0002	0.0002	0.99	0.09	0.03	0.77	0.0001
		Malting	87.4	18.28	13.0	0.46	0.37	6.7	3.89	0.18	0.15	0.45^{b}	0.48
		Feed	87.7	18.28	13.0	0.48	0.38	6.7	3.82	0.19	0.16	0.51^{a}	0.49
		SEM[v]	0.18	0.01	0.26	0.03	0.01	0.17	0.09	0.01	0.005	0.01	0.007
		P[x]	0.15	0.49	0.90	0.78	0.73	0.96	0.60	0.25	0.14	0.005	0.65

[v]Pooled standard of means, based on 6, 24, 30, and 36 samples for variety, two-row and malting, six-row, and feed type respectively.
[x]Probability of a significant difference
[w]Acid detergent fibre, based on 5 samples.
[a-f]Means in the same comparison and column, not followed by the same letter differ significantly ($p<0.05$).

Table 4. Trace element composition and particle size of concentrate dry matter

Lot No.	Barley Variety	Type	Cu (mg/kg)	Mn (mg/kg)	Zn (mg/kg)	Se (mg/kg)	Fe (mg/kg)	Na (mg/kg)	Al (mg/kg)	B (mg/kg)	Mn Pt Sz[w] (mm)	DM Pass 0.85 mm[w] (%)
1	Duke	6 Row-feed	14.75	27.17	59.33	0.17^{c}	69.7^{c}	1152.3	35.7^{cd}	5.7	2.00	7.59
2	Condor	Hulless-feed	25.03	40.83	58.83	0.25^{b}	123.2^{ab}	1622.2	71.0^{bc}	5.7	2.12	5.08
3	Ellice	2 Row-malt	11.07	21.00	47.67	0.39^{a}	74.0^{c}	745.3	36.7^{cd}	9.0	2.19	3.48
4	Harrington	2 Row-malt	9.80	36.33	58.00	0.21^{b}	98.2^{bc}	1201.7	37.5^{cd}	4.2	2.17	3.78
5	Duke	6 Row-feed	11.75	29.00	60.33	0.23^{b}	83.8^{c}	884.2	27.0^{d}	4.2	2.14	4.83
6	Virden	6 Row-feed	11.17	29.83	49.50	0.2^{b}	149.5^{a}	1000.3	114.7^{a}	5.5	2.06	5.77
7	Bonanza	6 Row-malt	12.08	24.5	57.00	0.27^{b}	74.8^{c}	948.5	33.3^{cd}	6.1	2.15	4.23
8	Abee	2 Row-feed	12.08	23.83	55.00	0.21^{b}	65.0^{c}	913.2	21.0^{d}	4.6	2.12	5.23
9	Leduc	6 Row-feed	10.80	28.67	48.33	0.16^{b}	71.3^{c}	841.3	34.2^{cd}	5.1	2.14	3.96
10	Harrington	2 Row-malt	10.90	24.33	55.33	0.21^{b}	130.5^{ac}	774.0	89.3^{ab}	5.8	2.12	4.98
	SEM[y]		4.45	4.77	4.83	0.03	10.65	332.63	9.64	1.95	0.09	2.10
	P[x]		0.46	0.14	0.48	0.0001	0.0001	0.78	0.0001	0.87	0.97	0.97
		2 Row	11.98^{b}	26.38^{b}	54.00	0.26	91.9	908.5	46.1	5.9	2.15	4.37
		6 Row	11.65^{b}	27.83b	54.90	0.21	98.8	965.3	50.0	5.3	2.11	5.25
		Hulless	25.03^{a}	40.83^{a}	58.83	0.25	123.2	1622.2	71.0	5.7	2.12	5.08
		SEM[y]	2.73	3.09	3.16	0.02	9.73	205.63	9.71	1.23	0.05	1.27
		P[x]	0.02	0.03	0.68	0.12	0.13	0.13	0.33	0.90	0.74	0.80
		Malting	11.75	26.54	54.5	0.27^{a}	94.4	917.4	49.2	6.3	2.16	4.12
		Feed	14.04	29.89	55.2	0.20^{b}	93.8	1068.9	50.6	5.1	2.10	5.39
		SEM[y]	2.03	2.26	2.21	0.02	7.00	147.20	0.86	0.85	0.04	0.86
		P[x]	0.43	0.30	0.82	0.004	0.95	0.47	0.89	0.36	0.30	0.31

[y]Pooled standard error of means, based on 6, 24, 30, and 36 samples for variety, two-row and malting, six-row, and feed type respectively.
[x]Probability of a significant difference.
[w]Percent of particle dry matter passing through a 0.85 mm screen.
[a-f]Means in the same comparison and column not followed by the same letter differ significantly ($p<0.05$).

Table 5. Dry matter disappearance (%) of ground barley from nylon bags

Lot No.	Barley	Type Variety	Degradability at various incubation times (h)						Degradable Fraction (%)		Rate (% h^{-1})
			0	2	4	8	12	24	A[z]	B[z]	Kd[z]
1	Duke	6 Row-feed	45.2^{d}	70.5	78.2^{b}	82.5^{c}	84.5^{bc}	87.6^{c}	45.4^{c}	39.9^{a}	47.3
2	Condor	Hulless-feed	52.7^{abc}	72.0	81.9^{a}	86.4^{a}	89.6^{a}	91.9^{a}	52.8^{ab}	37.8^{ab}	36.3
3	Ellice	2 Row-malt	51.3^{abcd}	70.9	79.0^{b}	82.5^{c}	84.6^{bc}	87.3^{c}	51.4^{abc}	34.1^{ab}	41.7
4	Harrington	2 Row-malt	57.5^{a}	74.5	81.7^{a}	85.0^{b}	85.7^{bc}	90.6^{ab}	57.7^{a}	30.3^{b}	41.0
5	Duke	6 Row-feed	53.8^{ab}	71.0	77.4^{b}	82.4^{c}	84.9^{bc}	88.3^{bc}	54.3^{ab}	32.3^{ab}	33.0
6	Virden	6 Row-feed	46.0^{dc}	70.2	77.9^{b}	81.5^{c}	83.1^{c}	88.3^{bc}	46.1^{c}	38.8^{a}	57.7
7	Bonanza	6 Row-malt	49.8^{bcd}	72.3	79.9^{ab}	82.7^{c}	85.9^{bc}	88.0^{bc}	50.0^{bc}	36.1^{ab}	49.0
8	Abee	2 Row-feed	54.2^{ab}	74.1	80.0^{ab}	84.3^{b}	86.4^{b}	89.3^{bc}	54.6^{ab}	32.7^{ab}	42.7
9	Leduc	6 Row-feed	48.7^{bcd}	72.4	78.9^{b}	82.0^{c}	83.8^{bc}	87.3^{c}	48.9^{bc}	35.8^{ab}	52.7
10	Harrington	2 Row-malt	53.4^{ab}	72.3	78.8^{b}	82.7^{c}	86.3^{b}	89.2^{bc}	53.9^{ab}	33.2^{ab}	36.0
	SEM[y]		1.57	0.97	0.57	0.40	0.62	0.59	1.57	1.56	0.06
	P[x]		0.0006	0.077	0.0002	0.0001	0.0001	0.0004	0.0005	0.006	0.21
		2 Row	54.1^{a}	72.9	79.9^{b}	83.6^{b}	85.7^{b}	89.1^{b}	54.4^{a}	32.6^{b}	40.3
		6 Row	48.7^{b}	71.3	78.4^{b}	82.2^{c}	84.4^{b}	87.9^{b}	48.9^{b}	36.5^{a}	47.9
		Hulless	52.7^{ab}	72.0	81.9^{a}	86.4^{a}	89.6^{a}	91.9^{a}	52.8^{ab}	37.8^{a}	36.3
		SEM[y]	1.39	0.74	0.53	0 39	0.50	0.44	1.39	1.21	0.04
		P[x]	0.004	0.122	0.002	0.0001	0.0001	0.0001	0.003	0.006	0.14
		Malting	53.0	72.5	79.8	83.2	85.6	88.79	53.2	33.4^{b}	41.9
		Feed	50.1	71.7	79.0	83.2	85.4	88.77	50.3	36.2^{a}	44.9
		SEM[y]	1.14	0.54	0.46	0.45	0.56	0.48	1.13	0.94	0.03
		P[x]	0.087	0.323	0.227	0.963	0.744	0.971	0.084	0.046	0.51

[z]A=soluble fraction, B=slowly degradable fraction, and Kd=degradation rate.
[y]Standard error of mean based on three samples of each variety at each time.
[x]Probability of a significant difference.
[a-d]Means within each comparison and column not followed by the same letter differ significantly ($P<0.05$).

Table 6. Correlation matrix chemical components and degradabilities of ten lots of barley

	Starch	Protein	ADF	VW	DMDig	DE	DM4	DM8	DM12	DM24	DMKd	TKWT	KHard	BLT	LVRABS	DMI	ADG	F/G
Starch	[illegible]	[illegible]	[illegible]	[illegible]	.58	0.51	.76*	.66*	.42	.39	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Protein		[illegible]	.64*	.65*	.58	[illegible]	[illegible]	.45	[illegible]	.34	.64*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ADF			[illegible]	[illegible]	.85*	.81*	.54	-.78*	.85*	.54*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
VW				[illegible]	.78*	.83*	.41	.62	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DMDig					[illegible]	.98*	.75*	.80*	.75*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DE						1.00	.65*	.72*	.75*	.46	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DM4							[illegible]	.90*	.74*	.73*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DM8								1.00	.88*	.91*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DM12									[illegible]	.82*	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DM24										[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
DMKd											[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TKWT												[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
KHARD													[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
BLT														[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
LVRABS															[illegible]	[illegible]	[illegible]	[illegible]
DMI																[illegible]	[illegible]	[illegible]
ADG																	[illegible]	[illegible]
F/G																		[illegible]

1 Abbreviations and units are: ADF, acid detergent fibre (%); VW, volume weigh (kg hL⁻¹); DMDig, total tract dry matter digestibility (%); DE, digestible energy (MJ kg⁻¹); DM4, DM8, DM12, DM24, dry matter disappearance of ground barley in situ after 4, 8, 12, or 24 h (%); DMKd, dry matter degradation rate (% h⁻¹); TKWT, thousand kernel weight (g); KHARD, kernel hardness (seconds grinding time); BLT, animals that bloated (no.); LVRABS, liver abscesses (%); DMI, dry matter intake (kg); ADG, average daily gain (kg); F/G, dry matter:gain ratio.

* P<0.05.

Table 7. Starch disappearance (%) from ground barley.

Lot No.	Barley Variety	Type	Degradability at various incubation times (h)				Degradable fraction (%)		Rate (% h^{-1})
			0	2	4	8[w]	A[z]	B[z]	Kd[z]
1	Duke	6 Row-feed	45.9^{d}	84.6^{a}	94.7	99.2^{a}	41.2^{c}	59.0^{a}	65.8
2	Condor	Hulless-feed	52.8^{bc}	81.1^{b}	94.3	98.5^{ab}	52.6^{ab}	47.3^{bc}	49.0
3	Ellice	2 Row-malt	53.8^{bc}	85.3^{a}	95.7	99.1^{a}	53.8^{ab}	46.1^{bc}	58.0
4	Harrington	2 Row-malt	60.7^{ab}	87.3^{a}	97.2	98.9^{ab}	60.6^{ab}	39.2^{bc}	63.7
5	Duke	6 Row-feed	52.3^{ab}	86.0^{a}	93.9	98.8^{ab}	57.3^{ab}	41.6^{bc}	62.0
6	Virden	6 Row-feed	46.7^{cd}	80.6^{b}	95.0	97.9^{b}	46.6^{bc}	53.4^{ab}	56.7
7	Bonanza	6 Row-malt	60.5^{ab}	88.7^{a}	96.5	98.6^{ab}	60.5^{ab}	38.6^{bc}	73.3
8	Abee	2 Row-feed	63.3^{a}	88.5^{a}	95.7	98.5^{ab}	63.4^{a}	35.5^{c}	64.7
9	Leduc	6 Row-feed	53.6^{bc}	88.9^{a}	96.3	99.0^{ab}	53.6^{ab}	45.4^{bc}	79.5
10	Harrington	2 Row-malt	60.2^{ab}	87.3^{a}	95.2	98.9^{ab}	60.2^{ab}	38.9^{bc}	66.3
	SEM[y]		1.79	1.01	1.02	0.23	2.91	3.08	0.06
	P[x]		0.0001	0.0001	0.464	0.035	0.006	0.006	0.17
		2 Row	59.5^{a}	87.1^{a}	95.9	98.8	58.6	40.7	63.2^{a}
		6 Row	52.8^{a}	85.7^{a}	95.3	98.7	53.2	46.2	66.6^{a}
		Hulless	52.8^{b}	81.1^{b}	94.3	98.5	52.6	47.2	49.0^{b}
		SEM[y]	2.28	1.11	0.69	0.20	2.57	2.73	0.04
		P[x]	0.025	0.017	0.370	0.543	0.14	0.16	0.06
		Malting	58.8^{a}	87.2	96.1	98.9	57.9	41.5	65.3
		Feed	53.3^{b}	84.9	95.0	98.6	53.6	45.8	61.7
		SEM[y]	1.62	0.85	0.46	0.13	1.85	1.96	0.03
		P[x]	0.024	0.081	0.089	0.271	0.14	0.16	0.43

[z]A=soluble fraction, B=slowly degradable fraction, Kd=rate of degradation
[y]Pooled standard error of the mean, based on three samples of each variety at each time.
[x]Probability of a significant difference.
[w]Starch degradability only up to 8 h were done since by this time 98-99% of the starch was degraded.
[a-d]Means within each comparison and column not followed by the same letter differ significantly ($P<0.05$).

Table 8. Dry matter disappearance (%) of rolled barley from nylon bags

Lot No.	Barley Variety	Type	Degradability at various incubation times (h)							Degradable Fraction (%)		Rate (% h^{-1})
			0	2	4	8	12	24	48	A[z]	B[z]	Kd[z]
1	Duke	6 Row-feed	3.5^{bc}	16.1^{abc}	22.2^{c}	38.0^{cd}	36.9^{b}	46.1^{b}	68.0^{ab}	8.2^{ab}	69.3^{a}	6.0
2	Condor	Hulless-feed	3.1^{c}	12.7^{c}	21.7^{c}	35.8^{de}	39.0^{ab}	43.4^{b}	67.6^{abc}	6.1^{ab}	61.5^{ab}	7.2
3	Ellice	2 Row-malt	3.8^{bc}	18.1^{abc}	32.5^{a}	46.9^{a}	46.3^{a}	58.0^{a}	69.9^{a}	4.9^{ab}	60.7^{ab}	13.7
4	Harrington	2 Row-malt	6.4^{a}	21.8^{a}	29.1^{ab}	40.7^{bc}	40.2^{ab}	48.0^{b}	63.2^{abcd}	10.7^{a}	50.0^{ab}	10.0
5	Duke	6 Row-feed	2.9^{c}	12.5^{c}	21.6^{c}	32.6^{f}	36.6^{c}	42.0^{b}	58.1^{bcd}	5.0^{ab}	50.4^{ab}	8.3
6	Virden	6 Row-feed	4.9^{abc}	20.2^{ab}	27.5^{b}	39.7^{bc}	41.5^{ab}	43.0^{b}	57.2^{cd}	6.5^{ab}	44.3^{b}	16.0
7	Bonanza	6 Row-malt	3.2^{c}	16.7^{abc}	22.5^{c}	33.7^{ef}	38.7^{ab}	38.7^{b}	56.3^{d}	5.1^{ab}	43.2^{b}	12.9
8	Abee	2 Row-feed	2.9^{c}	13.8^{c}	19.8^{c}	36.0^{de}	42.1^{ab}	42.2^{b}	57.8^{bcd}	3.1^{b}	50.6^{ab}	12.3
9	Leduc	6 Row-feed	5.1^{ab}	20.7^{a}	29.4^{ab}	42.3^{b}	44.4^{ab}	50.7^{ab}	60.2^{bcd}	6.5^{ab}	50.6^{ab}	16.0
10	Harrington	2 Row-malt	3.6^{bc}	16.0^{abc}	22.6^{c}	38.2^{cd}	37.8^{ab}	45.9^{b}	58.7^{bcd}	5.2^{ab}	50.5^{ab}	11.0
	SEM[y]		0.43	1.46	1.20	0.76	1.87	2.53	2.22	1.25	4.42	0.02
	P[x]		0.0002	0.0016	0.0001	0.0001	0.0253	0.0028	0.0014	0.02	0.02	0.07
		2 Row	4.2	17.4	26.0	40.4	41.6	48.5	62.4	5.9	53.0	13.6
		6 Row	3.9	17.2	24.7	37.2	39.6	44.1	59.9	6.3	52.1	12.6
		Hulless	3.1	12.7	21.7	35.8	39.0	43.4	67.6	6.1	61.5	7.2
		SEM[y]	0.52	1.54	1.85	1.68	1.57	2.44	2.29	1.22	4.22	0.02
		P[x]	0.490	0.208	0.409	0.133	0.423	0.199	0.149	0.95	0.75	0.45
		Malting	4.2	18.1	26.7	39.8	40.7	47.6	62.0	6.6	51.8	11.7
		Feed	3.7	16.0	23.7	37.4	40.1	44.6	61.5	5.9	54.0	11.8
		SEM[y]	0.35	1.00	1.19	1.16	1.15	1.65	1.57	0.76	2.67	0.013
		P[x]	0.314	0.149	0.093	0.152	0.695	0.206	0.809	0.57	0.73	0.77

[z]A=soluble fraction, B=slowly degradable fraction, and Kd=rate of degradation.
[y]Pooled standard error of the mean, based on three samples of each variety at each time.
[x]Probability of a significant difference.
[a-f]Means within each comparison and column not followed by the same letter differ significantly ($P<0.05$).

Table 9. Total tract digestibility of barley grains

Barley Variety	DM[z] Intake (g $kg^{-0.75}$)	Digestibilities (%)				DE[z] (MJ kg^{-1} diet)
		DM[z]	OM[z]	Energy	Nitrogen	
Duke	38.2	83.8[ab]	85.3[ab]	83.5	80.6[a]	15.3[ab]
Condor	38.8	87.4[a]	88.7[a]	87.0	84.8[a]	16.0[a]
Ellice	38.5	84.5[ab]	86.0[ab]	84.2	82.2[a]	15.5[ab]
Harrington	38.3	85.6[ab]	87.5[ab]	85.2	80.1[a]	15.5[ab]
Duke	38.1	83.7[ab]	85.2[ab]	83.5	82.6[a]	15.3[ab]
Virden	38.7	80.5[b]	82.4[b]	79.7	73.7[b]	14.5[b]
Bonanza	38.8	84.6[ab]	86.1[ab]	83.9	79.4[a]	15.3[ab]
Abee	38.8	85.9[ab]	87.5[ab]	85.1	81.8[a]	15.6[a]
Leduc	38.8	85.1[ab]	86.7[ab]	84.8	80.9[a]	15.5[ab]
Harrington	33.8	84.6[ab]	86.3[ab]	84.5	82.2[a]	15.4[ab]
SEM[y]	1.49	1.17	1.07	1.26	1.42	0.23
P[x]	0.44	0.05	0.04	0.07	0.003	0.03
Two-row vs. six-row						
2 Row	37.3	85.1	86.8[a]	84.8	81.6	15.5[a]
6 Row	38.5	83.5	85.1[b]	83.1	79.5	15.2[b]
SEM[y]	0.92	0.57	0.53	0.60	0.86	0.12
P[x]	0.38	0.056	0.03	0.058	0.09	0.04
Malting vs. feed						
Malting	37.34	84.8	86.5	84.5	81.0	15.5
Feed	38.49	83.8	85.4	83.3	80.0	15.2
SEM[y]	0.92	0.59	0.55	0.62	0.89	0.12
P[x]	0.38	0.24	0.17	0.20	0.42	0.20

[z]DM=Dry matter, OM=organic matter, and DE=digestible energy.
[y]Pooled standard error of means.
[x]Probability of a significant difference.
[a-b]Means in the same comparison and column not followed by the same letter differ significantly ($P<0.05$).

Table 10. Effect of barley variety and type on steer performance by period and overall

Lot No.	Barley Variety	Type	Anim[z] (No.)	In Wt. (kg)	Out Wt. (kg)	ADG[z] (kg)/period[z]				DM[z] intake (kg)/period[z]				DM[z]:gain ratio/period[z]				Anim[z] Bltd[w] (%)
						1	2	3	All	1	2	3	All	1	2	3	All	
1	Duke	6 Row-feed	20	366	549	1.65	1.74	1.41	1.60	8.45	10.42	12.93	10.87	5.14	6.03	8.51	6.63	5.0
2	Condor	Hulless-feed	20	364	537	1.46	1.55	1.43	1.50	7.92	10.13	12.92	10.63	5.53	6.57	8.00	6.84	25.0
3	Ellice	2 Row-malt	20	366	537	1.65	1.60	1.57	1.61	8.51	10.17	10.43	9.85	5.24	6.36	7.42	6.38	10.0
4	Harrington	2 Row-malt	20	363	537	1.69	1.69	1.33	1.57	8.48	10.89	12.05	10.72	5.03	6.43	9.10	6.85	10.0
5	Duke	6 Row-feed	20	368	543	1.66	1.54	1.49	1.57	8.88	10.28	12.15	10.63	5.38	6.70	8.20	6.76	20.0
6	Virden	6 Row-feed	19	365	537	1.50	1.48	1.41	1.46	7.71	9.08	12.56	10.05	5.44	6.44	7.96	6.78	0.0
7	Bonanza	6 Row-malt	19	364	532	1.57	1.55	1.41	1.54	7.90	9.83	10.82	9.72	5.42	6.75	7.88	6.71	15.8
8	Abee	2 Row-feed	19	366	543	1.48	1.67	1.42	1.54	8.07	9.75	12.17	10.24	5.80	6.20	8.01	6.75	15.8
9	Leduc	6 Row-feed	20	365	538	1.70	1.68	1.29	1.56	8.59	10.53	11.39	10.36	5.08	6.32	8.74	6.69	15.0
10	Harrington	2 Row-malt	19	365	540	1.44	1.52	1.46	1.49	7.68	9.54	11.93	9.97	5.71	6.62	7.76	6.71	26.3
	SEM[y]			6.11	4.91	0.10	0.08	0.08	0.04	0.46	0.59	1.18	0.49	0.34	0.29	0.53	0.24	
	P[x]				0.52	0.47	0.37	0.54	0.20	0.61	0.63	0.86	0.73	0.80	0.77	0.57	0.96	0.62
		2 Row	78	365	540	1.56	1.62	1.44	1.55	8.18	10.08	11.65	10.20	5.45	6.40	8.07	6.64	15.4
		6 Row	98	366	540	1.62	1.60	1.40	1.54	8.30	10.03	11.97	10.33	5.29	6.45	8.26	6.67	11.2
		Hulless	20	364	538	1.46	1.55	1.46	1.50	7.92	10.13	12.92	10.63	5.53	6.57	8.00	6.84	25.0
		SEM[y]		4.85	3.24	0.06	0.06	0.05	0.03	0.28	0.36	0.69	0.32	0.22	0.19	0.49	0.27	
		P[x]		0.95	0.90	0.39	0.72	0.67	0.58	0.70	0.98	0.57	0.73	0.71	0.87	0.64	0.86	0.27
		Malting	78	365	537	1.59	1.59	1.44	1.55	8.14	10.10	11.31	10.06	5.35	6.54	8.03	6.66	15.4
		Feed	118	366	542	1.58	1.61	1.41	1.54	8.27	10.03	12.35	10.46	5.39	6.38	7.26	7.25	13.7
		SEM[y]		3.31	2.39	0.04	0.03	0.03	0.02	0.19	0.25	0.47	0.22	0.16	0.12	0.62	0.34	
		P[x]		0.74	0.17	0.86	0.79	0.54	0.59	0.64	0.83	0.12	0.20	0.85	0.37	0.52	0.38	0.76

[z]Anim = animals; DM = dry matter; ADG = average daily gain; Bltd = bloated; period 1 = 1-28 days, period 2 = 29-69 days, period 3 = 70-111 days on average, all = 1-111 days on average. Period 3 and overall varied in length since animals were slaughtered as they reached enough finish to grade.
[y]Standard error of mean.
[x]Probability of a significant difference.
[w]Individual animals may have bloated a number of times, but were only counted once.
[a-b]Means within each comparison and column not followed by the same letter differ significantly ($P<0.05$).

Table 11. Effect of barley variety and type on steer carcass characteristics

Lot. No.	Barley Variety	Type	Anim[z] (No.)	Carcass Wt. (kg)	Dress (%)	Avg.[z] fat (mm)	REA[z] (cm^2)	Marb.[z]	Percentage in each grade				Cut.[z] Est.[z] (%)	Absc.[z] Livers (%)
									B1	A1	A2	A3		
1	Duke	6 Row-feed	20	315	57.3	6.90	87.5	7.95	5.0	75.0	20.0	0.0	62.3	5.0
2	Condor	Hulless-feed	20	314	58.2	7.85	87.4	7.90	5.6	83.3	11.1	0.0	61.6	10.5
3	Ellice	2 Row-malt	20	311	57.9	7.45	86.0	7.85	10.0	75.0	15.0	0.0	61.7	20.0
4	Harrington	2 Row-malt	20	314	58.5	8.30	87.2	7.75	0.0	85.0	15.0	0.0	61.8	30.0
5	Duke	6 Row-feed	20	314	57.8	7.80	88.5	7.90	0.0	90.0	0.0	10.0	62.3	20.0
6	Virden	6 Row-feed	19	309	57.6	7.40	88.3	7.90	5.3	94.7	0.0	0.0	62.2	10.5
7	Bonanza	6 Row-malt	19	305	57.2	6.85	84.1	7.79	5.3	89.5	5.3	0.0	62.3	5.3
8	Abee	2 Row-feed	19	313	57.6	7.94	84.1	7.78	5.3	78.9	15.8	0.0	60.8	15.8
9	Leduc	6 Row-feed	20	312	57.8	7.25	82.5	7.95	0.0	85.0	15.0	0.0	61.7	25.0
10	Harrington	2 Row-malt	19	313	58.0	6.98	86.6	8.00	10.5	84.2	5.3	0.0	62.1	21.1
	SEM[y]			3.62	0.36	0.63	1.85	0.10					0.52	
	P[x]			0.67	0.37	0.78	0.35	0.67	0.96	0.96	0.96	0.96	0.66	0.54
		2 Row	78	313	58.0	7.67	86.0	7.84	6.4	80.8	12.8	0.0	61.6	21.8
		6 Row	98	311	57.6	7.24	86.2	7.90	3.1	86.7	8.2	2.0	62.2	13.3
		Hulless	20	314	58.2	7.85	87.4	7.90	5.6	33.3	11.1	0.0	61.6	10.5
		SEM[y]		2.26	0.24	0.42	1.27	0.20					0.34	
		P[x]		0.56	0.12	0.50	0.81	0.70	0.69	0.69	0.69	0.69	0.23	0.25
		Malting	78	311	57.9	7.39	86.0	7.85	6.4	83.3	10.3	0.0	61.9	19.2
		Feed	118	313	57.7	7.52	86.4	7.90	3.4	84.5	10.3	1.7	61.8	14.5
		SEM[y]		1.60	0.17	0.30	0.84	0.05					0.25	
		P[x]		0.34	0.53	0.77	0.72	0.44	0.72	0.72	0.72	0.72	0.70	0.25

[z]Anim = Animals; Avg = Average; Marb. = Marbling; Cut. = Cutability; Absc. = Abscessed; Est. = Estimate; REA = Rib-eye area.
[y]Pocled standard error of means.
[x]Probability of a significant difference.
[a-b]Means within each column and comparison not followed by the same letter differ significantly.

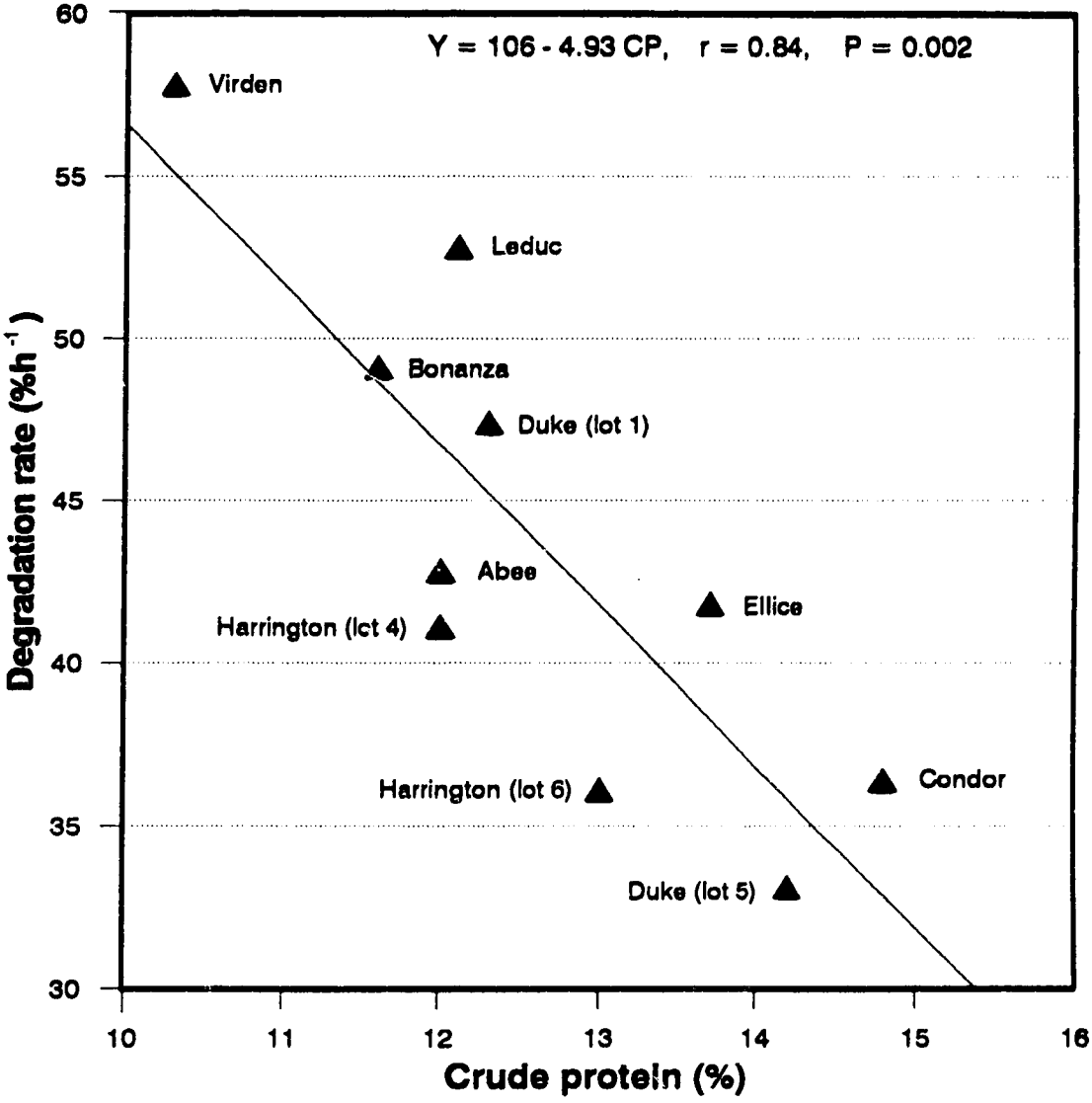

Fig. 1. Crude protein content of barley vs. in situ dry matter degradation rate of ground barley

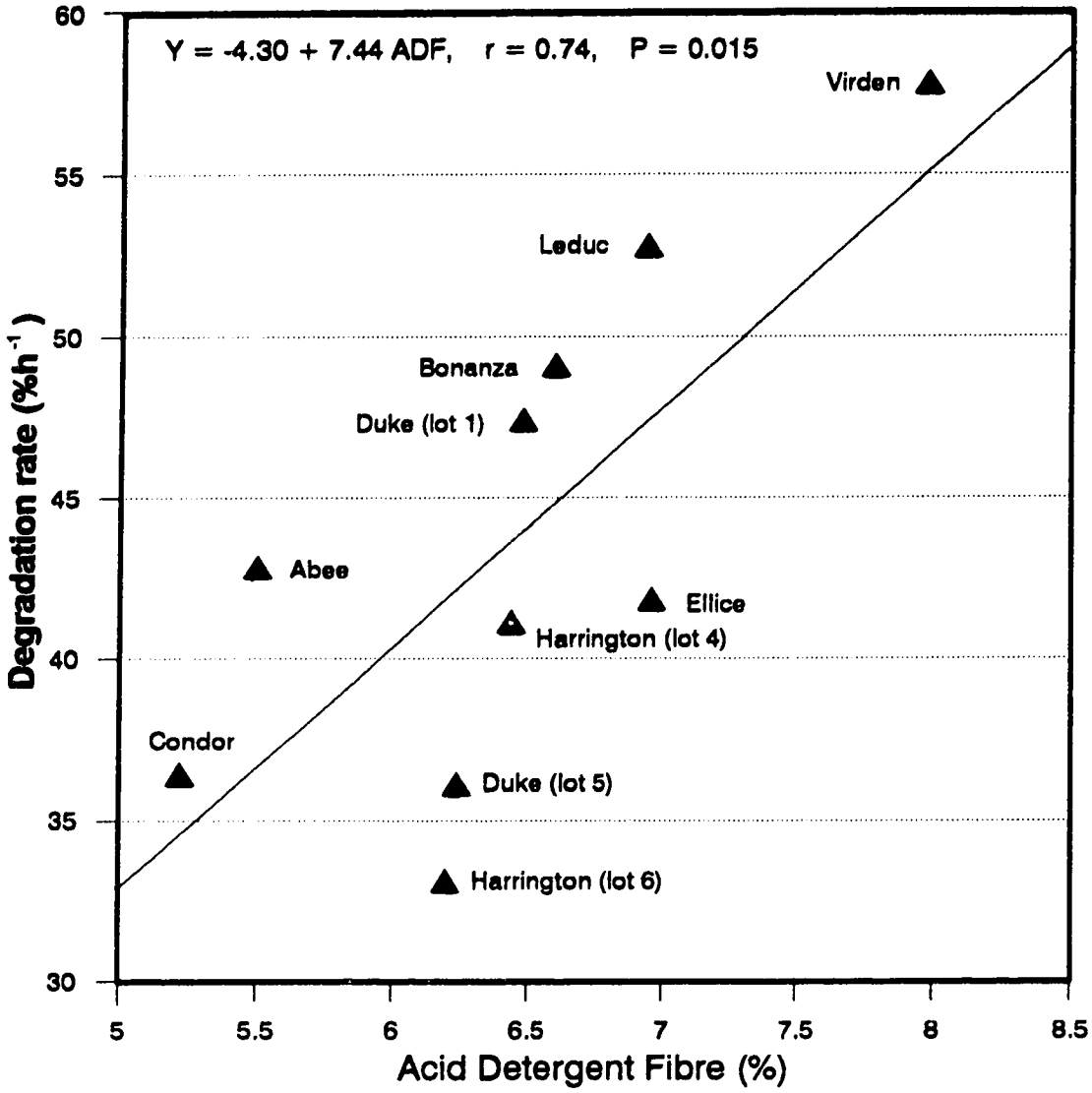

Fig. 2. Acid detergent fibre content of barley vs. in situ dry matter degradation rate of ground barley

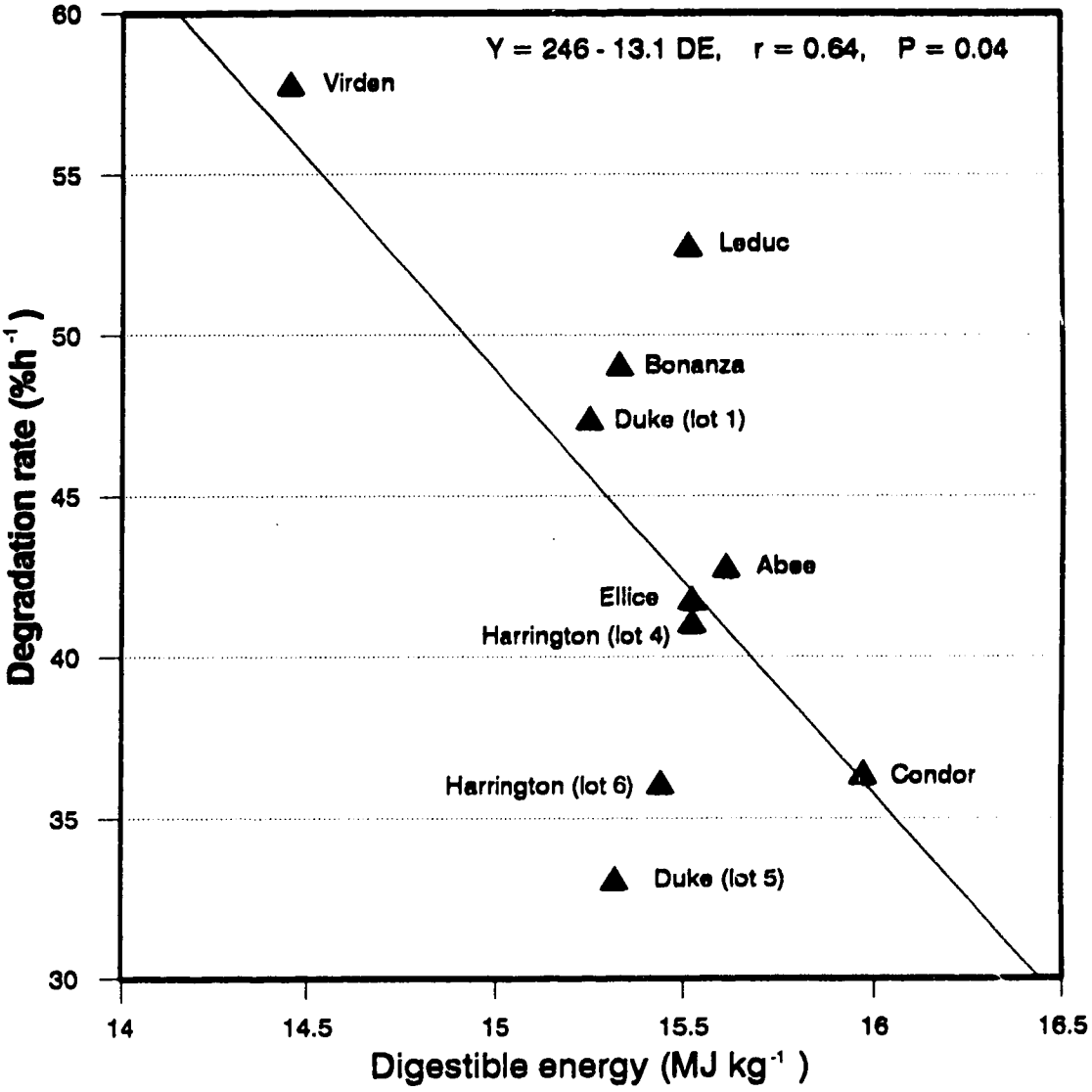

Fig. 3. Digestible energy content of barley vs. in situ dry matter degradation rate of ground barley

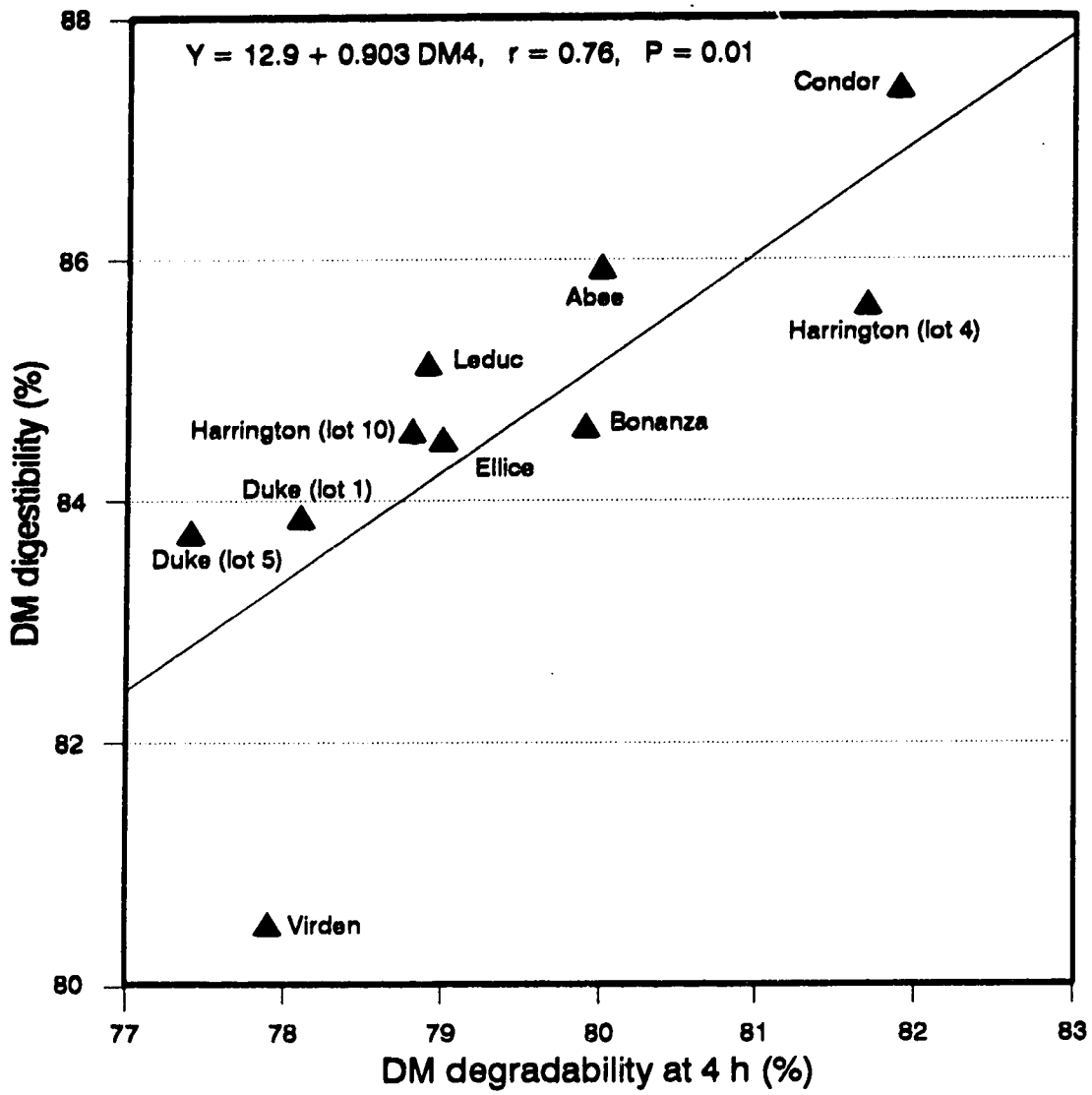

Fig. 4. In situ dry matter degradability of ground barley after 4 h vs. dry matter digestibility in vivo

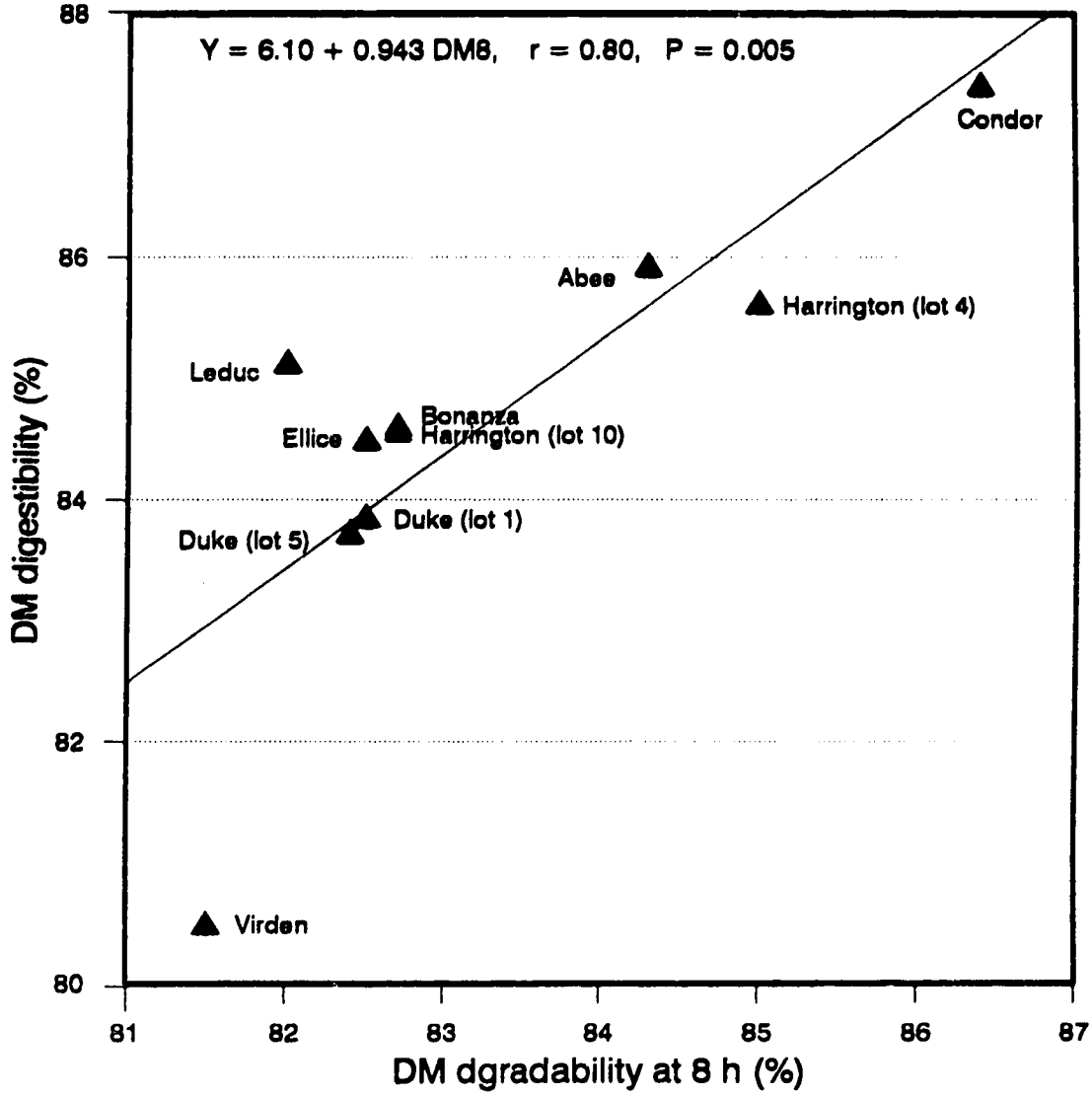

Fig. 5. In situ dry matter degradability of ground barley after 8 h vs. dry matter digestibility in vivo

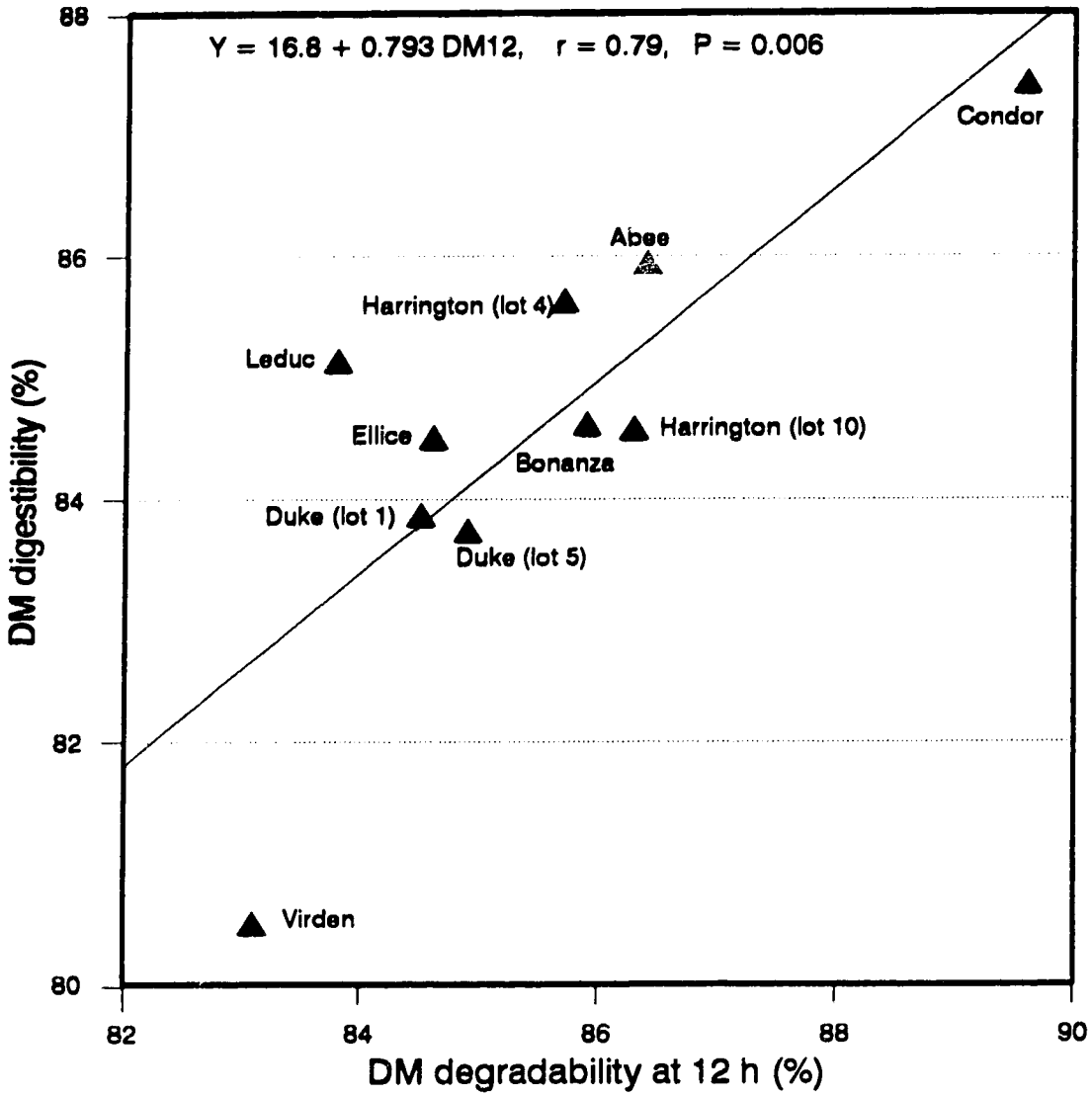

Fig. 6. In situ dry matter degradability of ground barley after 12 h vs. dry matter digestibility in vivo

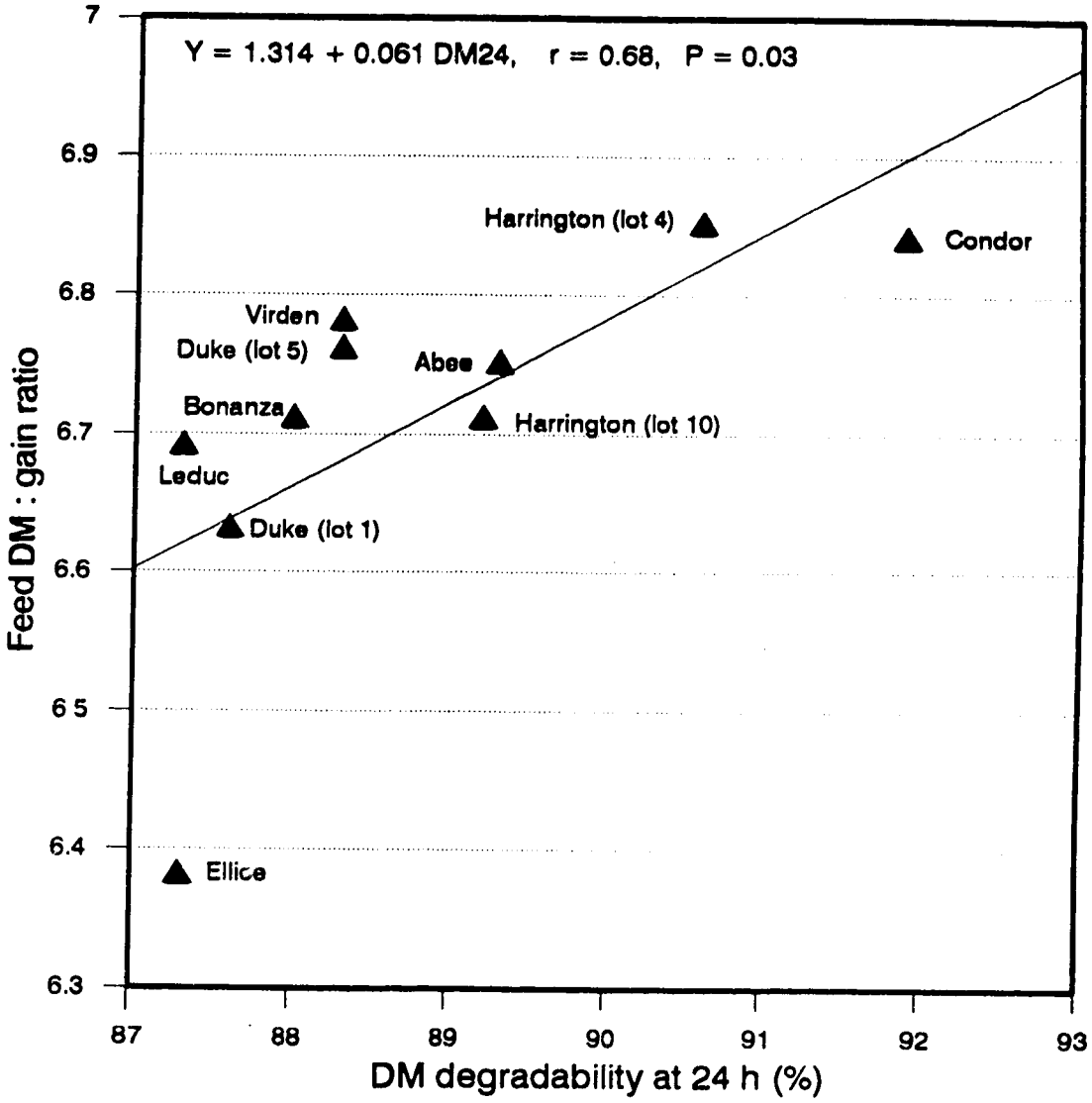

Fig. 7. In situ dry matter degradability of ground barley after 24 h vs. feed dry matter:gain ratio

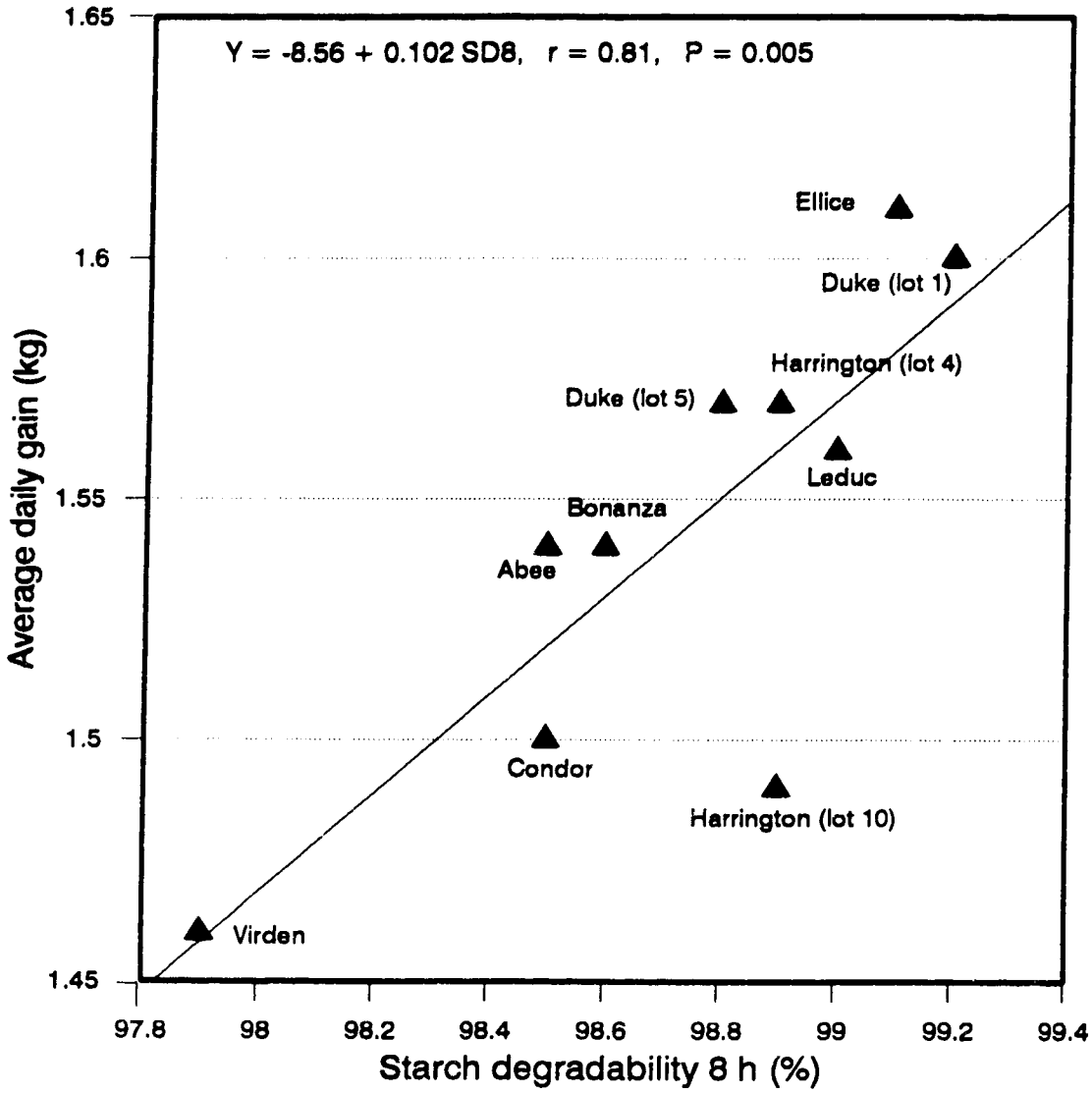

Fig. 8. In situ starch degradability of ground barley after 8 h vs. average daily gain

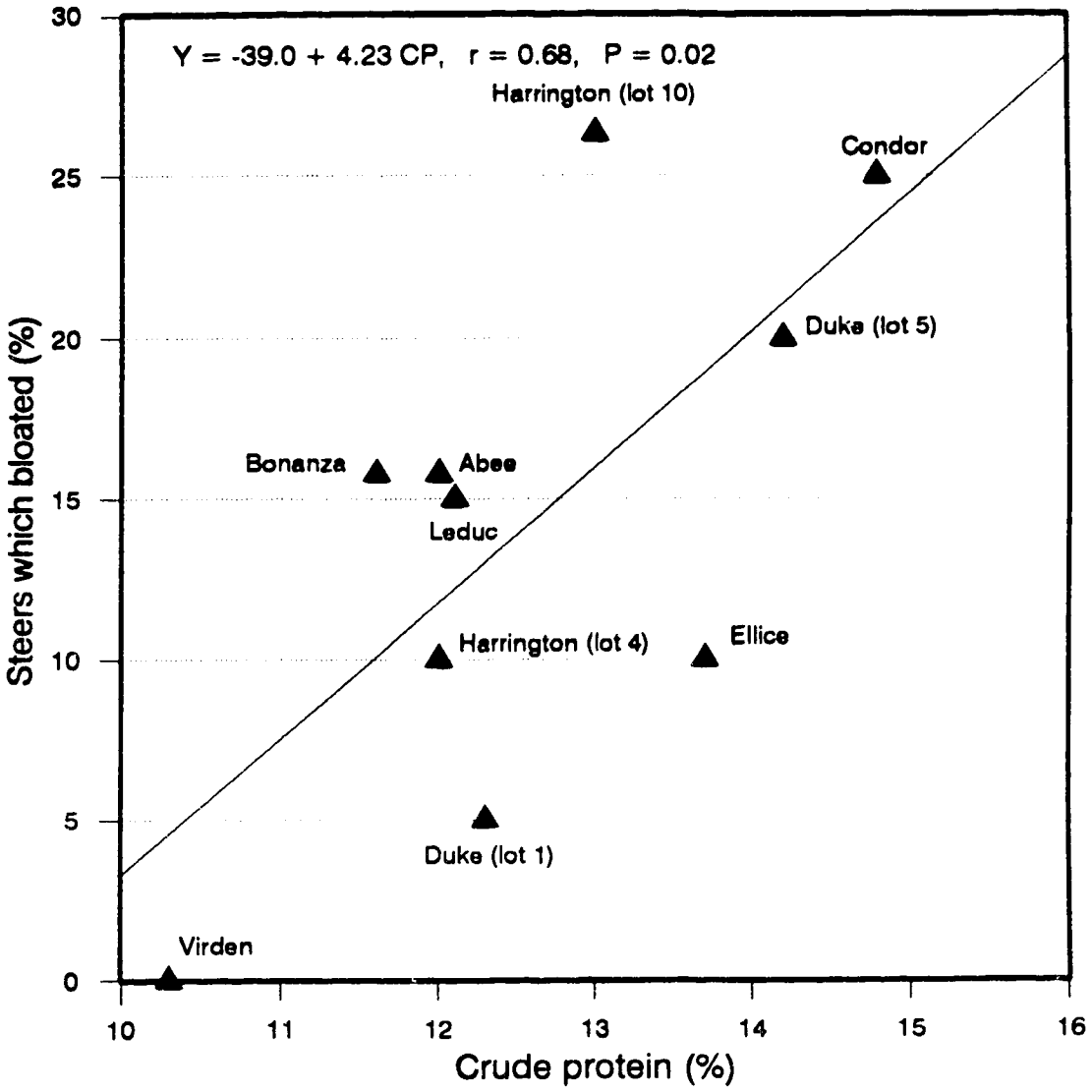

Fig. 9. Crude protein content of barley vs. percentage of steers which bloated

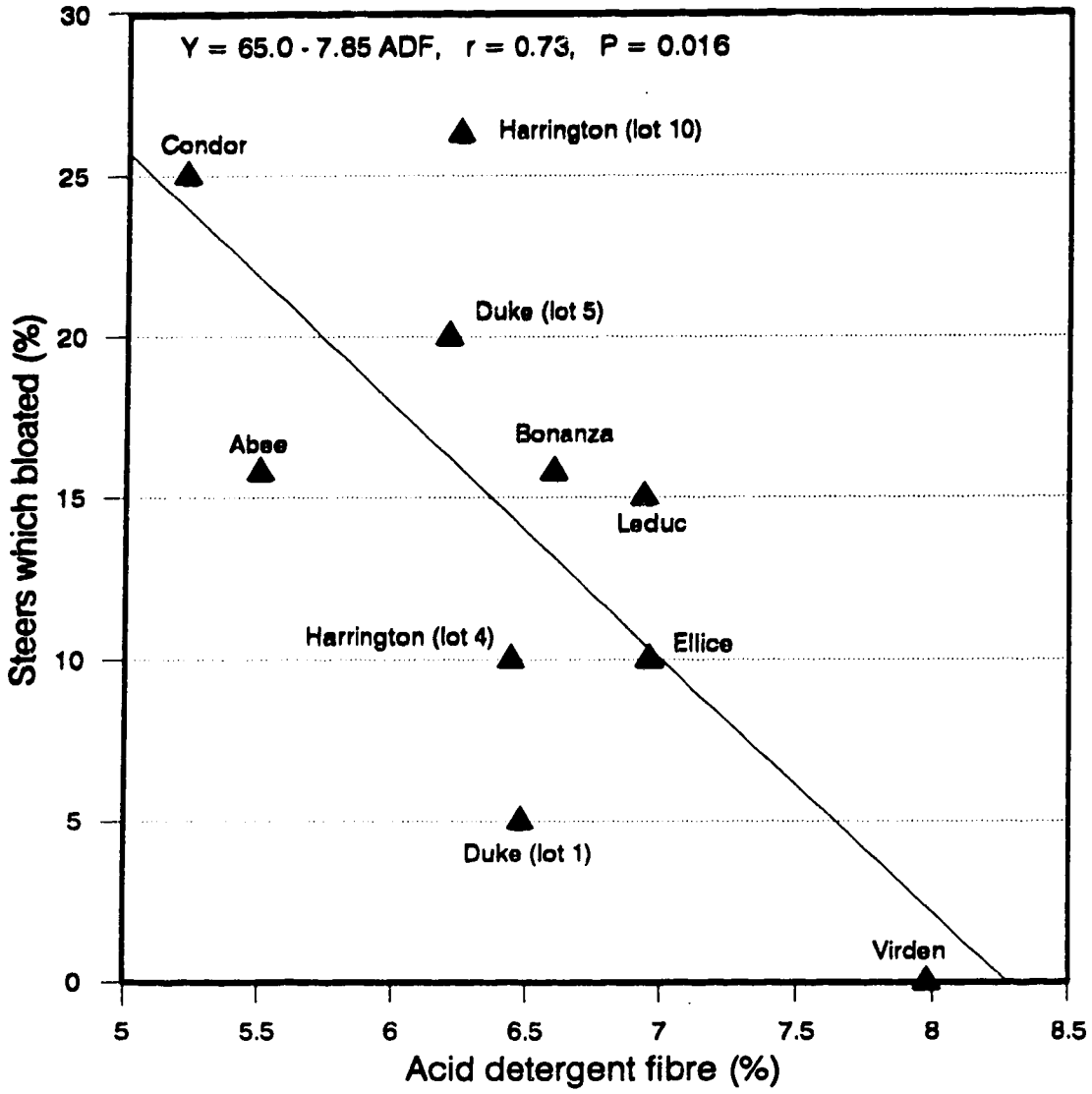

Fig. 10. Acid detergent fibre content of barley vs. percentage of steers which bloated

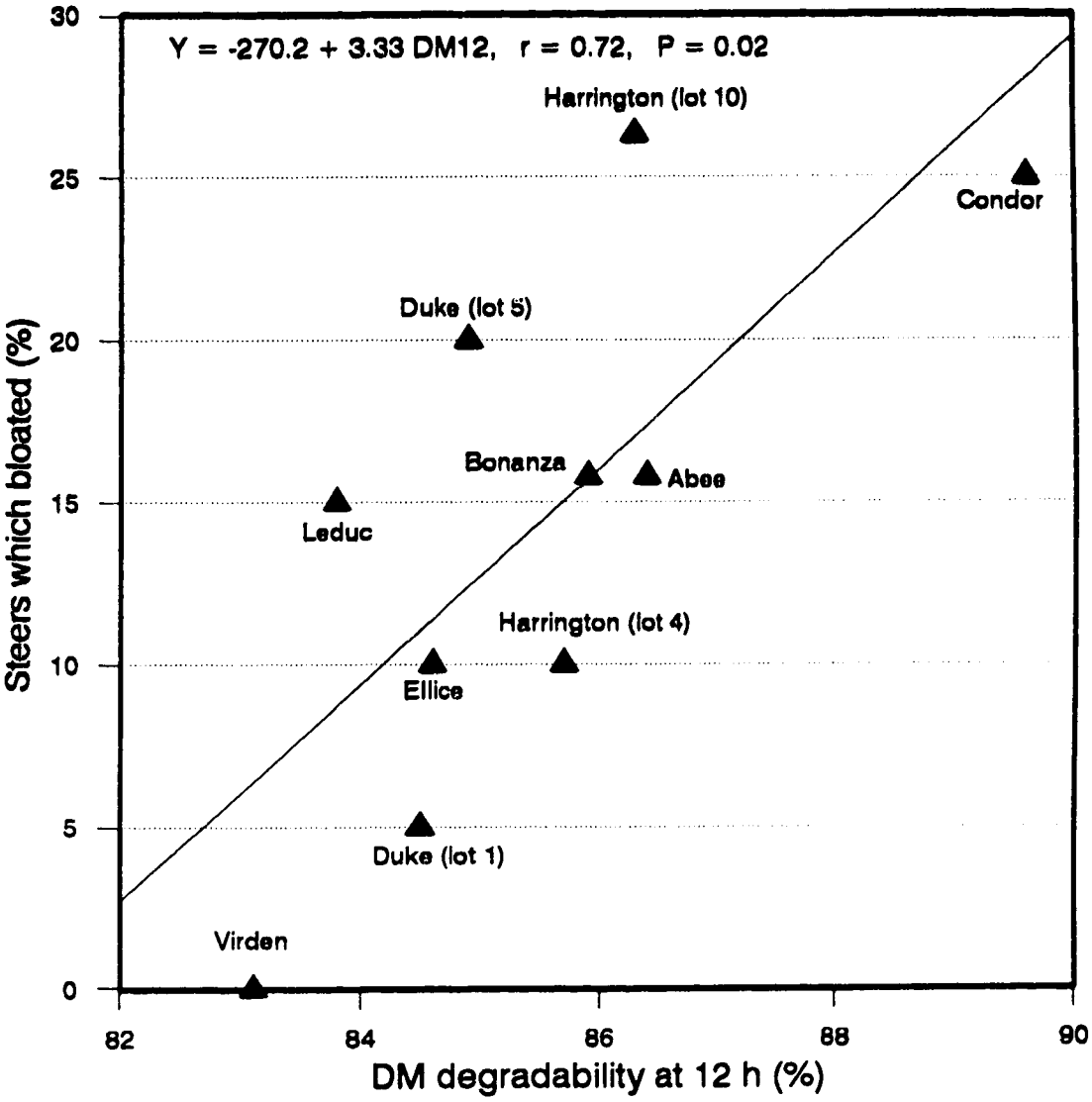

Fig. 11. In situ dry matter degradability of ground barley after 12 h vs. percentage of steers which bloated

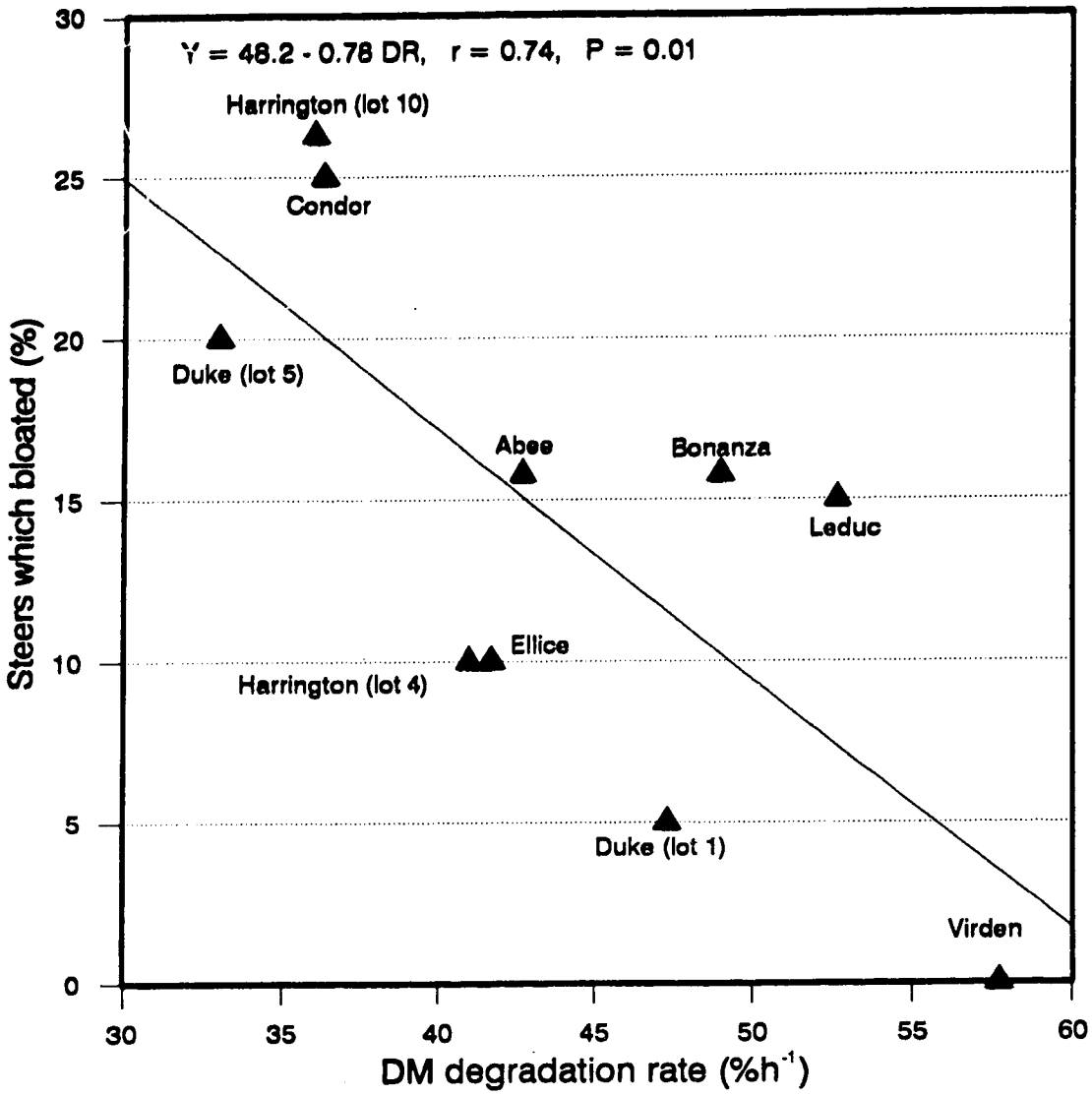

Fig. 12. In situ dry matter degradation rate of ground barley vs. percentage of steers which bloated