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MINNESOTA EXTENSION SERVICE
UNIVERSITY OF MINNESOTA
AGRICULTURE

53rd Minnesota Nutrition Conference

September 22-23, 1992
Bloomington, Minnesota



53rd Minnesota Nutrition Conference

Sponsored By:

- University of Minnesota**
- Minnesota Extension Service**
- Department of Animal Science**

American Feed Manufacturers Association
TAKEDA USA, Inc.
Diamond V, Cedar Rapids, IA
Chr. Hansen's Bio Systems
Northwest AgriDealers Association
Northwest Feed Manufacturers Association

Bloomington, Minnesota
September 22 & 23, 1992

ACKNOWLEDGEMENT

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A.M.
7:4

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P.M.

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TUESDAY, SEPTEMBER 22, 1992

53rd Minnesota Nutrition Conference

A.M. DAIRY

- 7:45 Registration
Presiding: **Jim Linn, University of Minnesota**
- 8:15 Welcome - **Richard Goodrich**
- 8:30 Body Composition of Dairy Cattle -
Brian Crooker
- 9:00 New Information Covering Passive Immunity
in Young Calves - **Robert DeGregorio**
- 9:30 Gene Reconstruction as a Means of
Creating an Acid Resistant Ruminant Bacteria
- **James Russell**
- 10:00 Refreshment Break - Sponsored by NFMA
- 10:20 Digestible Fiber Sources For Dairy Cattle -
Marshall Stern
- 10:50 Starch Utilization in Ruminants -
David Harmon
- 11:20 Speakers Panel and Discussion
- 12:00 LUNCHEON (Sponsored by Diamond V):
Consumer Attitudes and Perceptions on
Nutrition - **Joanne Slavin, Prof. Food
Science & Nutrition, U of M**

P.M. GENERAL RUMINANT

- Presiding: **Richard Larson, Qualitech**
- 1:30 Environmental Balance and Feeding Dairy
Cattle - **H.H. Van Horn**
- 2:00 Methane Emissions From Cattle: Global
Warming and Management Issues -
Donald Johnson
- 2:30 Nutrient Recycling With Ruminant Manure
Application - **Mike Schmitt**
- 3:00 Refreshment Break - Sponsored by NFMA
- 3:20 Fat Feeding to Feedlot Cattle -
Richard Zinn
- 3:50 The Influence of Beef Cattle Genetics on
Feedlot Performance - **Brent Woodward**
- 4:20 Speakers Panel and Discussion
- 5:00 Adjourn
- 5:30 NFMA Social Hour
- 6:30 NFMA Dinner
Speaker - **Sean Salisbury, Quarter Back,
Minnesota Vikings**
Motivation and Overcoming Adversity
Tickets from NFMA @ \$24

WEDNESDAY, SEPTEMBER 23, 1992

A.M. SWINE

- Presiding - **Mike Trotter - Hubbard Milling**
- 8:30 Nutritional Control of Growth - **Mike White**
- 9:00 Feeding for Lean Growth - **Roger Campbell**
- 9:30 Sow Feed Intake Patterns - **Gary Dial**
- 10:00 Speakers Panel and Questions
- 10:30 Refreshment Break
- 10:50 A Practical Evaluation of Starter Diets in
Multi-phase Feeding Programs - **Gerald
Shurson, Jerry Hawton & Lee Johnston**
- 12:00 LUNCHEON: The American Breakfast
Report - **Alta Engstrom, General Mills**

P.M. POULTRY

- Presiding **Paul Waibel, University of
Minnesota**
- 1:30 Digestibility of Starch by Poultry -
Jim McNab
- 2:00 Use of Barley in Turkey Diets - **Peter Ferket**
- 2:30 Vitamin E and Selenium Nutrition -
Gerald Combs
- 3:00 Refreshment Break
- 3:20 Energy and Amino Acid Nutrition -
Jim McNab
- 3:50 Performance of Male Turkeys Fed Canola,
Meat, Poultry By-Product, and Feather
Meals Replacing a Like Quantity of
Bioavailable Protein From Soybean Meal -
Wendell Carlson
- 4:20 Speakers Panel and Discussion
- 5:00 Adjourn

CONFERENCE COMMITTEE

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Darwin Britzman, GTA Feeds
- + Craig Coon, Department of Animal Science
- + Brian Crooker, Department of Animal Science
- + Gary Dial, Department of Animal Science
Larry Dunn, George A. Hormel & Co.
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- * Conference Chairman
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research with an emphasis on turkeys and conducts extension educational programs on poultry nutrition and management. His research is on evaluation of alternative grains for poultry.

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Roger G. Campbell is general manager, R&D and technical services, Bunge Meat Industries, Corowa NSW Australia. He is responsible for nutrition, genetics, veterinary health and R & D for Bunge Meat Industries which owns 40,000 sows. He spent one year with USDA at Beltsville working on growth and development, PST and B Agonists and genotype effects on nutrition. His MS and PhD are in agricultural science from Melbourne University.

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BODY COMPOSITION OF DAIRY CATTLE AND ITS RELATIONSHIP TO BODY CONDITION AND PRODUCTION

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INTRODUCTION

As milk production increases, energy status of the cow and her ability to mobilize body reserves become critical issues for the dairy producer. Producers need to monitor energy status of their cows during lactation to ensure efficient lactational performance. Body condition scoring is one of the simplest techniques of estimating energy status available to the dairy producer. Soon after parturition, body condition and weight of high producing cows rapidly decrease. The mobilized tissue consists primarily of fat but considerable amounts of protein can also be mobilized. A recent study estimated that during early lactation, cows of high genetic merit derived 54% of the carbon in milk fat from body fat reserves and 34% of the carbon in casein and 24% of the carbon in lactose from body protein (Wilson *et al.*, 1988). As dry matter intake increases, loss of condition is reduced and usually begins to increase by day 60 of lactation. Dairy producers should strive to have their cows replenish mobilized tissue by the end of lactation.

Although it is clear that loss of body weight and condition are associated with lactational performance, it is not always clear how these two measurements are related to each other or to body composition. This paper will address effects of body condition, body weight, and body composition on lactational performance, and relationships among these measurements.

TECHNIQUES

Estimates of Body Condition

Body Weight

One of the simplest methods for determining body condition is to weigh the animal. Repeated measurements of body weight on the same animal can indicate to the producer if the animal is mobilizing or replenishing tissue reserves. However, when comparing animals the producer must not assume the heavier cows are in better condition than the lighter cows. Frame size and maturity play important roles in determining body condition. In addition, not all producers have appropriate scales for weighing cattle. For these reasons, systems of scoring body condition have been developed.

Body Condition Score

Scoring systems that are independent of body weight and frame size have been developed to assist the estimation of body condition. Cattle are evaluated by visual and physical appraisal for the amount of flesh in particular areas and ranked (usually from 1 to 5 at quarter point intervals) against a set of standard cows that represent thin (score of 1) to obese (score of 5) cows. One of the most common systems in the midwest is the Wildman system (Wildman *et al.*, 1982). Other scoring systems have been developed and are similar (Edmonson *et al.*, 1989) or differ in the ranking scale (Mulvany, 1977; scale of 0 to 5). Body condition scoring is simpler and generally more useful to the producer than body weight measurements for estimating success of feed management programs. As with body weight, the most value is obtained when individual cows are monitored throughout lactation.

Estimates of Body Composition

Precise estimates of body composition require slaughter of the animals in question. This has serious limitations [primarily expense and limited observations (1!) per animal] and as a result several indirect methods have been developed. These indirect methods have generally been derived by developing regression equations between direct estimates of body composition and some repeatable measurement of the animal.

Comparative Slaughter

One of the early direct techniques compares, as the name implies, the composition of initial and subsequent slaughter groups. The technique assumes that the groups of animals utilized are similar and that the initial slaughter group accurately reflects the initial composition of the subsequent slaughter groups. This allows not only an estimate of the effect of a particular treatment on final composition of the animals but also the amount of change in composition from the start of the trial. Composition can be estimated from linear measurements (fat thickness, loin eye area) and appropriate regression equations or by chemical analyses of dissected fat and lean or of samples obtained from grinding a half or whole carcass. Accuracy of these methods vary, from good (linear measurements) to excellent (entire carcass). Analyses of noncarcass components can be conducted to determine total empty body composition.

Specific Gravity

This technique is based on the assumption that the body consists of fat and fat-free tissue. If these components have different but constant densities, the proportions of each can be determined from the density of the whole body. The assumption that density of fat-free tissue is constant is reasonable for mature animals but is not true for young, growing animals. Difficulties associated with accurate measurement of body volume can contribute a substantial amount of measurement variation (Topel and Kauffman, 1988).

Ultrasound

When high frequency sound is passed through tissues, its reflectance varies according to tissue composition. This variable reflectance can be used to estimate body composition. Estimates of body composition from ultrasound measurements vary depending on the specific location of the point of measurement (Bailey *et al.*, 1986, Bullock *et al.*, 1991). Real-Time ultrasound uses multiple transducers to obtain measurements at several locations and provides more accurate estimates of body composition than single transducer units with very little disturbance to the animal (Topel and Kauffman, 1988). This method can be relatively expensive due to the cost of ultrasound units and the need for trained operators to interpret the results.

Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) uses a magnetic field to obtain images of tissues that can be used to determine body composition. This method can be used to interpret several types of tissue and provides very accurate results. However, trained personnel must be used to evaluate the pictures, the cost of the apparatus is large (Topel and Kauffman, 1988), and machines are not currently available for large animals such as the dairy cow. This technique may become more practical as costs decrease.

Potassium-40 Estimation

Significant amounts of potassium are not found in fat, but are present in lean body mass. Because a small portion of all naturally occurring K is radioactive, the amount of radioactive K contained within an animal can be detected and this measurement can be used to estimate lean body mass. However, a building dedicated to this process and shielded to reduce background radiation is required. In addition, the counter must be routinely calibrated, and a constant distance between subject and detector must be maintained (Belyea *et al.*, 1978).

Dilution Techniques

Dilution techniques rely on the uniform distribution of a marker throughout a body pool. Body water is typically marked because it is the largest body pool and is easily accessible. Samples from the pool are obtained after dosing and concentration of the marker at time zero is determined by curve peeling. Size of the pool is then calculated and body composition determined from previously derived relationships between composition and size of the measured pool.

Deuterium oxide (D₂O) and urea are frequently used to mark the empty body water pool (Bartle *et al.*, 1983; Odwongo *et al.*, 1984). Although this technique can provide accurate estimates of body composition, it is quite labor intensive. In addition, equations developed

for one population of animals do not always accurately predict composition of other populations (Martin and Ehle, 1986; Rule *et al.*, 1986; Brown *et al.*, 1989).

Fat Cell Diameter

Relationships between fat cell size quantity of adipose have been developed from slaughter animals to allow prediction of body composition (Robelin, 1981; Gagliostro and Chilliard, 1991). The technique requires an adipose biopsy but provides considerable promise as an effective indirect estimator of body composition (Waltner *et al.*, 1992).

EFFECT OF BODY CONDITION ON LACTATIONAL PERFORMANCE

Variations in milk production, dry matter intake, and reproductive performance among cows have been attributed to variations in body condition prior to and during lactation. Although current recommendations are to have cows at a body condition score of about 3.5 (in the Wildman scale of 1-5) prior to calving, there are relatively few studies that compare body condition score at calving to milk production. Results from these studies provide conflicting results of whether this is indeed beneficial to productive efficiency. One possible explanation of these results is that body condition scoring can be very subjective. Considerable variation among scorers is highly likely unless they have received similar training with frequent refresher sessions (Edmonson *et al.*, 1989).

In addition, how cows arrived at their condition score prior to calving can influence the effect of condition score on lactational performance. Cows that attain a condition score of 3.5 just prior to calving likely differ considerably from cows that have been maintained at 3.5 since mid-lactation. Cows with more than adequate body condition at the beginning of lactation potentially achieved this through subpar performance during the previous lactation. Cows in less than adequate condition at calving may have had a stellar performance during the previous lactation.

Milk Yield

In one of the earliest studies of body condition and lactational performance, Davenport and Rakes (1969) classified 43 cows as either fat, medium, or thin at 4 days postpartum. By week 12 of lactation, fat cows had lost 20.7 kg body weight, medium condition cows had not lost any weight, and thin cows had gained 38.4 kg body weight. Fat corrected milk (4% FCM) yield of the fat cows was 468 kg greater than that of the thin cows.

Garnsworthy and Topps (1982) utilized 24 cows from calving to 16 weeks postpartum in each of two studies. In the first study, average condition scores (scale of 1 to 4) of thin, medium, and fat cows at calving were 1.75, 2.61, and 3.57, respectively. Body weights of the thin cows declined for 2 weeks with an average loss of 9.1 kg. Medium cows loss an average of 22.3 kg during the 4 week period following calving. Body weight of the fat cows declined for 7 weeks with an average loss of 54.8 kg. Milk yields were similar and peak dry matter intake of thin, medium, and fat cows occurred at 9.2, 12.7, and 14.5 weeks of lactation, respectively.

In their second study, thin, medium, and fat cows had mean condition scores of 1.65, 2.81, and 3.84 at calving and lost 8.6, 29.4, and 70.2 kg of body weight during early lactation

(Garnsworthy and Topps, 1982). Duration of body weight loss was 2, 3, and 5 weeks for thin, medium, and fat-cows, respectively. Condition scores, weight loss, and duration of weight loss were similar to those of cows in the first study. However, in contrast to the first study, milk yield of fat and medium cows was less than that of thin cows (380 and 236 kg, respectively). Peak dry matter intake was again delayed in fat cows compared to medium and thin cows, and occurred at 14.1, 9.6, and 7.9 weeks of lactation, respectively.

In another study with medium and well conditioned cows (1.94 and 3.57 on a scale of 1 to 4), Garnsworthy and Jones (1987) observed that dry matter intake of the medium conditioned cows was greater and weight loss less than that of the well conditioned cows. Milk yield was not affected by body condition in this study.

Grainger *et al.* (1982) evaluated 200 cows with a broad range of condition scores (2.5 to 6.5 on a scale of 1 to 8) and found that cows with more condition at calving lost more weight than under-conditioned cows during the first 5 weeks of lactation. Treacher *et al.* (1986) assigned 18 cows equally between a group that was fed to be thin and a group that was fed to be fat (scores of 2.82 and 3.93 on scale of 0 to 5, respectively). During the first eight weeks of calving, fat cows lost more body weight than thin cows (48 vs. 27 kg). In agreement with the results of Garnsworthy and Topps (1982), fat cows in this study produced 4.4 kg less milk per day than thin cows.

Fronk *et al.* (1980) conducted two identical studies and obtained conflicting results. The first study utilized 10 control cows and 10 over-conditioned cows. The over-conditioned cows lost more body weight by day 56 of lactation than the control cows (77.1 vs. 38.5 kg). In the second study, 22 cows were utilized and no difference between body weight loss of the two groups was detected. Garnsworthy and Huggett (1992) also observed no difference in weight loss of thin and fat cows during early lactation. However, well-conditioned (3.2 on a 4 point scale) cows produced more milk during early lactation than under-conditioned (score of 2.3) cows.

Frood and Croxton (1978) classified 225 dairy cows on a scale of 0 to 5 at parturition. Cows with low scores tended to achieve peak milk later, produce less milk initially, and have greater persistency than cows with high scores at calving. Other studies (Fronk *et al.*, 1980; Boisclair *et al.*, 1986; Garnsworthy and Jones 1987; Jones and Garnsworthy, 1989) have found no relationship between condition score at calving and subsequent milk production.

Reproduction

Reproductive performance of cows can be affected by their body condition at calving. Major changes in body condition during lactation can also affect reproductive performance. Compared to cows of medium condition, cows that were thin or fat experienced first estrus at a later date, had a longer time to first insemination, required more services, and had an increase in days to conception (Garnsworthy and Topps, 1982).

Smith *et al.* (1983) conducted a two year lactation study designed to evaluate effects of body condition at calving on reproductive performance of high producing, mature cows (n=92).

One group of cows was fed to achieve moderate condition at calving while two other groups were fed to be over-conditioned at calving. One of the over-conditioned groups was fed to promote body condition loss during the dry period and the other to maintain condition during the dry period. However, prepartum condition scores were similar between the two over-conditioned groups. Lactational performance did not differ among the three groups. The only observed difference in reproductive performance was a trend for over-conditioned cows to have an increased incidence of cystic ovaries. In a review by Butler and Smith (1989), cows that were over-conditioned at calving were associated with an increased incidence of retained placenta, metritis, and cystic ovaries. In addition, days to first estrus and conception were increased.

EFFECT OF BODY COMPOSITION ON LACTATIONAL PERFORMANCE

Changes in Body Composition During Lactation

Effect of Diet and Milk Yield

Belyea *et al.* (1978) used potassium-40 liquid scintillation detection as a method for determining loss of body composition in lactating dairy cattle. Primiparous and multiparous cows (total n=18) were separated into high and low production groups (7953 and 6784 kg/year). When compared with young cows, a greater amount and proportion of body fat (172 kg, 27.9% vs. 152 kg, 26.5%) and a greater amount but smaller proportion of body protein (102.4, 16.8% vs. 97.4 kg, 17.1%) was present in mature cows. No differences between high and low producers were detected. Effects of lactation on loss of body mass were averaged for all cows. At parturition, average fat and protein contents of the cows were 194.3 and 108.8 kg, respectively. Body weight loss occurred during the first 6 weeks of lactation and amounted to 58.4 kg body fat and 15.9 kg of body protein (Table 1). After week 6, body weight increased and by week 28 of lactation, mobilized fat and protein mass had been replenished.

Chilliard *et al.* (1984) used the deuterium oxide dilution technique to determine effects of feeding and milk yield on body lipid content of 12 Holstein x Friesian cows. Cows were assigned to one of three groups. One group was fed ad libitum and intake of the other two groups was restricted to 75% of their predicted intake. The restricted intake cows were further separated by low and high milk yield. The high producing, restricted intake group averaged 33 kg 4% FCM/day during the first 5-8 weeks of their previous lactation compared to 28.5 kg 4% FCM/day for the other two groups. Cows fed ad libitum mobilized 17 kg (20%) of their body fat during the first 8 weeks of lactation. The high-producing, restricted intake group mobilized 39 kg (43%) of their body fat, and the other restricted fed group mobilized 29 kg (36%) of their body fat.

Martin and Ehle (1986) used deuterium oxide dilution to determine loss of body fat of 36 lactating Holstein dairy cows at 2 to 4 weeks prepartum (initial fat determination included gravid uterus) and at 4, 8, 12, 16, and 20 weeks postpartum. Cows lost approximately 50 kg (41%) of body fat during the first 8 weeks of lactation. Replenishment of body fat began between weeks 8 and 12 of lactation but was not complete by week 20. Milk production data

were not reported.

Wilson *et al.* (1988) utilized the principle that products produced by an animal reflect the carbon-13:carbon-12 ratio of the diet consumed to determine the proportions of body tissue and dietary carbon used to synthesis milk. They first feed cows a standard diet with a known C13:C12 ratio and then switched the cows to a diet with a different C13:C12 ratio and monitored change in the C13:C12 ratio of milk components. During early lactation, cows (n=2) of high genetic merit (breeding index 127) utilized body fat to provide 54% of the carbon in milk fat and body protein to provide 34% of the carbon in casein and 24% of the carbon in lactose. In contrast, 43% of the carbon in milk fat was derived from body fat and 25% of the carbon in casein and 11% of the carbon in lactose was derived from body protein of cows of low genetic merit (breeding index 106) during early lactation.

Gagliostro and Chilliard (1991) conducted a study with 12 Holstein Friesian cows to evaluate effects of duodenal infusion of rapeseed oil. Fat cell diameter was used to estimate changes in body fat. During the first 3 weeks of lactation, cows produced approximately 30 kg milk/day and lost an average of 29.5 kg body fat.

Chilliard *et al.* (1991) fed 24 cows rations that provided either 4.2 Mcal/d less or 2.5 Mcal/d more of NEI than the cows required. Body fat and protein content of these cows were determined by the deuterium oxide dilution technique. During the first eight weeks of lactation, cows fed sufficient energy produced 29.6 kg milk/d and lost 25.5 kg of body fat and 3.3 kg of body protein while cows consuming less dietary energy produced 29.8 kg milk/day and lost 34.7 kg of body fat and .5 kg of body protein.

Effect of Bovine Somatotropin

Brown *et al.* (1989) used deuterium oxide dilution technique to determine effects of administration of bovine somatotropin on body composition of cows from week 11 through week 18 of lactation. In addition, all cattle were slaughtered at week 18 and body composition determined by chemical analyses. Cattle (n=10) treated with bST produced more milk than controls (34.3 vs. 30.2 kg/d) during the 8 week study. Estimates of body fat at the end of study for control vs. bST treated animals were 54.6 vs. 26.6 kg by direct analyses and 45.7 vs. 28.3 kg by dilution estimate (Table 2). Estimates of body protein at the end of study were 87.0 vs. 84.7 kg by direct analyses and 84.8 vs. 86.0 kg by dilution estimate (Table 3).

Soderholm *et al.* (1988) treated twenty-eight cows with either 0, 10.3, 20.6, or 41.2 mg bST/day. Treatments began during week 4 to 5 of lactation and lasted for 38 weeks. Body composition was estimated at treatment initiation, 12, 24, and 36 weeks thereafter using deuterium oxide dilution. Cows on 0, 10.3, 20.6, and 41.2 produced 29.9, 33.4, 37.5, and 36.9 kg 3.5% FCM/day, respectively. All cows were fed the same high production diet throughout lactation. Although no differences were observed, cows on the two high doses of bST appeared to lose body fat throughout lactation while control and low dose cows apparently began to replenish fat by week 24 of lactation.

In a study described in the previous section (Chilliard *et al.*, 1991), half of the cows in each energy treatment group received biweekly injections of 500 mg bST in a slow release product from week 8 of lactation through the end of the study (week 39). Cows were fed indoors until week 21 of lactation and were allowed to graze from week 21 through week 39 of lactation. Yield of milk was not affected by energy treatment. Cows treated with bST produced more milk (26.3, 29.2 kg/day) during weeks 8 to 21 of lactation but amounts of body fat loss (9.2, 21.1 kg) and protein gain (3.7, 2.2 kg) were not different between control and bST treated cows, respectively. Milk yield by control and bST treated cows was similar (18.3, 19.8 kg/day) during weeks 21 to 39 of lactation. Amounts of fat (23.7, 10.3 kg) and protein (.5, 6.25 kg) gain were also not affected by bST treatment during this period. However, these trends for bST treated cows to mobilize more fat (-14.5, 8.9 kg) and deposit more protein (4.3, 9.2 kg) were significant when summarized over the entire bST treatment period.

Estimates of Energy Contained in Body Weight

Bath *et al.* (1965) used a specific gravity method to determine the caloric value of body weight loss in lactating dairy cows. Primiparous (n=17) cows were fed ad libitum for six weeks postpartum. Six cows were slaughtered at week 6 of lactation. Intake of the remaining cows was restricted to 65% of requirement and they were slaughtered either 49 or 105 days later. The mean caloric value of body weight loss during these two periods was calculated to be 4.73 and 4.99 Mcal/kg, respectively. Reid and Robb (1971) reported an error in the equations utilized by Bath *et al.*, (1965) and recalculated the caloric value estimates as 6.30 Mcal/kg (Table 4) for the period ending after 49 days and 6.85 Mcal/kg for the period ending after 105 days of restricted feeding.

The National Research Council (1989) estimates the energy value of body weight loss as 4.92 Mcal NE₁/kg and body weight gain as 5.12 Mcal NE₁/kg (Moe and Tyrrell, 1974). Williams *et al.* (1989) proposed that energy values of tissues are a function of age and weight within age. They transformed Agricultural Research Council (1980) equations to estimate the energy value of 1 kg of body weight for dairy cows of various weights. The estimates for cows of 550, 600, and 650 kg were 5.65, 6.00 and 6.35 Mcal/kg, respectively. Based on these values, their estimates of fat and protein deposition by cows of various weights did not agree with literature values. Correction factors were developed and energy values of tissue deposited by cows weighing 550, 600, and 650 kg were calculated as 7.29, 7.79, and 8.29 Mcal/kg, respectively.

Chilliard *et al.* (1991) reported that 1 kg of body weight change corresponded to a change of 5.9 Mcal NE₁ in body energy during the first seven weeks of lactation, and a change of 5.5 Mcal NE₁ between weeks 20 and 39 of lactation.

RELATIONSHIP BETWEEN CONDITION SCORES AND BODY COMPOSITION

Chilliard *et al.* (1991) calculated that a change in body condition score of 1 unit (scale 0 to 5) from week 1 to 7 of lactation amounted to 44.4 kg of live body weight (corrected for gut fill). This body weight loss contained 29.2 kg fat and 3.9 kg protein. During weeks 20 to 39

of lactation when cows were depositing both fat and protein, a condition score change amounted to 35.2, 20.6, and 2.3 kg of corrected body weight, body fat, and body protein, respectively. At each stage of lactation, fat represented about 89% of the sum of fat and protein loss or gain and represented 66 and 59% of corrected body weight loss during the first 7 weeks of lactation and during weeks 20 to 39, respectively. These results indicate that composition of tissue mobilized in early lactation and of tissue deposited in late lactation is relatively similar.

Ferguson and Otto (1989) compared 9th to 11th rib sections from non-lactating Holstein cows to determine the relationship between body condition score and body composition. They determined a 1 unit change in body condition score (scale 1 to 5) amounted to a 56 kg change in body weight or a 47.6 kg change in body weight corrected for gut fill. Crude protein content of the deboned tissue decreased 12.2% and ether extract content increased 12.65% as body condition score increased 1 unit. Therefore, fat was a major component of the tissue associated with a unit increase in body condition score. Fox *et al.* (1988) also demonstrated that fat content of tissue gain per unit of condition score increased as relative condition score of beef cattle increased.

Ferguson and Otto (1989) also evaluated 40 lactating dairy cows during the first 21 weeks of lactation and found 32 kg of live weight corresponded to a unit of condition score change. However, they concluded that individual cow variation was too great to make this a useful estimate. This value does however correspond well to the value of 35.2 kg BW per unit of condition score determined by Chilliard *et al.* (1991).

In a review of the literature, Garnsworthy (1988) reported one unit of condition score (scale of 1 to 4) change in lactating cows was equivalent to 15 to 40 kg (mean of 25 kg) of live weight change. Not included in Garnsworthy's review was a study by Wright and Russel (1984) with non-lactating Friesian cows. In this study, a unit change in body condition score (scale 0-5) resulted in an extremely large change (110 kg) in body weight. Composition of this change was 84 kg of body fat and 7.35 kg of body protein.

SUMMARY

Reports of the effects of body condition score at calving on lactational performance have varied. In general, it appears that as condition score at calving increases, body weight loss during early lactation increases and peak dry matter intake is delayed. Fat cows tend to meet early lactation energy requirements more through tissue mobilization than through increased dry matter consumption. This appears to have little effect on overall milk production provided the fat cow avoids metabolic disorders and the thin cow does not deplete her body reserves. However, fat cows may have more reproductive problems compared to thin or moderate cows.

During early lactation, most cows lose about 33% of their body fat reserves and between 5 to 15% of total body protein. Although limited research has been conducted on the effect of bST, it appears that bST causes cows to lose fat for a longer period during lactation, and protein deposition appears to increase.

One unit of body condition score change is roughly equivalent to 40 kg of body weight, but depending on the initial score and the direction of change, the composition of the associated body weight may be markedly different. Proportion of fat in this tissue tends to increase at higher condition scores, and decrease at lower condition scores. An understanding of how these measurements relate to each other, and to lactational performance is useful in understanding how dairy producers may achieve maximum profits and productivity.

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Table 1. Change in total body fat and protein of Holstein cows during lactation.

Week of lactation	Fat change		Protein change	
	kg	%	kg	%
<i>Belyea et al. (1978)</i> ¹				
2	-48.4	-24.9	-14.9	-13.7
4	-47.9	-24.7	-14.4	-13.2
6	-58.4	-30.1	-15.9	-14.6
8	-57.7	-29.7	-15.0	-13.8
28 ^a	-29.9	-15.4	-9.8	-9.0
36	-13.8	-07.1	-7.9	-7.3
<i>Martin and Ehle (1986)</i> ²				
4	-34.3	-27.8	--	--
8	-49.8	-40.5	+2.1	+2.9
12	-34.0	-27.6	+1.0	+1.4
16	-29.4	-23.9	+1.0	+1.4
20	-26.7	-21.7	+2.8	+3.9
<i>Chilliard et al. (1984)</i> ³				
8	-17.0	-19.8		
18	+11.0	+12.8		
<i>Gagliostro and Chilliard (1991)</i> ⁴				
3	-29.5	-23.4		
<i>Chilliard et al. (1991)</i> ⁵				
Diet A	-25.5		-3.3	
Diet B	-34.7		-0.5	

¹ Average milk production of approximately 7300 kg/yr. Body fat and protein content at parturition were 194.3 and 108.8 kg respectively.

² No milk production data was reported for these cows. Body fat content 2-4 weeks prior to parturition was 123.0. Body protein content at week 4 was 71.8 kg. Protein changes are relative to week 4.

³ Average production was 28.5 kg 4% FCM/day during first 5-8 weeks of previous lactation. No initial body fat or protein contents were given.

⁴ Cows produced approximately 30 kg milk/day during this period. Body fat content during the first 3 weeks of lactation was 126 kg. Body protein was not determined.

⁵ Cows produced approximately 30 kg milk/day during this period. Initial body fat and protein were 100 and 87 kg respectively. Diet A provided more NEI (2.5 Mcal/d) than required; Diet B provided less NEI (4.2 Mcal/d) than required.

^a Week 28 measurements of body fat were similar to those observed at 6 weeks prepartum.

Table 2. Effect of bovine somatotropin (bST) on total body fat of Holstein cows during lactation.

Week of treatment	mg bST/day			
	0	10.3	20.6	41.2 ^{1,2}
	----- kg -----			
	Brown <i>et al.</i> (1989) ³			
10, total direct	54.6 ^a			26.6 ^b
10, total indirect	45.7 ^a			28.3 ^b
	Soderholm, <i>et al.</i> (1989) ⁴			
1, total	160.8	149.8	151.4	138.7
12, change from week 1	-30.5	-35.9	-28.8	-33.6
24, change from week 1	+ 6.2	- 3.4	-41.2	-19.6
36, change from week 1	+27.0	+11.0	-42.0	-23.5
	Chilliard <i>et al.</i> (1991) ⁵			
1-13, change during period	- 9.2			-21.1
13-31, change during period	+23.7			+10.3
1-31, change during period ⁶	+14.5 ^c			- 8.9 ^d

¹ 40 mg/day for Brown *et al.*, 1989.

² 500 mg/biweekly (35.7 mg/d) for Chilliard *et al.*, 1991.

³ Week 18 of lactation, after 8 weeks of treatment.

⁴ Treatment was initiated during week 4 to 5 of lactation.

⁵ Treatment was initiated after week 8.

⁶ Individual periods do not add up to total period because a cow was lost from treatment during second period and was not included in total period.

^{a,b} Values in same row differ, $P < .01$.

^{c,d} Values in same row differ, $P < .10$.

Table 3. Effect of bovine somatotropin (bST) on total body protein of Holstein cows during lactation.

Week of lactation	mg bST/day			
	0	10.3	20.6	41.2 ^{1,2}
----- kg -----				
Brown <i>et al.</i> (1989) ³				
18, total direct	87.0			84.7
18, total indirect	84.8			86.0
Soderholm, <i>et al.</i> (1989) ⁴				
1, total	70.9	71.8	76.6	71.9
12, change from week 1	+10.7	+ 9.9	+ 9.3	+11.2
24, change from week 1	+10.3	+ 8.5	+14.9	+12.7
36, change from week 1	+15.2	+ 9.5	+23.1	+13.0
Chilliard <i>et al.</i> (1991) ⁵				
1-13, change during period	+ 3.7			+ 2.25
13-21, change during period	+ 0.5			+ 6.25
1-31, change during period ⁶	+ 4.3 ^a			+ 9.2 ^b

¹ 40 mg/day for Brown *et al.*, 1989.

² 500 mg/biweekly (35.7 mg/d) for Chilliard *et al.*, 1991.

³ Week 18 of lactation, after 8 weeks of treatment.

⁴ Treatment was initiated during week 4 to 5 of lactation.

⁵ Treatment was initiated after week 8.

⁶ Individual periods do not add up to total because a cow was lost from treatment during second period and was not included in total period.

^{a,b} Values in same row differ, $P < .01$.

Table 4. Estimated energy content per kg of tissue loss and gain.

Weight (kg)	Tissue energy (Mcal/kg)	NE ₁ loss (Mcal/kg) ¹	NE ₁ gain (Mcal/kg) ²
Bath <i>et al.</i> (1965) as modified by Reid and Robb (1978)			
455.5	6.30	5.20	5.42
437.4	6.85	5.66	5.89
ARC (1980) as determined by Williams <i>et al.</i> (1989)			
450	4.92	4.06	4.23
500	5.29	4.37	4.55
550	5.65	4.67	4.86
600	6.00	4.96	5.16
650	6.35	5.25	5.46
700	6.70	5.53	5.76
750	7.04	5.82	6.05
Williams <i>et al.</i> (1989)			
450	6.25	5.16	5.38
500	6.77	5.59	5.82
550	7.29	6.02	6.27
600	7.79	6.44	6.70
650	8.29	6.85	7.13
700	8.78	7.25	7.55
750	9.26	7.65	7.96
NRC (1989)			
N/A ^a	6.0	4.92	5.12

¹ Mcal x .826.

² Mcal x .86.

^a Not applicable because NRC values do not consider body weight.

NEW INFORMATION CONCERNING PASSIVE IMMUNITY IN YOUNG CALVES

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INTRODUCTION

The neonatal bovine is almost completely dependent on passively acquiring immunoglobulins (antibodies) through the dam's colostrum. In utero transfer of maternal antibodies is, for practical purposes, insignificant. This high dependency on colostrum antibodies to protect against ensuing diseases provides special challenges in that colostrum must be of adequate "quality" and consumption must occur within 24 hours after birth. Given that suckling is successful, the neonate will be only protected against those diseases which the dam has "recognized" and developed antibodies against. The degree with which maternal antibodies are developed by the dam are dependent on many factors such as antigen (i.e., disease, vaccine) type, antigen load (challenge strength) and timing of the disease or vaccine challenge. There are also many other factors that relate to the dam's individual immunological capabilities.

In general, the neonatal bovine will not have its own immunological capability until 4 weeks of age or older. This fact, along with the precarious nature of maternally-provided passive immunity, provides an opportunity for scientific intervention. This paper will discuss recent information concerning the use of exogenous immunoglobulins and their usefulness as a preventative tool in the case of the bovine neonate.

FAILURE OF PASSIVE TRANSFER STUDIES

Failure of passive transfer of maternal antibodies increases the risk of disease in the young calf (1). Because of the variable nature of colostrum quality, the potential for colostrum management "miscues" and individual calf differences; there remains an opportunity to improve the colostrum status of each newborn calf. In an effort to address this issue, commercial colostrum additive products have been developed. One such product is a whey-deprived product (Colostrx). Recently a colostrum-based product (First Milk) was also cleared by the USDA. These two products were compared in a controlled study. In this study, 30 calves were fed the colostrum based supplement, the whey-based supplement or no supplement (control). Serum IgG levels (mg/ml) were tested at 0 through 168 hours (table 1). Control calf serum IgG levels did not rise above 0-hour values. Both colostrum supplements increased serum IgG levels at 24 hours and beyond. However, calves receiving the colostrum based supplement elevated serum values by nearly 2 times those levels observed for the calves fed the whey based supplement. Given that IgG dosage of each product were similar (20.6 and 25 g/dose for the whey and colostrum product, respectively), it is apparent that bovine colostrum is a more efficacious product. Apparently, whey derived immunoglobulins (in current commercial form) are not absorbed to the expected level.

SPECIFIC DISEASE ANTIBODY STUDIES: PRE GUT CLOSURE

Figure 2 demonstrates at what point in time the three major enteric diseases of the neonatal calf are important. *E. coli* is a prominent disease very early in life, while the enteric viruses affect the young calf in the latter days.

A study was designed to determine the effect of bovine immunoglobulins, from an immunized cow source, on *E. coli* infection in newborn calves (2). All new born calves were challenged with K99 *E. coli*. Treated newborn calves received (within first 6 hours) processed immunoglobulins with high anti *E. coli* specific activity (bovine immunoglobulin concentrate; BIC). Calves not receiving BIC served as controls (CON). Table 2 shows that BIC significantly reduced calf death loss and *E. coli* shedding. When serum levels were measured for anti-K99 activity in BIC-treated calves, it was evident that there was substantial absorption of antibody in *E. coli* within 48 hours (Table 3).

Another study was conducted using a similar protocol as in the previous BIC study. In this study the effect of bic was compared to that of an anti-*E. coli* preparation from a monoclonal antibody source. Figure 2 showed the reaffirmed efficacy of BIC, but also a trend towards improved efficacy of BIC over the monoclonal antibody. Figure 3 indicates that BIC reduces fecal shedding to a greater extent than do the monoclonal.

SPECIFIC DISEASE ANTIBODY STUDIES: POST GUT CLOSURE

Given the success of BIC in pre-gut closure studies, it was postulated that immunoglobulins with high specific activity against specific diseases might be promising in the post-gut closure calf model. Therefore, a study was designed to determine the effect of BIC (immunoglobulins with high anti-*E. coli* activity) on calf health. In this study, calves 3 to 4 days of age were challenged with K99 *E. coli*. A control group, receiving just milk replacer, was compared with groups fed milk replacer containing BIC at 4 levels (16X, 4X, X and .4X; X being a target dose), a group fed medicated milk replacer (neomycin and oxytetracycline) and a group fed medicated milk replacer and a 16X BIC dose. No specific pattern of death loss could be related to treatments. This was the case even though fecal *E. coli* shedding was reduced ($P < .05$). It may be concluded that although the infection of *E. coli* may have been reduced, there are other factors contributing to calf death loss. One of the factors that did appear to contribute is the presence of rotavirus. Rotavirus shedding was occurring in about 80% of the calves, across treatments. When rotavirus shedding and death loss was measured over time across treatments (Figure 4), it was apparent that the majority of the death loss occurred after the peak rotavirus infection. One can therefore conclude that preventing rotavirus infection may be more of value than preventing *E. coli* infection in calves over 3 days of age.

There is good evidence that a passive immunity scheme using exogenous immunoglobulins can be effective in reducing rotavirus infection (3,4). Therefore, further studies were conducted in order to determine if rotavirus infection could be prevented in the 3 day old calf challenged with rotavirus. The first two studies compared calves receiving milk replacers containing rotavirus-specific BIC and non-specific (low rotavirus titer) BIC to calves fed milk

replacers without the additives. Rotavirus-specific BIC reduced fecal rotavirus shedding which would be highly indicative of disease reduction. Figure 5 shows the results of a third study in which rotavirus specific BIC was dose titrated in milk replacers fed to rotavirus challenged calves. High doses of the anti-rotavirus preparation reduced fecal rotavirus shedding to the point where shedding was not significantly greater than that seen for unchallenged controls. Fecal dry matters were also reduced ($P < .05$) as the dose of anti-rotavirus BIC was increased.

It is apparent that the use of exogenous immunoglobulins holds great promise for disease prevention. It is believed that new benefits may be derived through the continuance of the research with exogenous immunoglobulins.

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TABLE 1. Absorption of IgG from colostrum or whey-based colostrum additives fed to newborn calves

Hours	Control	Colostrum-Based	Whey-Based
	Serum IgG (mg/ml)		
0	.42 ^a	.35 ^a	.20 ^a
24	.44 ^c	2.02 ^a	1.14 ^b
48	.45 ^c	1.95 ^a	.90 ^b
72	.49 ^b	1.89 ^a	.80 ^b
168	.41 ^c	1.81 ^a	.80 ^b

a, b, c Means tended to be different (P<.10).

TABLE 2. Influence of BIC on calf death loss and E. coli shedding during the first 4 days after birth.

	CON	BIC
Percent Calf-Days Shedding K99 Antigen	86%	27%
Shedding Index ^a	3.6	1.3
No. Calves Dies/No. on Treatment ^a	7/10	2/20

^a Treatment differences (P<.05).

TABLE 3. Absorption of E. coli antibody in calves when calves received BIC.

	CON	BIC
Bovine IgG, mg/ml Serum		
0 hours	.178	.137
48 hours	1.096	1.100
Anti-K99 Activity, OD		
0 hours	.005	.081
48 hours	.011	1.076

FIGURE 1. No. of cases of calf enteric diseases over time (S. Dakota State Univ. Diagnostic Lab; adapted; unpublished).

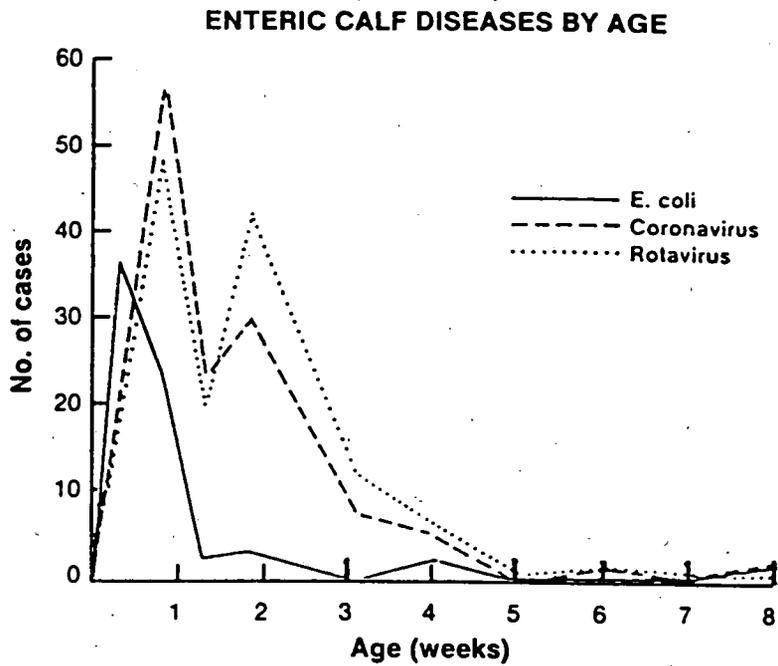


FIGURE 2. Influence of BIC on calf death loss in first 4 days after birth.

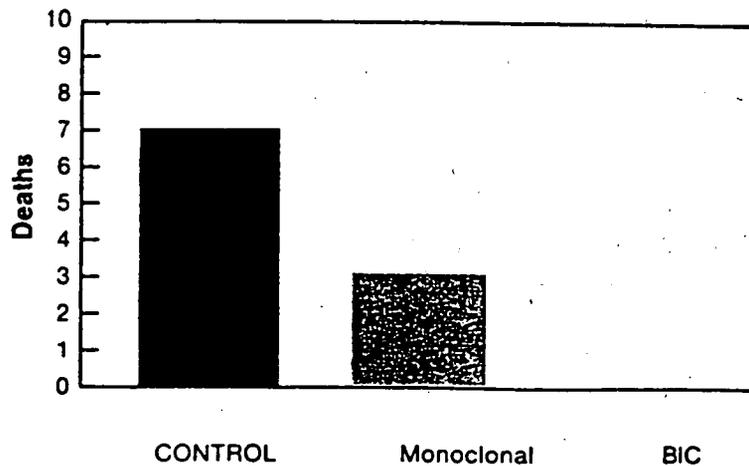


FIGURE 3. Influence of BIC and a monoclonal antibody on K99 *E. coli* fecal shedding.

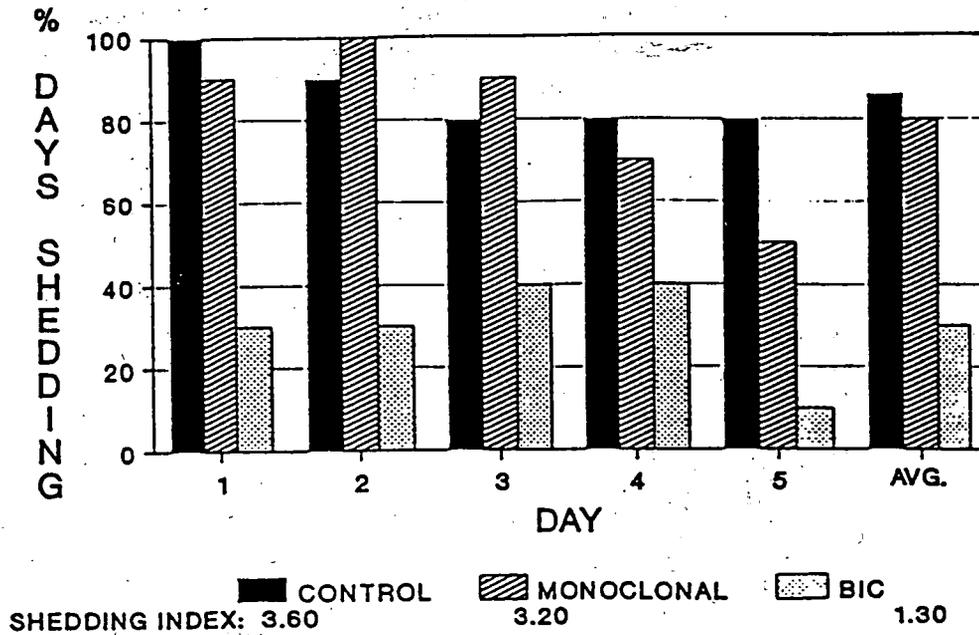


FIGURE 4. Pattern of rotavirus shedding and calf death loss over time.

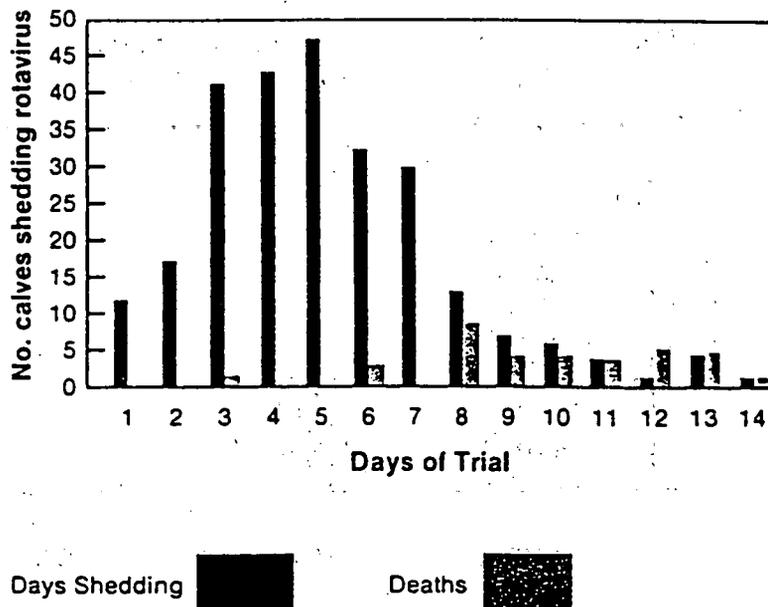
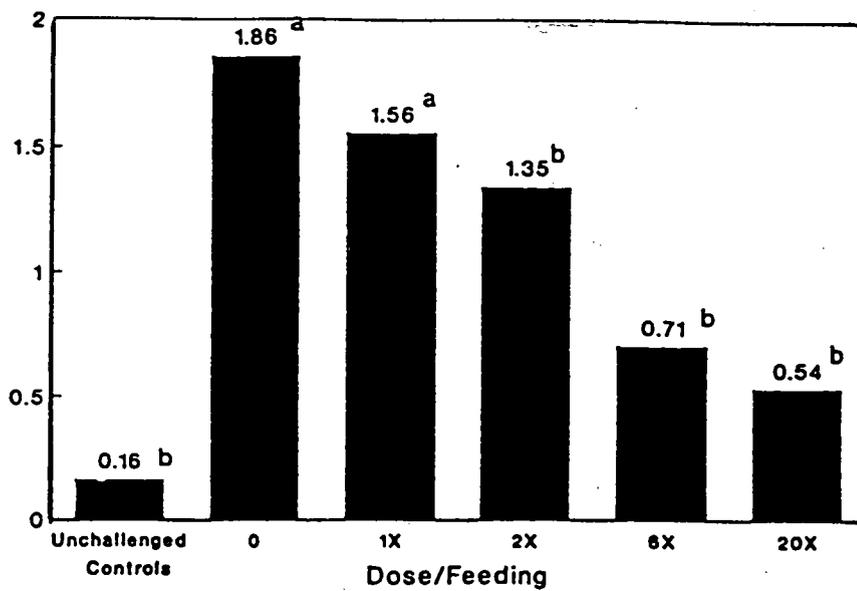


FIGURE 5. Rotavirus Shedding Index Score



GENE RECONSTRUCTION AS A MEANS OF CREATING AN ACID-RESISTANT CELLULOLYTIC RUMINAL BACTERIUM

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INTRODUCTION

The interaction between rumen microorganisms and the ruminant animal is an example of symbiosis. The animal provides a suitable environment for the growth of microorganisms, and the microorganisms supply the animal with short-chain volatile fatty acids and microbial protein. This symbiotic relationship is particularly strong when the diet contains large amounts of cellulose because mammalian enzymes are unable to digest this type of carbohydrate. During rumen fermentation, methane, heat and ammonia are also evolved and these products unfortunately represent a loss of either energy or nitrogen to the animal. Successful attempts at modifying the rumen ecosystem must enhance the beneficial aspects of ruminal fermentation while minimizing the fermentation losses (Russell and Hespell, 1981).

An ideal rumen fermentation would be one that: 1) promotes rapid rates of fiber digestion, 2) provides rapid and efficient production of microbial protein, 3) minimizes the production of methane gas, 4) has slow rates of protein fermentation and only minimal accumulation of ammonia, 5) produces an acetate to propionate ratio that is ideal for tissue metabolism, and 6) protects the animal from toxic substances. This idealistic representation is confounded by: 1) the number of species involved in the fermentation process, 2) the interactions among these species, 3) the fact that indigenous flora is already very well adapted to the ruminal environment and thus is not easily changed.

GENETIC MODIFICATIONS

Recent progress in recombinant DNA technology has made it possible to "genetically engineer" bacteria which are capable of performing new and sometimes amazing functions, and people have asked if these techniques can be used to improve the rumen microflora. Rumen microbiologists are just beginning to apply these techniques (Smith and Hespell, 1983; Teather et al., 1984; Teather, 1985; Forsberg et al., 1986; Howard and White, 1988; Ohmiya et al., 1988; Gong et al., 1989; Woods et al., 1989), but progress may be rapid in the next few years. Since the application of these methods is now likely, we should begin to carefully consider both the potentials and limitations of this technology in the manipulation of the rumen microbial ecosystem.

The genetic engineering of non-ruminal bacteria like *E. coli* has already given us useful products which include human insulin and bovine growth hormone, and these successes have spurred a great amount of optimism about further applications, particularly in agriculture. While the scientific pessimist has usually been proved wrong, we feel that the "can do anything" attitude of some genetic engineering proponents should be tempered by a realistic appraisal of the biological constraints. The major genetic engineering accomplishments have been associated with industrial microbiology. These DNA recombinants have for the most part been grown in carefully controlled stainless steel vats with antibiotics as selective agents.

Recombinant organisms have fared well in industrial environments, but life in the "real world" may not be so hospitable. In natural environments like the rumen, energy sources are usually limiting and competition is very intense. Factors like substrate affinity, maintenance energy expenditures, resistance to toxic substances, attachment to solid surfaces, and the ability to tolerate periods of nutrient starvation can be of critical importance to survival (Russell, 1984). These physiological factors are of little significance in industrial fermentation where the energy source is provided in excess and potential competitors are excluded.

Since *E. coli* has been the focus of genetic engineering, one might envision the use of this species in the rumen, but enumeration studies have shown that non-rumen bacteria do not compete well in the rumen microbial ecosystem. Based on these observations, it is unlikely that genetically engineered forms of non-rumen bacteria would be able to maintain themselves in the rumen. Successful attempts at genetic engineering will probably involve subtle changes of existing rumen microorganisms. Since the microflora is already very well adapted to the rumen, improvements are not immediately obvious. Many practical problems (e.g. lactic acidosis, deamination, etc.) might be better served by genetic engineering approaches that delete, rather than add genes. The difficulty with this approach is that a highly selective means of preventing wild types from re-colonizing the rumen would be needed.

Modern feeding practices have imposed new stresses on the rumen (lower pH, detoxification, resistance to poisonous materials, the digestion of novel feed materials, etc.), and it is possible that genetic engineering may provide a means of alleviating some of these problems. Some people have indicated that genetic engineering might be used to increase the rate of cellulose digestion or change the amino acid composition of the microflora, but such changes may be restricted by the pressures of microbial growth efficiency. Genetic engineering represents a new and powerful tool to manipulate the rumen, but it is not immune to the constraints of rumen microbial competition.

GENETIC ENGINEERING

Techniques

Despite the sometimes complex jargon, the basic concept of genetic engineering is rather simple (Drlica, 1984). The first step is to break open the cells of an organism which has a desired function and isolate the DNA, which contains the information determining the function. Next the DNA is cut into smaller pieces with commercial enzymes (restriction endonucleases) that act at specific sites and the fragments are spliced into specific vectors that can be used to translocate DNA. These cloning vectors are either small plasmids or viruses that are capable of being transcribed and replicated, and their transfer into a cell can occur via three types of mechanisms, transformation, conjugation, or transduction.

Some bacteria are able to take up free DNA through their cell walls via a process known as transformation (Hotchkiss and Gabor, 1970). This mechanism of gene transfer was first studied by Griffith in the 1920's and he showed that dead (lysing) cells of a virulent strain of *Diplococcus pneumoniae* (characterized by smooth colonies) were able to transfer the virulence factor to previously avirulent (rough) strains. While transformation works exceedingly well in enteric bacteria and bacilli, some bacteria including intestinal bacteroides are not easily transformed. In the rumen, bacteria are almost always limited by the availability of carbohydrate and they rapidly degrade nucleic acids to get the sugar that is present in the molecule. Since ruminal fluid contains extremely high extracellular nuclease activity, it is unlikely that the process of transformation would occur in the rumen under natural conditions. Smith et al, developed a transformation procedure for *Bacteroides fragilis*, but it is not known whether similar procedures will work in ruminal bacteria (Smith, 1985). The uptake of DNA can be facilitated by a procedure known as

electroporation. Cells are subjected to a high voltage for a short period of time and the electric current creates pores in the cell membrane. There have been several recent reports that electroporation can be used in ruminal bacteria (Liss et al., 1989; Thomson and Flint, 1989).

Conjugation entails the close physical contact of two bacteria (sometimes via sex pili) and a plasmid mediated transfer of DNA from the plasmid-containing, "male" bacterium to the plasmid-lacking, "female" bacterium (Lederberg et al., 1951). In E. coli every female bacterium is converted to a male bacterium by conjugation, but the inheritance of the fertility factor, F, is not as well understood in other bacteria (Curtiss, 1969). However, since ruminal bacteria are known to carry antibiotic resistance plasmids, conjugation may be a workable system for moving genetic elements between rumen bacteria. Conjugation systems have been developed for colonic bacteroides (Shoemaker et al., 1985; Salyers et al., 1987), and it appears that these systems can be used to transfer genes into the ruminal bacterium, Bacteroides ruminicola (Shoemaker et al. 1991, Shoemaker et al. 1992).

Viruses (phage) can infect specific species of bacteria and infection entails the transfer of the viral genome to the host. The process of transduction was first studied by Lederberg and his colleagues and they showed that small pieces of non viral DNA could also be incorporated into phage particles (Lederberg, 1956). Some of the recipient cells survived the infection and these survivors contained genetic material that was derived from cells in which the virus had originally grown. Nowadays it is possible to purchase modified lambda phage and ligate pieces of DNA into them. Lambda phage readily infect sensitive strains of E. coli. Some phage have been isolated against rumen bacteria (Tarakanov, 1971; Orpin and Munn, 1973; Tadesc and Yokoyama, 1989), but transduction at the present time only represents a potential means of transferring genes into rumen bacteria.

Transduction into E. coli, however, is an effective method of screening and amplifying specific genes. Pieces of DNA that are produced by the restriction enzymes (described above) can be ligated into lambda phage DNA and the phage can be used to infect E. coli. Since each lambda phage only carries a fixed amount of additional DNA and since lambda phage produce a repressor that protects the bacterial cell from infection by other lambda phage, each bacterium will usually only receive one piece of foreign DNA. Once inside the cell, the lambda phage can kill the cell or be replicated along with the rest of the bacterial chromosome. When the phage initiates the lytic phase of the infection, the bacterium makes many phage particles, the bacterial cells lyse, and the gene is amplified. These lytic infections can be easily recognized as plaques (clear zones) on agar plates covered with bacteria.

Because each cell contains thousands of different genes, finding one gene is a bit like looking for "a needle in a haystack" (Drlica, 1984). Identification is greatly facilitated by radioactive probes that are complimentary to the desired gene. Since the probe is radioactive and will not bind to other fragments of single stranded DNA, the specific gene can be recognized on X-ray film. Probes can be synthesized if you know a sequence of at least 5 amino acids in the gene product. More than 5 amino acids are needed if leucine, serine or arginine are present because these amino acids each have six different codons. The code is less degenerate for other amino acids. Phage particles within each plaque are then screened to identify the phage that contains the desired gene. Since the procedure is very sensitive and relatively straightforward, literally thousands of plaques can be tested for the desired piece of DNA (Maniatis et al., 1982; Dillon et al., 1985).

Survival

Microorganisms in general are very efficient organisms and rarely, if ever, produce material that does not increase their chances of survival. The elegance of this survival strategy is exemplified by the diversity of mechanisms (induction, repression, catabolite repression, and phosphotransferase system repression) that E. coli uses to regulate lactose utilization and the transcription of the lactose operon (Saier, 1977). Organisms that over produce unneeded proteins are at a disadvantage in much the same way as corporations that divert capital away from production and toward frivolous corporate luxuries. The only difference is that nature makes much faster decisions regarding fitness and never provides exclusive subsidies.

Most genetic engineering problems involve the positioning of a gene on plasmid DNA, and it is well documented that plasmids can be lost if plasmid transcription provides no added benefit to the organism. Antibiotic resistance genes are often added to the plasmid to increase its stability. If the genetically engineered strain is grown in the presence of antibiotic, it is generally accepted that only those individuals retaining the plasmid will survive. Although antibiotic resistance is caused by the transcription and translation of resistance factor genes, the cost of this additional protein synthesis has received little attention.

Antibiotics are often used as a means for selecting recombinant organisms in commercial fermentation systems, but this type of strategy may be less effective in natural environments. Pigs and chickens are routinely fed antibiotics, but the amount is usually very low (approximately 10 ppm) (Visek, 1978). When Ahart et al. fed calves tetracycline as a feed additive, greater than 80% of the coliforms were resistant to tetracycline, but less than 50% of the strict anaerobes were resistant (Ahart et al., 1978). The persistence of sensitive forms in the presence of antibiotic was also noted by Rollins et al, and they reported that more than 2 ppm antibiotic in the diet was necessary to cause a detectable increase in resistant forms (Rollins et al., 1975). These observations indicate that the levels of antibiotics (e.g. only 10 ppm) needed to give animal growth promotion might not insure the survival of organisms carrying genetically engineered plasmids. Stability might be increased, if recombinant genes were incorporated into the chromosome.

Regulation

Even after the genes are transferred into the recipient organism, there is no guarantee that they will be turned on and off at the appropriate times. Some genes are regulated by special proteins called repressors that bind specifically to a region (the operator) adjacent and upstream from the coding region of the gene. As long as the repressor occupies the operator site on the DNA, RNA polymerase is unable to read and transcribe the gene. Repressors can be removed from the operator by small molecules called inducers. Inducers are often substrates for the gene product (enzyme) or molecules that are made from the substrate (Jacob and Monod, 1961).

RNA polymerase is only able to bind DNA at discrete sites called promoters which are at the beginning of genes (Epstein and Beckwith, 1968). If genes are to be transferred from one organism to another it is important that the recipient's RNA polymerases are able to recognize the promoter regions from the donor. There is some evidence to suggest that Bacillus promoters work in E. coli, but E. coli promoters do not necessarily work in Bacillus. When the promoter does not work, another promoter, possibly from the recipient itself must be substituted, and this substitution can complicate a seemingly straightforward genetic engineering strategy.

Some genetic regions such as the lactose operon in E. coli are under the control of cyclic AMP by a mechanism known as catabolite repression (Magasanik, 1961; Rickenberg, 1974). In these cases, the RNA polymerase is only able to bind the promoter after a cyclic AMP-catabolite activating protein (CAP) complex destabilizes the hydrogen bonds in an adenosine-thymine rich region of the DNA that is approximately 15 base pairs from the promoter. Since CAP is only able to bind to the DNA after it has complexed with cyclic AMP, transcription is controlled by the intracellular concentrations of cyclic AMP. In E. coli cyclic AMP synthesis appears to be regulated by the transport of substrates into the cell (Saier, 1977).

Another type of regulation called attenuation was recognized in the tryptophan operon of E. coli. The RNA polymerase begins making mRNA some distance before the first gene and this initial sequence, called the leader, codes for a peptide, containing more than one tryptophan codon. When tryptophan is abundant, the leader peptide is made and the RNA polymerase is stopped. If tryptophan is scarce the leader peptide is made slowly and RNA polymerase is allowed to continue (Drlica, 1984).

"Expression vectors" are often used to clone the gene and make sure that it will be read efficiently. To serve as an expression vector, the molecule must have, in addition to all the requirements of a good cloning vector, promoters that are strong and well regulated. Lac (lactose operon) promoters from E. coli are often used and these promoters have mutations that can be transcribed without cyclic AMP and CAP. Tac promoters which are a fusion of lac and trp (tryptophan operon) promoters are even more efficient than lac promoters (Dillon et al., 1985).

ACID RESISTANT CELLULOLYTIC RUMINAL BACTERIA

Low pH and cellulose digestion

Since World War II there has often been a surplus of cereal grain, and cereal grains are currently an inexpensive energy source for ruminant animals. Cereal grains are fermented at a faster rate than cellulose, and this increased fermentation rate provides a greater rate of nutrient release. However, as ruminal fermentation rates increase there is often a decline in ruminal pH, and in vitro and in vivo studies have indicated that cellulose digestion can be severely inhibited by even modest declines in ruminal pH.

The effect of ruminal pH on cellulose digestibility has often been confounded by changes in food intake or the concentration of fiber in the diet, but Burroughs et al. (1949) noted that there was a "substantial decrease in roughage dry matter digestibility" when purified corn starch was added to a diet containing corn cobs and alfalfa hay. Similar results were obtained by Kane et al. (Kane et al., 1959). One of the most detailed studies of the interrelationship between rumen pH and fiber digestion was carried out by Orskov and Fraser (Orskov and Fraser, 1975). They fed the same barley and dried grass ration to sheep, but varied the method of barley preparation. When the barley was pelleted to increase the rate of starch fermentation, pH declined to 5.5 and food intake decreased 25%. In a later study Mould et al. (Mould et al., 1983/84) concluded that ruminal "cellulolysis was totally inhibited" at pH values less than 6.0. The ruminal pH of fattening beef cattle and high-producing dairy cows is often less than 6.0 (Slyter, 1976).

One might argue that modern diets which emphasize cereal grains do not contain much fiber, but it should be realized that even cereal grains contain a considerable amount of fiber (greater than 10%). Cereal grains generally contain more hemicellulose than cellulose, but the ruminal cellulolytic bacteria also play a dominant role in hemicellulose digestion. The relevance of fiber digestion is supported by the practical observation that cattle are usually fed at least 10-15% forage to insure normal rumen movements and digesta flow.

When ruminal cellulose digestion decreases, there is some increase in the amount of fiber which is digested in the lower gut (cecum and large intestine). However, whole tract studies have indicated that lower gut fiber digestion is usually inadequate to prevent a decline in cellulose digestion (De Gregorio et al., 1982). The shift in digestion from the rumen to the lower gut can also have a negative impact on amino acid availability. When substrates are fermented in the rumen, microbial protein is digested and absorbed in the small intestine. Microbial protein from the lower gut is lost unless the animal practices coprophagy.

Inhibition of cellulolytic bacteria

McCullough obtained rumen contents from animals fed different amounts of rapidly fermented corn and noted that pH decreased as the amount of corn increased (McCullough, 1968). When the rumen contents were incubated in vitro there were smaller losses of cellulose at low pH values. These results indicated that a low pH in the rumen decreased the activity and/or number of cellulolytic microorganisms in vivo. Terry et al (Terry et al., 1969) noted that the extent of cellulose digestion by mixed rumen microorganisms was dependent on the pH of the incubation medium. Digestion was "greatly reduced at pH values similar to those found within the rumen of sheep fed diets rich in readily digestible carbohydrate." Stewart noted little disappearance of cotton cellulose in vitro at pH values less than 6.0 (Stewart, 1977).

The rumen is a complex microbial ecosystem, but few rumen bacteria are cellulolytic. Early work by Hungate demonstrated that Ruminococcus albus, Ruminococcus flavefaciens and Fibrobacter succinogenes were the predominant cellulolytic bacteria in the rumen (Hungate, 1950). Some strains of Butyrivibrio fibrisolvens are also cellulolytic but their capacity to digest cellulose is not great (Halliwell and Bryant, 1963). Cellulolytic protozoa and fungi have also been isolated from the rumen (Bauchop, 1979), but bacteria are primarily responsible for cellulose digestion in vivo. The in vivo results and mixed culture studies described above indicate that ruminal cellulolytic protozoa and fungi are either sensitive to low pH or do not contribute significantly to cellulose digestion.

When pure cultures of cellulolytic ruminal bacteria were grown in cellobiose limited chemostats, the cultures washed out at near neutral pH values (Russell and Dombrowski, 1980). The ruminococci and F. succinogenes could not tolerate pH values less than 5.9. B. fibrisolvens was somewhat more resistant, but even this species washed out when the pH was decreased to 5.7. Since cellobiose was the energy source limiting growth it appeared that some parameter related to growth in general rather than cellulase activity was responsible for the pH sensitivity.

When F. succinogenes, the most active digester of crystalline cellulose, was incubated at decreasing pH values, the organism increased its pH gradient across the cell membrane and attempted to maintain a near neutral intracellular pH (Russell, 1987). However, as Δ pH across the cell membrane increased there was a decline in the electrical potential (Δ Y) and an eventual drop in total proton motive force (Δ p). When extracellular pH was less than 5.8, p dropped below 150 mV and the organism was no longer able to take up sugar. Because an artificial membrane potential was unable to drive glucose transport at low pH, it appeared that pH was having a direct effect on the glucose carrier (Chow and Russell, 1992).

Cellodextrin-utilizing bacteria

Early work by Bryant and Burkey (1953) indicated that there were high numbers of noncellulolytic bacteria in ruminants fed fibrous diets. When Scheifinger and Wolin co-cultured Selenomonas ruminantium and F. succinogenes on cellulose, S. ruminantium persisted even though it was unable to grow on intact cellulose (Scheifinger and Wolin, 1973). They hypothesized that S. ruminantium was living on "cellulose fragments" that were released by F. succinogenes. Recent experiments indicated that B.

ruminicola B₁₄ (another noncellulolytic bacterium) was able to grow on water soluble cellodextrins containing as many as 7 glucose units (Russell, 1985).

B. ruminicola is a common rumen bacterium that is found at high numbers in the rumen on virtually all diets (Russell and Wilson, 1988), and continuous culture experiments indicated that it was able to grow at pH values as low as 5.1 (Russell and Dombrowski, 1980). Based on its ability to utilize the products of cellulose digestion and its resistance to low pH, B. ruminicola was an attractive candidate for genetic modifications to produce an acid-resistant cellulolytic ruminal bacterium. This bacterium has the advantage of already producing some extracellular enzymes (amylase, xylanase and proteinases). It appears that attachment is necessary for rumen bacteria to digest cellulose (Rasmussen et al., 1988; Rasmussen et al., 1989), and B. ruminicola can attach to solid substrates. Somewhat to our surprise we found that B. ruminicola already produced an extracellular β -1-4 endoglucanase which hydrolyzed the soluble derivative, carboxymethylcellulose (CMC). This enzyme hydrolyzes CMC at pH values as low as 5.0, but it does not degrade native cellulose or bind to cellulose.

Gene reconstruction

Because the rumen represents an open system and bacterial competition in the rumen is very intense, it is unlikely that genetically modified versions of non-rumen bacteria will persist in the rumen (Russell and Wilson, 1988). A more promising means of manipulating rumen fermentation would involve subtle changes in the naturally occurring bacteria. Until now genetic engineering has involved the transfer of DNA encoding entire genes or pathways from one species or strain to another, but this approach is confounded by questions regarding the stability of foreign DNA in rumen bacteria, efficient expression of these genes, and the activities of the gene products.

We had originally planned to transfer an acid-resistant cellulase gene from Thermomonospora fusca to B. ruminicola. While this approach may still be viable, we currently feel that reconstruction of the CMC_{Case} gene to include a cellulose binding site has some distinct advantages. All crystalline cellulases have cellulose binding sites which are present in a separate domain from the catalytic site (Ghangas and Wilson, 1988; Gilkes et al., 1988; Hall et al., 1988; McGavin and Forsberg, 1989). Crystalline cellulases which have lost their cellulose binding sites retain activity against CMC but lose activity against crystalline cellulose (Gilkes et al., 1988). The structure of the Trichoderma reesei cellobiohydrolase I cellulose binding site has been determined (Hall et al., 1988), and recent work indicated that a modified alkaline phosphatase which contained a cellulose binding site bound to cellulose (Ong et al., 1989). Since cellulose binding sites are relatively small (approximately 5000 daltons), operate as separate domains and do not require a strict orientation relative to the catalytic domain (D. B. Wilson, unpublished results), it appeared that genetic modification of the B. ruminicola CMC_{Case} gene to include a cellulose binding site might provide a means of creating an acid-resistant, cellulolytic ruminal bacterium.

Gene reconstruction would involve the insertion of a small piece of foreign DNA into the genome. However, B. ruminicola B₁₄ already has all the sequences determining regulation, initiation of transcription, initiation of translation, and secretion of the CMC_{Case}. Therefore it is much more likely that an organism produced by gene modification will synthesize and secrete the protein and be able to compete with unmodified organisms in its natural environment than an organism containing a foreign gene.

Progress

B. ruminicola B₁₄ cultures grown on glucose, fructose, maltose, mannose and cellobiose had high specific activities of CMC_{Case} (>3 nmol reducing sugar/mg protein/min). Sucrose caused a significant repression of CMC_{Case} synthesis, but this sugar is rapidly fermented in the period soon after feeding. A crystalline

cellulase (E3) was purified from Thermomonospora fusca, and this enzyme was able to digest cellulose at pH values as low as 4.5. B. ruminicola could not digest either ball-milled or acid swollen cellulose even if the cultures were provided with a small amount of glucose. However, when purified cellulase (E3) was added to B. ruminicola B₁₄ cultures there was a rapid disappearance of cellulose and an increase in bacterial protein at pH values as low as 5.2. These results indicated that the inability of B. ruminicola to digest cellulose was due to the absence of a crystalline cellulase (Matsushita et al., 1990).

A 6 kb EcoRI fragment of B. ruminicola DNA containing the CMCase gene was cloned into E. coli, and unidirectional deletion analysis indicated that the CMCase gene was contained in a 3 kb Kpn I fragment. The nucleotide sequence of this fragment contained a single open reading frame. The 3' end of this reading frame could code for a protein of 40,481 molecular weight. S1 mapping indicated 4 potential transcriptional initiation sites. All of these sites were preceded by putative promoter sequences which resembled the consensus sequence for E. coli sigma 70 RNA polymerase. Although the N-terminal end of the gene did not contain a normal signal peptide sequence, E. coli secreted the CMCase into the periplasm. Another peculiar feature of the CMCase gene was the absence of any stop codons preceding the initiation codon (see below).

Under control of a tac promoter E. coli overproduced the CMCase, and the enzyme was purified to homogeneity. The N-terminal sequence, amino acid composition and molecular weight of the purified enzyme were similar to the values predicted from the open reading frame of the DNA sequence. However, Western blots showed that B. ruminicola produced two CMCase with monomer molecular weights of approximately 88,000 and 82,000. Based on the Western blots and the absence of a stop codon upstream, it was clear that the cloned CMCase gene contained only a portion of the B. ruminicola CMCase gene.

Another 2.6 kb fragment of B. ruminicola DNA that showed homology with the 5' end of the original EcoRI fragment was cloned into E. coli. This fragment was cut to remove the overlapping DNA and ligated to produce the "maxi" CMCase gene. Western blots showed that the new clone continued to produce the "mini-CMCase," but it also produced two CMCases which had molecular weights similar to the ones detected in B. ruminicola supernatants. The 5' end of the entire open reading frame that coded for the mini CMCase coded for a normal signal sequence (2 basic amino acids followed by 15 neutral or hydrophobic amino acids) and was immediately preceded by several stop codons.

Based on our initial results we originally thought that the B. ruminicola CMCase had a molecular weight of 40,000. Even though E. coli produced this "mini" CMCase, Western blots showed that B. ruminicola did not make even trace amounts of this protein. The mini-CMCase had promoters and ribosome binding sites which functioned in E. coli, but these sequences did not function in B. ruminicola. When the larger B. ruminicola CMCase was purified, its N-terminal amino acid sequence was not encoded anywhere in the 40 k open reading frame. Further sequencing upstream, however, showed a second 485 base pair open reading frame that encoded the B. ruminicola N-terminal sequence. This latter DNA sequence was preceded by a 19 residue peptide which resembled a normal signal sequence. This open reading frame was 1 base pair out of frame from the 40 k CMCase reading frame. It appears that the larger B. ruminicola CMCase arises from a frameshift which joins the two open reading frames.

The DNA sequence itself revealed another ambiguity. The two open reading frames coding for to the 88,000 molecular weight B. ruminicola CMCase had enough DNA to produce a protein of 104,000 molecular weight! SDS-gel electrophoresis sometimes gives aberrant molecular weights, but the CMCase is a soluble protein with an acid isoelectric point. Because SDS-gel electrophoresis almost always gives accurate estimates for such proteins, it is unlikely that the 20% difference in molecular weight was an artifact. On the basis of the -1 frame shift and the large deviation in theoretical versus actual size. it

appears than an unusual event (e. g. ribosome hopping or RNA splicing) is involved in either the translation or the transcription of the 88,000 molecular weight CMCase (Matsushita et al. 1992).

The idea that the 88,000 molecular weight CMCase has a large region of untranslated DNA was supported by experiments in which stop codons were inserted at various restriction sites in the gene. The B. ruminicola CMCase gene has 10 RsaI sites which are located along the CMCase gene, and it was possible to use these sites to insert stop codons. When the stop codons were inserted at a site near the 3' end, E. coli was no longer able to produce any functional CMCase. If the stop codons were inserted at a site just before the region coding for the 40 k CMCase, the 82 and 88 k CMCases were not produced, but the 40 k CMCase was. If the stop codons were inserted at a site just before the 82 k coding region, the 88 k CMCase was not produced, but the 82 and 40 k CMCases were. However, if the stop codons were inserted at two sites within the first reading frame all three CMCases were produced. This result proves that this region is not being translated even though it is after the region coding for the N-terminus of the 88 k protein.

Maglione et al. (1992) recently joined the DNA coding for the cellulose binding site of a T. fusca cellulase to the 3' end of the 40,500 molecular weight B. ruminicola CMCase. The reconstructed CMCase was able to bind cellulose, and its activity on CMC, amorphous and ball-milled cellulose were 1.5, 10 and 8 times greater than the native enzyme. We are currently trying to construct a hybrid with the 88,000 molecular weight CMCase. If the high molecular weight hybrid shows a similar increase in activity, we will attempt to move the reconstructed enzyme back to B. ruminicola by conjugation.

Gene expression is always a concern in recombinant DNA schemes, but we feel that our approach has a reasonable chance as: 1) B. ruminicola already regulates and produces the maxi-CMCase, 2) the reconstructed gene (which includes a region coding for the cellulose binding site) will be only slightly larger than the original gene, 3) B. ruminicola is already able to utilize the products of cellulose digestion, 4) and B. ruminicola can grow at low pH. The rumen is a very competitive microbial habitat, but the cellulose digesting niche is currently unoccupied at low pH.

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DIGESTIBLE FIBER SOURCES FOR DAIRY CATTLE

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INTRODUCTION

Carbohydrates are the main energy yielding substrates for the rumen microbial population and are important precursors of energy yielding nutrients for the host dairy cow. Fibrous or structural carbohydrates have been most commonly defined as those occurring in the plant cell wall as determined by neutral detergent fiber (NDF) analysis. Non-fibrous or nonstructural carbohydrates, typically the more readily digested carbohydrate fraction found in animal feeds, are vague and not as well defined.

Van Soest (1986) noted that various terminology has been used to describe carbohydrates not detected in the NDF fraction including: nonstructural carbohydrates; soluble carbohydrates, rumen available carbohydrates, non-fibrous carbohydrates and nitrogen-free extract. These terms are not synonymous and use of these various terms is confusing. However, these terms do attempt to describe the readily available carbohydrate fraction of feedstuffs which can have a considerable impact on milk yield. Generally, these terms include carbohydrates not found in the NDF fraction including sugars, starches, fructosans, galactans, pectins and beta glucans. Pectins and beta glucans are associated with the cell wall, but are not covalently linked to the lignified portions and are almost completely digested (90 to 100%) in the rumen (Nocek, 1991). These carbohydrates have been referred to as soluble fiber. The major problem associated with each of the non-fibrous carbohydrate terms is that they do not differentiate between type of carbohydrate present in the feedstuff. Non-fibrous or nonstructural carbohydrates in most instances are simply calculated as:

$$100 - (\text{NDF} + \text{crude protein} + \text{ash} + \text{ether extract}).$$

Until a few years ago, relatively little attention was given to the role of carbohydrates in diets fed to dairy cattle (Tamminga et al., 1990). Structural carbohydrates in roughages were known to act as a source of fiber with important stabilizing properties for rumen fermentation while carbohydrates in roughages and concentrates were an important energy yielding part of the diet. We now realize that the complexity of the nonstructural carbohydrate components, as described above, and large variation among feedstuffs in the quantities of sucrose, starches and pectins, can result in extreme differences in rates of ruminal fermentation and end product formation.

Rates of ruminal carbohydrate fermentation can have a major impact on the efficiency of microbial protein synthesis in the rumen thus significantly altering protein utilization by the animal. Nonstructural carbohydrates (starch, sucrose) provide an excellent source of readily fermentable energy for microbial protein synthesis. However, feedstuffs high in starch and sucrose fed to dairy cows produce primarily propionic acid and lactic acid in the rumen with a concomitant decrease in ruminal pH. This type of carbohydrate fermentation can be

potentially devastating if too high, resulting in acidosis, off-feed and/or low fat tests. In contrast, structural carbohydrates in roughages are usually in a long form and provide stimuli

to induce rumination, salivation and rumen motility. These factors influence conditions in the rumen such as buffering capacity, pH and VFA concentration (Tamminga et al., 1990). However, the conditions in the rumen are not only influenced by the structural value of the diet, but also dependent upon other factors such as rate and extent of VFA production, which are influenced by the rate and extent of carbohydrate fermentation. Therefore, structural carbohydrates (fiber) in concentrates can also play an important positive role in the stabilization of fermentation.

EFFECTIVE FIBER

Because many non-forage feedstuffs contain substantial quantities of fiber, they may be used effectively and economically to replace a portion of the forage in diets fed to dairy cows. Replacement of forage with by-product feedstuffs is an important concept, especially when forage harvest is poor and in other parts of the world where forage is limiting. Armentano and Clark (1992) indicated that there is general agreement that these feedstuffs do contain some value as fiber sources, however, their fiber value may not be as effective as that in forage. Effectiveness of the fiber content of a diet is a critical characteristic in formulation of the dairy cow diet and is a subject that has recently received a great deal of attention (Harris, 1991; Armentano, 1992; Firkins, 1992). Effective fiber can be defined as the actual capacity of the fiber to stimulate rumination, salivation, ruminal acetate production and, subsequently, milk fat percentage. Various methods have been used with varying degrees of success to quantitate fiber effectiveness. Some of these methods are chewing time, ruminal acetate to propionate ratio and milk fat test.

Compiled values for NDF composition, extent of ruminal NDF digestion and effective fiber of selected high fiber by-product feedstuffs commonly available for use in dairy cattle diets are presented in Table 1. These values indicate that a major problem associated with using by-product feedstuffs to replace forage in the diet is their variability in fiber composition and extent of digestion. Falk et al. (1992) observed large coefficients of variation in fiber composition of various by-product feeds collected during a two-year period. Variation in fiber composition of by-product feeds can result in significant changes in total dietary fiber content and can markedly alter effective fiber values. For example, effective fiber (eNDF%) of brewers dried grains could range from 15.2 to 21.5% derived by using .33 as the effective fiber factor (Armentano and Clark, 1992) and NDF values of 46% (NRC)

Table 1. NDF composition, extent of ruminal NDF digestion and effective fiber of selected feedstuffs.

Feedstuff	NDF (% of DM) ^a	Extent of ruminal NDF digestion (%)	Effective fiber factor		Effective fiber, % of DM	
			(ADF) ^b	(NDF) ^c	(ADF) ^b	(NDF) ^c
Beet pulp	46 ¹ , 48 ² , 49 ³ , 56 ⁴ (54)	39 ⁵ , 42 ¹ , 69 ⁴	--	.43	--	21
Citrus pulp	19 ³ (23)	20 ⁸	.70	--	15	--
Corn gluten feed	34 ² , 35 ¹ , 39 ⁴ , 40 ³ , 52 ⁵ (45)	30 ¹ , 42 ⁴ , 74 ⁹ , 83 ⁵	--	.56	--	19
Cottonseed, whole	45 ² , 49 ⁵ (44)	67 ⁵	.85	1.30	25	57
Cottonseed hulls	74 ⁶ (90)	33 ¹⁰	.90	--	66	--
Dried brewers grains	58 ² , 63 ¹ , 65 ⁴ (46)	47 ¹ , 50 ⁸ , 51 ⁴	.68	.33	16	19
Dried distillers grains	30 ² , 33 ⁵ , 39 ⁴ , 48 ⁷ (43)	77 ⁴ , 79 ⁹ , 81 ⁵	--	.80	--	32
Soybean hulls	65 ⁴ , 69 ⁶ , 73 ⁵ (67)	38 ⁴ , 87 ⁵ , 91 ¹⁰ , 95 ¹¹	.30	--	15	--
Wheat middlings	40 ¹ , 40 ⁴ , 44 ² (37)	24 ¹ , 52 ³	--	.57	--	25

^a Values in parentheses are from feed composition tables (NRC, 1989). Other values were chemically derived by respective researchers.

^b Adapted from Harris (1991) and based on ADF as fiber measurement.

^c Adapted from Armentano and Clark (1992) and based on NDF as fiber measurement.

¹ Tamminga et al. (1990).

² Armentano and Clark (1992).

³ Durand et al. (1988).

⁴ Varga and Hoover (1983).

⁵ Belyea et al. (1989).

⁶ Hsu et al. (1987).

⁷ Armentano (1992).

⁸ Nocek (1988).

⁹ Firkins et al. (1985).

¹⁰ Nocek and Russell (1988).

¹¹ Klopfenstein and Owen (1987).

and 65% (Varga and Hoover, 1983). The difference in effective fiber values is approximately 30% and appears to be highly dependent upon by-product source and NDF analysis. Therefore, it is imperative that by-product feeds be analyzed for nutrient composition to ensure proper ration balancing. It is also unclear what effect variation of NDF composition of a by-product feedstuff will have on the effective fiber factor. Armentano and Clark (1992) emphasize that the effectiveness factors that have been determined are only rough estimates and should be treated as such.

Regardless of the problems associated with determination and utilization of effective fiber, the concept is sound. Further evaluation could increase the use of effective fiber as a reliable predictor of forage replacement by non-forage fiber sources. The remainder of this review will provide a brief synopsis for several selected digestible fiber sources that are available for use in dairy cattle diets and have potential for providing effective fiber.

DIGESTIBLE FIBER SOURCES

Beet Pulp

Nutrient composition. Dried beet pulp is a by-product derived from the processing of sugar beets to obtain pure beet sugar. Crude protein and NDF composition of beet pulp are 10 and 54% (DM basis), respectively. Beet pulp is an excellent digestible energy source for ruminants because of the type of carbohydrate associated with the cell wall fraction. The high pectin content of beet pulp (20 to 25% of DM) provides a readily available source of energy for microbial protein synthesis in the rumen. This is important because under most feeding practices, microbial protein synthesized in the rumen comprises a substantial part of the protein entering the small intestine (60 to 85% of total protein), where enzymatic digestion of the protein releases amino acids that are absorbed to meet the cow's need for milk production. There is also some evidence that beet pulp is a good source of undegradable protein. Almost all of the nitrogen in beet pulp is present as true protein (97% of the crude protein) as amides are largely removed during the sugar extraction process (Kelly, 1983). Therefore, beet pulp appears to be an excellent feed ingredient for dairy cattle diets because of its high fiber content, readily fermentable energy and potential value for providing undegradable protein.

Ruminal fermentation. Until recently, there was limited data available concerning ruminal digestion of dried beet pulp and its effect on ruminal fermentation and supply of nutrients to the lower gastrointestinal tract. Stern et al. (1985) examined the effects of supplying corn vs beet pulp as the energy substrate for metabolism by rumen microbes (Table 2). True OM digestion (corrected for contributions of bacterial OM in the effluent) was not different between carbohydrate sources. Neutral detergent fiber digestion was greater and nonstructural carbohydrate digestion was less for diets containing beet pulp compared with corn. In contrast to what might be expected, ammonia-N concentration was lower for diets containing beet pulp than those containing corn. This effect can be due to lower protein degradation or greater microbial uptake of ammonia-N with the beet pulp diets. In fact, there was a trend for protein degradation of the beet pulp diets to be lower ($P < .06$). This observation is supported by the lower branched chain VFA concentration with the beet pulp diets. Branched

chain VFA are derived from degradation of branched chain amino acids. Total bacterial crude protein production was not different between corn and beet pulp diets. This latter effect indicated that ruminal energy availability was similar between carbohydrate sources in spite of the lower nonstructural carbohydrate (13 vs 70%) and higher NDF (54 vs 9%) of beet pulp compared with corn. Similar energy availabilities can best be explained by the high pectin content of beet pulp which is completely and rapidly available for ruminal microbial fermentation (Van Soest, 1986).

Table 2. Effect of corn vs beet pulp on carbohydrate and protein metabolism by ruminal bacteria maintained in continuous culture fermenters.

Item	Dietary carbohydrate source	
	Corn	Beet pulp
Organic matter digestion, %	61.0	58.8
Neutral detergent fiber digestion, % ^a	62.2	53.7
Nonstructural carbohydrate digestion, % ^a	88.6	78.8
Branched chain VFA concentration, mM ^a	9.4	2.7
Ammonia-N, mg/100 ml ^a	17.6	8.9
Bacterial-N flow, mg/d	1387.6	1458.1
Efficiency of bacterial synthesis, g N/kg OM digested ^a	32.0	34.9
Protein degradation, %	66.2	59.8
Total amino acid flow, g/d ^a	10.9	12.1

^a Mean values are different (P<.05).

Mansfield and Stern (1991) evaluated diets in vitro that were fed to lactating dairy cattle. Beet pulp replaced 50% of corn DM in these diets. Consistent with observations of Stern et al. (1985), they indicated that partial replacement of corn with beet pulp decreased ammonia-N concentrations, decreased molar proportion of total branched chain VFA and increased total protein flow. There were no differences between carbohydrate sources in organic matter digestion, efficiency of bacterial synthesis and total bacterial crude protein production. Similar observations were also made in cattle when beet pulp was compared to barley (Huhtanen, 1988; Rooke et al., 1992). They found that ruminal ammonia-N concentration and crude protein degradation were lower in cattle fed beet pulp compared with barley. Feeding beet pulp tended to increase the quantities of total protein and microbial crude protein entering the small intestine. Reductions in ruminal branched chain VFA and ammonia-N concentrations were also detected when beet pulp replaced approximately 50% of corn silage DM in dairy cows (deVisser, 1991).

Milk production. Energy supplements for dairy cows are primarily cereal grains with high sugar and starch content. Feeding high levels of these supplements to dairy cows can lead to digestive disturbances such as acidosis, reduction of cellulolytic activity in the rumen, lower concentrations of milk fat and changes in energy partitioning towards fat deposition. Replacement of high starch supplements with highly digestible fibrous by-products such as

sugar beet pulp can alleviate some of these problems. For these reasons, there has been interest in replacing cereal grains with beet pulp in diets fed to lactating cows. Several experiments were conducted by Bhattacharya and Sleiman (1971) and Bhattacharya and Lubbadah (1971) to determine the nutritional value of dried beet pulp for use in dairy cow diets. They concluded that when beet pulp is properly supplemented, it can be equal to barley or corn as a source of energy for milk production. More recent research supports these conclusions that beet pulp can replace barley (Castle et al., 1981; Huhtanen, 1987; Spornly, 1991) or corn (Valk et al., 1990; Mansfield et al., 1990) as an energy source. The latter two studies also indicated that milk fat percentage increased when beet pulp replaced corn. This response was probably due to higher ruminal acetate concentrations observed by Mansfield and Stern (1991) when beet pulp replaced corn. W. H. Hoover, West Virginia University (personal communication), conducted a study to compare diets that contained rapidly vs slowly degradable fiber for lactating cows. Beet pulp comprised 28% of the DM in the rapidly degradable NDF diet which replaced hay crop silage and corn cobs as the major sources of fiber in the slowly degradable NDF diet. Both diets were isocaloric, isonitrogenous and had equal amounts (34%) of NDF. Cows fed the diet high in beet pulp produced 34.8 kg milk/d and the other group produced 32.1 kg milk/d during the first 10 weeks of lactation. This response in milk production with beet pulp could have been elicited by its effective fiber content (.44; Swain et al., 1991), readily fermentable energy and(or) undegradable protein.

Citrus Pulp

Nutrient composition. Citrus pulp is the main by-product from the citrus processing industry used as a feedstuff for ruminants. Citrus pulp is a mixture of peel, inside portions and cull fruits of the citrus family (orange, grapefruit, etc.), which has been dried to produce a coarse, flakey product (Harris, 1991). The nutrient content of citrus pulp is influenced by several factors including source of fruit and type of processing (Ammerman and Henry, 1991). It is considered a bulky concentrate that is high in energy, low crude protein (7%) and fiber (23% NDF) but with some roughage replacement value (effective ADF .70; Harris, 1991).

Ruminal Fermentation. Citrus pulp in the ruminant diet can promote a greater ruminal concentration of acetate and lower concentration of propionate resulting in a higher acetate:propionate ratio compared with other concentrates such as corn gluten feed and barley (Sutton et al., 1987; Durand et al., 1988; Ben-Ghedalia et al., 1989). Reduction in ruminal pH has been observed when citrus pulp replaced corn silage (Schably and Wing, 1974) and other concentrates such as cassava, coconut meal, corn meal, beet pulp, soybean meal and corn gluten feed (Malestein et al., 1984) in diets fed to cattle. Lower ruminal pH can be attributed to greater production of lactic acid during fermentation of pectin and other carbohydrates from citrus pulp (Malestein et al., 1984; Cullen et al., 1986). Therefore, there may be some concern about the potential risk of lactic acidosis when feeding citrus pulp to dairy cows.

Milk production. Ammerman and Henry (1991) indicated that over 90% of the dried citrus pulp fed in the U.S. is fed to lactating cows. However, there has not been much research on the value of citrus pulp for milk production. Van Horn et al. (1975) evaluated citrus pulp as

a replacement for ground corn at levels of 8 or 43%. Milk production was not influenced by level of pulp, however solids-corrected milk (kg/d) and milk fat (%) were greater with the higher concentration of citrus pulp as a replacement for corn. No differences in milk production or composition were found when citrus pulp was used to replace corn and barley. (Lanza, 1984).

Corn Gluten Feed

Nutrient composition. Corn gluten feed is that portion of the corn kernel that remains after extraction of starch, gluten and germ (Weigel, 1991). It is composed primarily of bran, the fibrous fraction of the kernel. Corn gluten feed contains 45% NDF, considered highly digestible, and is fairly high in crude protein (26% of DM). The effective fiber factor, determined by Swain et al. (1991), was .56; relatively high when compared with some other by-products that were evaluated. Corn gluten feed is available in wet and dry forms. The wet form consists primarily of corn bran and steep liquor.

Ruminal Fermentation. Much of the research conducted with corn gluten feed has shown no effect on total ruminal VFA concentration (Staples et al., 1984; Fleck et al., 1988; Ohajuruka and Palmquist, 1989; Fellner and Belyea, 1991; Sarwar et al., 1991); however, various changes in molar proportions of individual VFA have been found. Firkins et al. (1985) reported a linear decrease in ruminal pH and acetate:propionate ratio when corn gluten feed replaced 35 or 70% of forage DM. Fellner and Belyea (1991) fed corn silage-based diets that contained 20, 40 or 60% (DM basis) corn gluten feed to lactating cows. Increasing levels of corn gluten feed in the diet reduced ruminal acetate concentration but did not affect N, NDF, ADF or starch digestibilities. Fleck et al. (1988) compared supplemental soybean meal and corn gluten feed in grass hay diets fed to cows and detected higher molar proportions of ruminal propionate and butyrate with corn gluten feed. In contrast to these findings, Staples et al. (1984) noted a linear increase in ruminal acetate and a linear decrease in propionate when wet corn gluten feed comprised 0, 20, 30 and 40% of dietary DM fed to lactating cows.

Milk production. Fellner and Belyea (1991) reported no change in milk yield when dried corn gluten feed increased from 20 to 60% of DM in corn silage-based diets. Cows fed diets with 20% corn gluten feed produced milk with the highest milk fat test (3.6%) compared to cows fed 40 (3.5%) and 60% (3.1%). Milk protein percentage was greater for cows fed 40 and 60% corn gluten feed diets. A similar observation was made by Macleod et al. (1985) who found that feeding wet corn gluten feed to dairy cows resulted in greater milk protein percentage and also greater DM intake and solids corrected milk. Dry matter intake and 4% FCM yield of cows increased but milk protein percentage decreased when dried corn gluten feed was included in diets at 16.5 and 33% of DM (Ohajuruka and Palmquist, 1989). Based on their observations, Ohajuruka and Palmquist (1989) suggested that corn gluten feed should be limited to 30% of concentrate mixtures or 15-20% of dietary DM when used to replace corn in diets for lactating cows. Staples et al. (1984) showed a linear decrease in milk yield, milk fat (%) and milk protein (%) when wet corn gluten feed comprised 0, 20, 30 and 40% of dietary DM. Bernard et al. (1991) compared wet and dry corn gluten feed and found no differences in DM intake, milk yield and percentage of milk protein, but milk fat percentage

was lowest when dry corn gluten feed was fed to cows in early lactation. They concluded that corn gluten feed can replace 27% of dietary DM without altering milk yield. When wet corn gluten feed is available within reasonable hauling distance, it could be an economical source of energy, protein and highly digestible fiber for dairy cows.

Whole Cottonseed

Nutrient composition. Whole cottonseed is a unique feedstuff with high densities of energy, protein and fiber. Fat (ether extract), crude protein and NDF composition of whole cottonseed are 20, 23 and 44% (DM basis), respectively. The diet of the high producing dairy cow can be deficient in energy and fiber and whole cottonseed is an important feedstuff that can contribute both of these nutrients. In addition to these factors, effectiveness of the NDF in whole cottonseed was found to be worth 1.23 times the NDF in alfalfa (Clark and Armentano, 1992). Because of the high effective fiber value of whole cottonseed, it is the only non by-product feedstuff included in this review.

Ruminal fermentation. Horner et al. (1988a) evaluated effects of including 0 or 15% whole cottonseed in diets fed to cannulated heifers on ruminal fermentation. Protozoal numbers and molar percentage of propionate were reduced while molar percentage of acetate increased with whole cottonseed feeding. Reduction of rumen protozoal numbers with whole cottonseed feeding has been reported by others (Mohamed et al., 1988; Kajikawa et al., 1991). Effects of whole cottonseed (0, 5, 15 or 30% of the total dietary DM) on in vitro ruminal fermentation increased ruminal pH and ammonia concentration but lowered microbial protein (Horner et al., 1988b). Acetate concentration was greatest with diets of 15 and 30% whole cottonseed, but propionate and total VFA concentrations were lowered by increasing whole cottonseed from 0 to 30%.

Milk production. Utilization of whole cottonseed in diets for lactating cows often increases milk yield and milk fat test, but decreases percentage of milk protein (Coppock and Wilks, 1991). Coppock et al. (1987) summarized 18 studies with whole cottonseed and found no significant reduction in DM intake when included at up to 25% of the ration, however, there were some numerical decreases. They also noted that milk production responses were variable, usually small but positive. In 8 of 13 studies, milk fat percentage increased and in approximately 50% of the studies, milk protein percentages were lower compared with the controls. However, it should be emphasized that the impact of feeding whole cottonseed on animal performance appears to be influenced by forage type in the diet (Harris, 1991). Five studies summarized by Staples et al. (1991) showed that when corn silage was the primary forage source, milk production increased and milk fat decreased with the addition of 10 to 15% whole cottonseed to the diet. In contrast, Harris (1991) summarized five studies that showed a different effect when whole cottonseed was added to diets where the primary forage source was alfalfa. Whole cottonseed addition at 10 to 30% had little effect on milk yield with alfalfa in the diet but consistently increased milk fat percentage.

Cottonseed Hulls

Nutrient composition. Cottonseed hulls are a by-product of cottonseed processing to cottonseed meal. Cottonseeds are cleaned and dehulled before kernels are crushed and subjected to oil extraction. Cottonseed hulls consist primarily of the outer covering of cottonseed with lint fibers clinging to the hulls (Harris, 1991). Because of the extremely high NDF content (90% of DM) and effective ADF (Table 1) in cottonseed hulls, they are commonly used in cattle diets to supply fiber.

Ruminal fermentation. There is relatively little information on the effect of cottonseed hulls on ruminal fermentation compared with other fibrous by-products. Hsu et al. (1987) evaluated the potential of corn fiber (CF), cottonseed hulls (CSH), oat hulls (OH) and soybean hulls (SH) as roughage sources for ruminants. In situ rate and extent of ruminal DM disappearance indicated that CF and SH were more fermentable in the rumen compared with OH or CSH. Ruminal pH and molar percentage propionate were greatest while total VFA concentration and molar percentage acetate were lowest for cottonseed hulls compared with the other by-products. Total tract digestibilities of DM, OM, NDF and ADF were above 70% for sheep fed CF and SH diets but were 50% or less for sheep fed OH and CSH diets. A ranking of by-products in terms of nutritive value followed the trend: CF > SH > OH > CSH.

Milk production. Harris et al. (1983) compared corn silage and cottonseed hulls in several experiments. In the first experiment, they found that cows in mid-lactation fed cottonseed hulls had a higher DM intake than cows fed corn silage; however, there were no differences in milk yield, milk fat and milk protein. In another experiment, they observed no differences in DM intake, milk yield and composition when cows were fed diets with 35% cottonseed hulls or 25% sunflower hulls with 10% cottonseed hulls. Van Horn et al. (1984) noted that cows fed cottonseed hull diets had greater DM intake, milk yield and milk protein (%) and lower milk fat (%) than cows fed sunflower hull diets. Morales et al. (1989) showed that cows in mid to late lactation fed 30% cottonseed hulls had greater milk yield and protein yield but less milk fat (%) and yield compared with cows fed 30% alfalfa haylage.

Dried Brewers Grains

Nutrient composition. Dried brewers grains are spent grains derived from the brewing of beer. This feedstuff consists of dried extracted residues of barley malt, alone or in combination with other cereal grains (Harris, 1991). Crude protein and NDF composition of dried brewers grains are 25 and 46% (DM basis), respectively. The effective fiber factor determined by Swain et al. (1991) was lowest for dried brewers grains (.33) compared with other by-product feedstuffs (Table 1). Heating grains during mashing and drying processes provides a product that is high in undegradable protein. Therefore, brewers dried grains are attractive to the producer feeding high producing dairy cows in early lactation with high protein requirements. For these reasons, brewers grains are considered by the brewing industry as a medium protein concentrate and not a forage replacement (Stengel, 1991). In contrast, Harris (1991) indicated that dried brewers grains add bulk to the diet, contribute to the fiber needs of dairy cattle and may be included at the rate of 15 to 20% of the total diet

DM. Brewers grains are also marketed as wet brewers grains; however, movement is limited to within 200 miles of major breweries because of freight costs (Chandler, 1991). The wet product is subject to rapid biodegradation and must be handled properly on the farm to ensure nutritional value to the dairy cow.

Ruminal fermentation. Extent of ruminal NDF digestion of dried brewers grains is approximately 50% (Table 1). Rogers et al. (1986) compared wet vs dried brewers grains fed to Holstein steers and found that ruminal digestibility of DM decreased with wet grains from 56.9 to 39.3%. Ruminal fiber digestion and VFA concentrations were not affected by form of the product. Bacterial numbers, concentration of ciliated protozoa and ammonia concentration in the rumen were higher and ruminal pH was lower for steers fed wet brewers grains. Santos et al. (1984) compared soybean meal, corn gluten meal, brewers grains and distillers grains with regard to fermentation in the rumen and amino acid flow and absorption in the small intestine. They concluded that diets containing corn gluten meal, brewers grains or distillers grains will generally supply more total amino acids to the intestine than a diet containing soybean meal due to the high undegradable protein found in the by-product feedstuffs. Total ruminal VFA concentration and bacterial protein synthesis were not affected by protein source. Total tract digestibility of DM, OM, CP, ADF or NDF was not different in cows fed brewers wet and dried grains and soybean meal (Hoffman and Armentano, 1988).

Milk production. A review of the literature indicates that there is a lack of research concerning the effect of brewers grains (dry or wet) on milk yield. Polan et al. (1985) found that milk production (kg/d) for cows in mid-lactation fed dried brewers grains (29.4) and wet brewers grains (28.9) was higher than soybean meal (26.2). Hoffman and Armentano (1988) showed an average 3.5% fat corrected milk yield of 36.7, 37.8 and 36.2 kg/d for cows in early lactation fed wet brewers grains, dried brewers grains and soybean meal. Milk production, milk fat and milk protein did not differ among treatments. They concluded that all three protein sources proved adequate as the sole protein supplement to alfalfa forage diets for high producing cows in early lactation and that choices among these supplements be made on the basis of cost and availability.

Dried Distillers Grains

Nutrient composition. Distillers grains are a by-product of the distillation industry. These grains are commonly produced using corn, rye or barley in the fermentation process. The majority of distillers grains originate from corn distillation. Distillers grains can be fed fresh, dried or ensiled, however the dried product is the easiest to handle and store. Dried distillers grains contains 43% NDF and 23% crude protein (DM basis). The effectiveness of the NDF in distillers grains is approximately 76% that of alfalfa (Armentano, 1992). Similar to brewers grains, distillers grains are considered a good source of highly undegradable protein. One of the concerns with using distillers grains in a dairy ration is the variability which may exist in nutrient composition. Several factors which influence composition of distillers grains are type of grain used, grain quality, grinding procedure, fermentation conditions, drying conditions and the quantity of solubles blended into the fibrous portion of the grains (Chase, 1991).

Ruminal fermentation. Santos et al. (1984) observed a lower molar percentage of ruminal acetate when distillers grains were compared with brewers grains fed to dairy cows with no difference in total VFA concentration. Studies by Firkins et al. (1986) and Broderick et al. (1990) compared distillers grains with various feedstuffs such as expeller soybean meal, solvent extracted soybean meal and corn gluten feed. They found no differences in total and individual ruminal VFA concentrations. Steers fed dry corn gluten feed had higher apparent ruminal digestibilities of organic matter (45.5 vs 40.1%) and NDF (60.2 vs 56.0%) and lower duodenal flows of nonammonia-nonbacterial N (40.1 vs 52.2% of N intake) than when they were fed dry distillers grains (Firkins et al., 1986). Lambs fed either wet or dry distillers grains showed no differences in DM intake or digestibility of DM, NDF or ADF (Firkins et al., 1985).

Milk production. Satter and Stehr (1984) reviewed earlier research and deduced that there was a small increase in milk production in 5 of 6 studies when cows were fed distillers grains. In contrast, Voss et al. (1988) noted a decrease in milk production and milk protein when distillers grains were fed in combination with corn gluten meal, using corn silage as the sole forage source. In a second experiment, they fed corn silage and alfalfa haylage (1:1 DM) as the forage source and observed similar milk production with the distillers grains-corn gluten meal supplement compared to soybean meal. They suggested that the poor response to the combination supplement in the first experiment may have been due to decreased microbial growth (low degradable protein) or low lysine levels derived from corn, which was the predominant product in the diet. Owen and Larson (1991) stated that distillers grains included in the diet at high levels (36% of DM) may be detrimental to lactation performance compared with lower levels or with soybean meal. They indicated that factors causing poor performance of cows fed a high distillers grains diet are its poor digestibility and a shortage of available lysine. They concluded that distillers grains can yield lactation responses equal to or exceeding soybean meal when the amount in the total dietary DM does not exceed 19%. Grings et al. (1992) demonstrated that increasing the concentration of CP in the diet from 13.9 to 18.1% by the addition of distillers dried grains with solubles was beneficial to cows fed alfalfa-based diets in early lactation. Little additional benefit was observed by feeding greater than 18.1% dietary CP.

Soybean Hulls

Nutrient composition. Soybean hulls are a by-product of soybean processing for oil and soybean meal production. Crude protein and NDF values for soybean hulls are 12 and 67% (DM basis), respectively. Extent of ruminal NDF digestion can approach 95% (Table 1) and its high digestibility makes it comparable to corn as an energy source for the lactating cow (NE_1 of 1.77 vs 1.96 Mcal/kg for soybean hulls and corn, respectively; NRC, 1989). Effectiveness of fiber in soybean hulls is relatively low compared with other by-products discussed in this review. However, soybean hulls are very palatable for dairy cattle and are frequently fed at 20 to 25% of total ration DM (Harris, 1991).

Ruminal fermentation. Anderson et al. (1988) compared soybean hulls to corn as an energy supplement (0, 25 or 50% of the diet) for growing beef calves. They found that steers consuming the corn diet at the 50% level showed a rapid drop in ruminal pH to below 5.65

compared with steers fed soybean hulls, which showed a more gradual decline in ruminal pH to 6.0. Ruminal pH up to 6 hr postfeeding was lower in steers fed soybean hulls compared with steers fed corn gluten feed (Bernard et al., 1988). Concentrations of ruminal acetate were higher and propionate lower in steers fed soybean hulls. Grigsby et al. (1992) substituted 0, 15, 30, 45 or 60% soybean hulls for bromegrass hay fed to steers. Total ruminal VFA concentration, molar proportion of acetate and acetate:propionate ratio increased linearly with increasing level of soybean hull substitution, but molar percentage propionate and ruminal fluid passage rate decreased. Ruminal pH and ammonia concentration decreased more rapidly and to a greater extent and duration as level of soybean hulls increased; neither decreased to levels detrimental to fiber digestion. However, Firkins (1992) suggested that negative associative effects can occur with fiber degradation of by-products, such as soybean hulls, as well as with forage. This statement was based on the observation of Sarwar et al. (1991) who detected a decreased rate of soybean hull digestion with a decrease in ruminal pH in Holstein heifers.

Milk production. Macgregor and Owen (1976) substituted soybean hulls at 0, 27, and 48% for corn in diets fed to dairy cows and observed no difference in milk production. Soybean hulls comprised 0, 50 and 95% of a concentrate mixed with alfalfa silage (1:1 DM basis) to lactating cows (Nakamura and Owen, 1989). They reported that cows fed soybean hull diets produced less milk (27.3 kg/d) and greater milk fat (3.49%) compared with cows fed corn diets (29.8 kg milk/d; 3.13% milk fat). This resulted in similar 3.5% FCM yield and feed efficiency between corn and soybean hulls. Bernard and McNeill (1991) substituted corn gluten feed and soybean hulls for a portion of corn silage in the control diet to provide 22% of total dietary DM fed to lactating cows. They found no differences in milk yield due to treatment but they detected an increase in milk fat percentage when cows consumed diets with soybean hulls. Milk protein percentage and yield were greater when cows consumed corn gluten feed compared with soybean hulls. Sarwar et al. (1992) determined the effect of replacing forage NDF with soybean hull NDF and varying concentrations of nonstructural carbohydrates on milk production. They concluded from this study that in dairy rations containing soybean hulls, 60% of dietary NDF from forage should maintain lactation performance and decreasing nonstructural carbohydrates to 25 to 35% of DM, coupled with supplemental dietary fat, may reduce negative associative effects and improve efficiency of milk production. These results were recently substantiated by Firkins and Eastridge (1992) who used these parameters and found that replacing concentrate with soybean hulls (reducing forage NDF to 62.5% of total dietary NDF) and fat tended to increase yields of milk and FCM, resulting in improvements in efficiency of milk production.

Wheat Middlings

Nutrient composition. Wheat middlings are a by-product of the flour milling process. They contain several grades of granular particles containing different proportions of endosperm, bran and germ. The product contains less than 9.5% crude fiber. Crude protein and NDF content of wheat middlings are 18 and 37%, respectively. The effective fiber factor for wheat middlings determined by Vaughan et al. (1991) is .57.

Ruminal fermentation. Bernard et al. (1988) examined the influence of various digestible fiber sources on ruminal fermentation and protein metabolism. Ruminal NDF digestion was not different between diets containing corn gluten feed and wheat middlings alone; however, combining the two fiber sources increased digestion by approximately 12%. Rapid ruminal degradation of protein from corn gluten feed and wheat middlings decreased the amount of dietary protein reaching the abomasum and produced greater concentrations of isoacids in the rumen fluid. Wagner et al. (1992) showed a decrease in ruminal pH and acetate:propionate ratio when wheat middlings replaced 15% of corn silage DM in diets fed to cows.

Milk production. Acedo et al. (1987) formulated concentrate mixtures with 0, 20 and 40% and 0, 40 and 60% wheat middlings in two experiments. Milk yield of cows fed 20 or 40% middlings was similar to that of cows fed the control ration, however, milk yield of cows fed 60% middlings in the concentrate decreased. Milk fat percentage was similar for all groups within experiments. Feeding wheat middlings, as a replacement for 15% corn silage DM, increased FCM yield from 26.5 to 27.2 kg/d and DM intake from 19.3 to 20.6 kg/d (Wagner et al., 1992). Bernard and McNeill (1991) found that high fiber energy supplements (corn gluten feed, soybean hulls or wheat middlings) supported milk production equally; however, there were differences in DM intake and milk composition.

CONCLUSIONS

Digestible fiber sources discussed in this review were chosen for their potential ability to replace a portion of the forage in diets fed to dairy cows by providing effective fiber. Effectiveness of the fiber content of a diet is a critical characteristic in formulation of the dairy cow diet. It is apparent that more research is required to provide reliable effective fiber values for non-forage fiber sources. A major problem associated with using by-product feedstuffs to replace forage in the diet is the variation in nutrient composition within and among feedstuffs. Several factors influence composition of by-products including grain quality and consistency in processing procedures. Similar to forage testing, it is imperative that every batch of by-product feeds be analyzed for nutrient composition to ensure proper ration balancing. In addition to their ability to replace a portion of forage DM, many by-products fed to dairy cattle have other desirable characteristics. Feeding high levels of cereal grains, with high sugar and starch content, to dairy cows can lead to digestive disturbances such as acidosis, reduction of cellulolytic activity in the rumen, lower concentrations of milk fat and changes in energy partitioning towards fat deposition. Replacement of high starch supplements, such as barley and corn, with highly digestible fibrous by-products can alleviate some of these problems. Some of these fibrous sources may induce rumination; however, others reduce acid load by diluting or decreasing starch content of the diet. Another benefit of by-product feedstuffs is that several are good sources of undegradable protein. In conclusion, the decision to use non-forage fiber sources in the dairy cow diet should be made based upon nutritive value, availability and cost of the product.

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STARCH UTILIZATION IN RUMINANTS

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INTRODUCTION

The production of finished beef and dairy products derives the bulk of dietary energy from the consumption of feed grains. Starch typically constitutes 70% of the dry matter of feed grains, making it the major dietary energy constituent. Ruminants have evolved utilizing cellulosic materials with a digestive system designed for slow digestion of fibrous feedstuffs and an apparently limited capacity for host enzymatic hydrolysis of α -linked glucose (Owens et al., 1986).

Optimizing starch utilization in the ruminant requires that we as researchers and nutritionists consider our options to affect starch digestion in the ruminant. By choice of grain, processing, forage level etc., we can impact how and where the starch is digested. Theoretical calculations suggest that digestion of starch in the small intestine is energetically favorable (Owens et al., 1986), but experimental data have not been able to establish relationships between small intestinal starch digestion and glucose absorption (Gross et al., 1988; Kreikemeier et al., 1991). In the remainder of this paper I will describe factors that affect starch digestion in the ruminant, and discuss current research information that describes starch digestion in the ruminant.

STARCH DIGESTION IN THE RUMINANT

Fermentation of starch in the rumen can be quite extensive, but is variable depending on grain source, degree of processing, etc. Table 1 summarizes ruminal starch digestion in cattle as affected by grain source and processing. Overall, ruminal starch digestion varies from 39 to 94%, depending on grain source and processing method. Processing tends to reduce the variability and increase ruminal digestion, (e.g. high-moisture and steam-flaked corn) with milo exhibiting the greatest degree of variability.

It follows that since 39 to 94% of starch intake is digested in the rumen, 6 to 61% is potentially available for digestion in the small intestine. Small intestinal starch digestion in the ruminant occurs via the same processes as it does in the nonruminant. Pancreatic α -amylase initiates the hydrolysis of the starch molecule, producing shorter chain glucosides containing 2 to 5 glucose molecules. These shorter chain glucosides are then hydrolyzed at the surface of the intestinal mucosa by various glucosidases producing glucose that is then available for absorption. Table 2 summarizes experiments determining starch disappearance in the small intestine. Starch disappearance in the small intestine ranges from 10 to 96%, while the quantity disappearing ranges from 40 to nearly 900 g/d. The variability is considerable, particularly for the sorghum grains.

TABLE 1. Ruminal Digestion of Starch from Various Grain Sources in Cattle¹

Grain Source	Range of Values	Percentage of Starch Intake Digested in the Rumen ²	
Wheat	-	94	n = 1
Barley	-	88	n = 1
High-moisture corn (bunker)	89-90	89.5 ± 5	n = 2
Steam-flaked corn	79-94	84.5 ± 1.3	n = 10
Dry-rolled corn	61-93	79 ± 3.3	n = 11
Steam flaked or Reconstituted Milo	61-96	78 ± 3.1	n = 13
Whole-shelled corn	52-75	63.5 ± 5.6	n = 4
Dry-rolled milo	39-86	62 ± 4	n = 15

¹Adapted from Theurer (1986); Zinn (1990^{a,b}); Spicer et al. (1986); Streeter et al. (1989;1990); Brink and Steele (1985); Stock et al. (1987)

²Mean ± SE; n = number of experiments

Ideally, we would formulate diets to ensure the digestion of starch prior to reaching the terminal ileum. Starch passing to the large intestine would be subjected to further microbial fermentation. Fermentation of starch in the large intestine would result in the production and absorption of volatile fatty acids, but any resulting microbial protein would be lost in the feces. This results in the large intestine being the least efficient site for starch digestion. However, before we can formulate diets based on starch degradability we need to be able to predict rumen degradability and understand the limitations to small intestinal digestion.

CAPACITY FOR SMALL INTESTINAL STARCH HYDROLYSIS

Numerous workers have postulated that the ruminant small intestine has a limited capacity for starch hydrolysis. These conclusions were based on experiments in which pulse doses of starch were given abomasally and either the response in blood glucose was monitored (Larson et al., 1956; Huber et al. 1961) or the disappearance of starch at the ileum was measured (Mayes and Orskov, 1974). Karr et al. (1966) fed steers diets containing increasing amounts of corn (decreasing amounts of alfalfa hay) to evaluate the influence of starch supply on small intestinal disappearance. Their results showed that with increasing starch supply to the small intestine, starch digestibility decreased, and there was a plateau in the amount of starch that disappeared. Conversely, Little et al. (1968) fed steers alfalfa hay and dosed them abomasally with starch and monitored small intestinal starch disappearance. Starch digestibility averaged 44%, and the amount of starch disappearing from the small intestine increased linearly with starch supply. Owens et al. (1986) summarized results from several experiments and derived the following relationship for steers fed various forms of corn grain; Starch digested = .55 Starch supply + .04 ($r^2 = .645$; $n = 31$; $P < .001$). This relationship suggests two very important points. First, an average of 55% of the starch flowing to the small intestine disappeared there and secondly, the

relationship is linear, indicating no apparent limit to the quantity of starch that will disappear in the small intestine.

TABLE 2. Summary of experiments determining small intestinal starch digestion in steers

Source	Body weight	Adaptation	Small intestinal starch		Starch intake	Grain source
			Disappearance	Digestibility		
	kg	d	g/d	%	g/d	
Karr et al. (1966)	360	30	range 331-624 mean 507	64-93 80.2	1002-2684 2018	Corn
Little et al. (1968)	370	14	range 120-290 mean 179	31-60 47.0	4000	Corn Starch
Russell et al. (1981)	350	10	range 221-415 mean 318	46-49 47.5	1699-3216 2458	Corn
Hill et al. (1991)	350	14	range 270-585 mean 420	51-63 55.0	3753-3843 3804	Sorghum
Hibberd et al. (1985)	340	7	range 281-668 mean 478	29-71 47.0	4126-4822 4578	Sorghum
Axe et al. (1987)	295	7	range 493-867 mean 635	62-95 76.4	2669-2827 2724	Sorghum
Streeter et al. (1989)	315	7	range 40-220 mean 122	10-33 17.3	4079-4495 4210	Sorghum
Streeter et al. (1990)	230	7	range 168-330 mean 231	24-42 33.8	2769-3085 2893	Sorghum
Zinn (1988)	220	14	range 130-168 mean 148.3	71-77 74.0	2062-2246 2154	Barley
Zinn (1989)	315	14	range 154-173 mean 162	77-81 78.9	2012-2222 2108	Corn
Zinn (1990)	395	14	range 368-544 mean 439	54-96 84.9	2710	Corn
Bock et al. (1991)	347	10	range 346-487 mean 400	67-78 72.4	4090-4342 4183	Corn

From Harmon (1991)

However, limitations to starch digestibility in the small intestine do exist. Many factors influence starch digestion and it is difficult to control these in a single study. Another problem with the studies described above is that they involve measurement of starch "disappearance"

from the small intestine as an indication of starch digestion and utilization. This disappearance is often equated to digestion and assumed absorption of glucose. Numerous reports in the literature for animals fed high grain diets indicate that net absorption of glucose from the portal-drained viscera (portal-arterial glucose concentration difference x bloodflow) is negative, meaning that gut tissues are utilizing greater quantities of arterial glucose than are being absorbed into portal blood. No data are currently available that simultaneously document intestinal disappearance of starch and portal appearance of glucose in animals fed high concentrate diets. Axe et al. (1987) fed duodenally and ileally cannulated steers 90% concentrate diets with the grain portion supplied by dry-rolled wheat, high-moisture sorghum grain or a 50:50 combination of the two. Starch disappearance from the small intestine was 493, 546 and 867 g/d for the wheat, 50:50 and sorghum grain diets, respectively. In a follow-up study (Gross et al., 1988) steers equipped with portal and arterial blood sampling catheters were used to evaluate the influence of small intestinal starch supply on net portal glucose absorption. Similar diets were fed, except that dry-rolled sorghum grain replaced the high-moisture grain. Net portal glucose absorption was not affected by dietary treatment and contributed a maximum of 4% to the total portal energy flux measured. These studies suggest that metabolism by gut tissues may strongly impact the portal supply of nutrients and that other factors such as microbial metabolism within the intestinal lumen may contribute to small intestinal starch disappearance. In a study designed to quantitate intestinal contributions to portal glucose supply, Huntington and Reynolds (1986) abomasally infused glucose and corn starch into heifers. Overall, they recovered an average of 65% of the glucose and 35% of the starch as glucose in portal blood. There was no difference in the amounts of glucose recovered from animals fed alfalfa hay or a high concentrate diet at two intakes.

The only reported effort to simultaneously evaluate small intestinal carbohydrate disappearance and portal appearance of glucose was conducted by Kreikemeier et al. (1991). Steers were fed alfalfa hay to minimize intestinal carbohydrate supply and infused abomasally with glucose, corn starch or corn dextrans at 20, 40 and 60 g/h. These quantities were chosen to provide carbohydrate to the terminal ileum without causing diarrhea or changes in feed intake. Infusions were all 10 h, with samples taken the final 6 h. With all carbohydrates, increasing the amount infused increased the amount that disappeared from the small intestine. Glucose infusion resulted in linear increases in arterial glucose, whereas arterial glucose for steers receiving starch and dextrin infusions plateaued at the 20 g/h level of infusion. Changes in arterial glucose concentration mirrored those in net portal glucose flux. Net portal glucose flux increased with increasing glucose infusion; however, net portal glucose flux plateaued at 20 g/h for the starch and dextrin infusions. Glucose infusion resulted in approximately 18 g/h flowing at the terminal ileum, which meant that 42 g/h disappeared. Net portal glucose flux was 38 g/h, leaving a difference of 4 g/h unaccounted for. For starch, 22 g/h flowed past the ileum, meaning 38 g/h disappeared. Net portal glucose flux was 12 g/h, leaving 26 g/h unaccounted for. Dextrin disappearance was 52 g/h; however, net portal glucose flux was only 10 g/h, leaving a difference of 42 g/h unaccounted for. Previously mentioned factors, such as microbial fermentation and gut tissue metabolism, must certainly make a large contribution to small intestinal carbohydrate disappearance. This is supported by the greater quantity of unaccountable substrate for dextrin, a less complex carbohydrate that may be more subject to degradation in the gastrointestinal tract. These results suggest that studies measuring only intestinal disappearance may overestimate feeding values for starches.

One limitation of measurements of net portal glucose absorption is that actual glucose absorption from the small intestine may be much greater than net portal flux estimates would indicate because of glucose utilization by gastrointestinal, mesenteric fat and pancreatic tissues. Janes et al. (1984) developed procedures to catheterize the mesenteric vein of sheep, which allowed a more direct assessment of absorption from the small intestine, because mesenteric venous blood would exclude blood draining the reticulo-rumen. Their estimates of glucose absorption in sheep fed a corn-based diet accounted for 110% of the starch that disappeared from the small intestine of intestinally cannulated sheep in a companion experiment (Janes et al., 1985). A similar experimental approach was used by Reynolds and Huntington (1988). They fed steers alfalfa and corn-based diets and measured both net portal and net mesenteric glucose absorption. When steers were fed alfalfa, all values for net glucose absorption were negative, indicating that tissues were utilizing greater quantities of glucose than were being absorbed. When the diet contained corn, mesenteric glucose absorption became positive, whereas overall net portal glucose absorption increased but still remained negative, indicating that tissues of the reticulo-rumen were still using greater quantities of glucose than were being absorbed, on a net basis, from the small intestine. Theurer et al. (1990) compared dry-rolled versus steam-flaked sorghum feeding to steers equipped with hepatic portal and mesenteric venous catheters as described above. The dry-rolled sorghum diet should have supplied 50% more starch to the small intestine than the steam-flaked. Despite this apparent large difference in site of starch digestion, net portal glucose absorption was still negative for both diets. Net intestinal glucose absorption was 42 mmol/h for the dry-rolled sorghum compared with 0 for the steam-flaked diet. However, the 42 mmol/h intestinal glucose absorption accounted for only 40% of estimated intestinal disappearance. Although the studies of Kreikemeier et al., (1991) discussed above employed control infusions (water) from which to calculate the quantities of glucose absorbed, any changes in glucose utilization by tissues of the reticulo-rumen because of carbohydrate infusion would not have been detected.

One conclusion from the studies of Kreikemeier et al., (1991) was that the quantity of carbohydrate disappearing from the small intestine increased with intestinal carbohydrate supply. The digestibility (percentage of that entering the small intestine) of that carbohydrate continually decreased, and complex carbohydrates, as well as glucose, were present in ileal digesta. From a digestive efficiency standpoint, the capacity of the small intestine was exceeded, even though greater quantities of carbohydrate would disappear from the small intestine, increasing quantities would flow to the hindgut for fermentation. If the data for net portal glucose were representative of small intestinal absorption (no change in reticulo-rumen glucose utilization), then the capacity for digestion of corn starch and dextrans and the absorption of glucose from their degradation, was maximized at or below 20 g/h supplied to the small intestine.

NUTRITION AND CARBOHYDRASES

Pancreatic and intestinal carbohydrases are thought to respond to changes in diet much the same in ruminants as they do in nonruminants. Pancreatic α -amylase increases with increased intake of starch. Clary et al. (1969) sampled pancreatic tissue from steers grazing pasture or consuming an all-concentrate diet and reported that pancreatic α -amylase concentration was much greater in the concentrate-fed steers. A similar approach was used with sheep fed either dried grass or ground-corn based diets for 4 wk (Janes et al., 1985). There was an increase in

pancreatic α -amylase activity (34%, although not statistically significant) for the grain-fed animals. Interpretation of these results is difficult, because the measured activity of α -amylase in the pancreas may not relate to amounts secreted into the small intestine.

Studies have been conducted with sheep and cattle surgically implanted with reentrant cannula in the pancreatic duct to more directly address dietary influences on pancreatic secretion (Clary et al., 1967; Van Hellen, 1979). Increasing amounts of corn in the diet of sheep increased α -amylase concentration of secreted protein. Steers consuming an 80% concentrate diet at amounts to support gain of .75 kg/d had nearly twofold greater secretions of pancreatic α -amylase; however, specific information on dietary ingredients, processing and actual feed intakes and animal gains was not reported. Chittenden et al. (1984) infused sheep with glucose intraduodenally and reported a 35% increase in pancreatic α -amylase secretion at 16 days of infusion, whereas no changes in α -amylase secretion were reported for sheep infused with propionate duodenally (Johnson et al., 1986), despite changes in blood glucose and insulin. These results suggest that increasing carbohydrate supply increases pancreatic α -amylase. Data for pancreatic enzyme concentrations, in these studies, was in agreement with data for pancreatic secretion. However, the studies cited above may not reflect differences in starch intake, because dietary forage concentration is confounded with metabolizable energy intake. Animals consuming greater quantities of starch also consume greater quantities of metabolizable energy, making interpretation of results tenuous. Few studies have compared metabolizable energy and starch intake independently. Russell et al. (1981) fed Holstein steers either alfalfa hay or a 32% corn, 60% corn silage diet to meet maintenance requirements, then slaughtered them to obtain measures of pancreatic α -amylase concentrations. Steers consuming corn had 31% lower pancreatic α -amylase concentrations than animals fed alfalfa hay, but the difference was not statistically different. In the same study, steers were fed diets based on corn:corn silage at 1, 2 or 3 multiples of maintenance energy. Pancreatic α -amylase concentration increased 185% as energy intake increased from 1 to 2 times maintenance and was not different for 3 times maintenance. These data suggest that pancreatic α -amylase is responsive to metabolizable energy or starch intake, making interpretation of many of the early comparisons of forage versus grain impossible. Recently, Kreikemeier et al. (1990) addressed these questions by feeding calves either a 90% forage (alfalfa) or a 90% concentrate (wheat:milo) diet at either 1 or 2 multiples of their net energy for maintenance requirements (NE_m). As energy intake increased from 1 to 2 times NE_m , pancreatic α -amylase concentration increased by 55% (Table 3). As the diet changed from forage to grain, pancreatic α -amylase concentration decreased by 34%. In an attempt to assess pancreatic α -amylase secretion, the total α -amylase activity of the digesta contents of the small intestine was measured (Table 3). Total small intestinal α -amylase activity decreased with increased grain intake, paralleling the changes seen in pancreatic concentration.

These results suggest that metabolizable energy intake, not starch intake, exerts a major influence on pancreatic α -amylase. Duodenal starch infusion has been shown to decrease pancreatic α -amylase secretion in wethers (Chittenden et al., 1984). Johnson et al. (1977) demonstrated that in rats, the pancreatic response to carbohydrate was dependent on having a high quality protein in the diet. Whether dietary protein quality interacts with dietary carbohydrate and pancreatic adaptation in ruminants is not known. However, animals fed alfalfa hay had higher α -amylase activities than those fed grain at equal energy intakes in the study by Kreikemeier et al. (1990), suggesting that a similar mechanism may be involved. Secretion of

α -amylase in the nonruminant is regulated by changes in blood glucose and insulin (Lahaie, 1984), however the exact mechanism is not well understood. Ruminant glucose metabolism is closely linked to metabolizable energy intake (Schmidt and Keith, 1983) thus, equal metabolizable energy intake of forage or concentrate diets may be expected to influence pancreatic α -amylase similarly. These results may suggest a negative influence of increased small intestinal starch on adaptation of the pancreas.

SUMMARY

Considerable variability exists among feed grains for both ruminal and small intestinal starch digestion. The major site of digestion is generally the rumen, but considerable quantities of starch can be presented to the small intestine depending on grain source and method of processing. The degree of variability in both ruminal and small intestinal starch digestion makes prediction of site of digestion through diet formulation difficult. Experiments determining both small intestinal starch disappearance and glucose absorption indicate that disappearance of starch and absorption of glucose are poorly related. This indicates that availability of small intestinal starch may be lower than previously thought and would suggest that ruminal digestion should be maximized. Studies evaluating small intestinal enzymes revealed that starch digesting enzymes increase with increased feed intake, but decrease with increased starch intake. These changes may contribute to a limited digestion of starch and absorption of glucose. A careful and more detailed analysis of starch digestion in the ruminant will allow us to better understand and optimize the utilization of starch in the ruminant.

TABLE 3. Small intestinal and pancreatic data for calves fed forage or a high-grain diet at two levels of energy

Item	1M ^a		2M		SE
	Forage	Grain	Forage	Grain	
Pancreas					
weight, g ^b	237	227	346	300	26
protein, mg/g	122	111	121	113	3
α -amylase					
units/g pancreas ^{bcd}	388	267	620	397	73
total $\times 10^{-3}$ ^{bc}	88	53	221	120	32
Small intestinal digesta					
weight, kg ^{bc}	3.7	2.8	5.1	4.2	0.5
Total digesta α -amylase,					
units $\times 10^{-3}$ ^c	19.3	12.2	39.4	16.9	6.8
Small intestinal length, m ^b	22.6	20.2	26.8	26.9	1.4

^aM stands for net energy for maintenance.

^bIntake ($P < .05$).

^cDiet ($P < .05$).

^dOne unit of enzyme activity is equivalent to 1 μ mol of reducing sugar liberated per minute using glucose as the standard.

Adapted from Kreikemeier et al., (1990).

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ENVIRONMENTAL BALANCE AND FEEDING DAIRY CATTLE

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Concerns regarding nutrient losses from manure of large dairy herds to ground water or surface runoff have become extremely acute in most regions. These widely publicized concerns are with P contamination, e.g., case of Lake Okeechobee, FL where P washed off farms in surface runoff during summer rainy season, and with N losses in form of nitrate into ground water. An example of the latter is expressed in the deep sands region of Suwannee River basin, also in Florida. Florida is not unique. All states are starting to monitor farms where large numbers of food producing animals are maintained on small acreage to avoid nutrient leakage to the environment. Similar concerns exist with over-application of commercial fertilizers which might lead to leakage of nutrients to surface or ground waters..

Nutrients in manure are recyclable in many ways which can be utilized to avoid nutrient losses to the environment. All methods involve applications of manure nutrients in some form to plants that benefit from nutrient fertilization. However, to avoid excessive concentrations of these nutrients at inappropriate points, it is helpful to budget nutrient flow through the total dairy farm system. If there is a problem concentration at some point, corrective measures can be taken which are environmentally accountable. To do this, quantitative information is needed on nutrient flow through all segments of system. Critical questions are:

1. How much of individual nutrients are excreted?
2. How does manure management system affect nutrient flow?
3. What is potential nutrient uptake by plants?
4. How do you develop a manure nutrient budget?

HOW MUCH OF INDIVIDUAL NUTRIENTS ARE EXCRETED?

Nutrient excretion standards most often used in design of manure management systems are those of American Society of Agricultural Engineers (ASAE, 1990). These standards are based on body weight of cows; however, they do not account for large variation among dairies in feeding levels and consequently excretion levels. Variation is caused by differing voluntary feed intake, supplement levels, and amounts of nutrients harvested in milk. For example, University of Florida experiments (Morse, 1989; Tomlinson, 1992) showed that P and N excretion by dairy cows vary dramatically with level of P or N intake and was predictable with equations based on daily P or N intake, DMI, and milk yield. Data confirmed that excretion estimates based on dietary intake of a nutrient minus amount secreted into milk are good methods of predicting total annual excretion of minerals by mature dairy cows. The following milk composition, typical of Holsteins, was used along with pounds of milk to determine recovery of fed nutrients in milk: protein, 3.30% (N .512%); phosphorus (P), .10%; calcium (Ca), .12%; potassium (K), .15%; magnesium (Mg), .01%.

sodium (Na), .05%; chlorine (Cl), .11%.

Phosphorus excretion estimates in Table 1 illustrate dietary-P of .40%, .45%, or .60% of total diet DM causes changes in estimated annual excretion of actual P from 40 to 46 to 69 lb per cow per year. Thus, dairymen have considerable control of mineral excretion through control of mineral contents in diets they feed. Feeding adequate P is important for animal health and performance but .40% of total diet DM or slightly more is very near estimated requirements for lactating cows (NRC, 1989). Although these data do not lead to lowering of recommended feeding levels for P below standard feeding recommendations, data point out that future committees which develop NRC feeding standards need to review recommended feeding levels for N and environmentally sensitive minerals with objective to keep excretion of these nutrients as low as possible and still maintain optimum animal performance.

Table 1 shows excretion estimates for N from two different diet formulation procedures used by NRC. One is for cows consuming diets formulated to supply crude protein standards (NRC, high); the other (NRC, low) minimizes dietary N by providing minimal nonprotein N and ruminally degradable intake protein (DIP) for optimum rumen microbial fermentation and provides remaining animal requirements with ruminally undegraded intake protein (UIP). Numeric estimates of yearly N excreted by high producing 1400 lb cows were 260 lb per cow per year when fed according to the NRC CP standards and 223 lb N per year when diet protein was formulated for minimum needs of UIP and DIP. As with P, these data suggest that some diet control over N excretion is possible.

Although, yearly excretion estimates in Table 1 are based on diets designed to support higher milk production than many dairymen currently are achieving, most dairies with lower milk production choose to feed as much protein as was used in this example (e.g. up to 17.5% crude protein of total diet DM for high producing groups). Excretion estimates for cows eating enough to produce more than 20,000 lb of milk per year were used because most herds feed diets to support that level of production even if they still are not achieving that production. Individual farms, however, should develop their management plan based on excretion estimates for their cows: e.g., if their herd averages 50 lb milk per day for all milking cows, use excretion estimates for cows producing 50 lbs milk (Table 1) and multiply by average number of days in milk per year, e.g. 305, plus average excretion for dry cows times average days dry, e.g. 60.

Information in Table 1 easily can be extrapolated to any herd size by multiplying number of cows by appropriate factor, e.g., a herd with 100 cows would be estimated to excrete 100 times as much as the yearly excretion estimates in Table 1. With values of \$.30/lb N, \$.60/lb P and \$.15/lb K, total value of these fertilizer nutrients in manure calculate to be about \$10,770 for 100 cows for one year. Although the value of N, P, and K fertilizer nutrients in manure usually is not as great as total costs of recovery of them from the waste management system, their value helps minimize net cost of waste handling. However, this will happen only if nutrients in dairy manure displace purchased inorganic fertilizer nutrients. Also, these values do not take into account losses from the system that decrease amount actually applied to crops. For example, data in Table 1 imply that fresh dairy manure contains:

Table 1. Daily and yearly excretion estimates of various fractions and nutrients by 1400 lb Holstein cows.

	From ASAE (1990)	Daily milk and DMI for:				Total for year
		30 days	70 days	205 days	60 days	
Milk, lb/cow ==>		100	70	50	Dry	21750
DMI, lb/cow ==>		46.3	39.2	25.2	25.2	14462
Excretion for cow described in column above ¹						
Fraction or nutrient	Lb/day	Lb/day	Lb/day	Lb/day	Lb/day	Lb/yr/cow
Raw manure (feces +	120.0	195.0	160.0	125.0	80.0	47475
Feces (wet)		125.0	100.0	75.0	45.0	28825
Urine	36.4	70	60	50	35	18650
Total solids (38% of DMI)	16.8	21.2	17.6	14.9	9.6	5496
Volatile solids	14.0	17.7	14.7	12.4	8.0	4580
BOD, 5-day	2.24	2.82	2.34	1.98	1.28	732
COD, lb	9.8	19.4	16.1	13.7	8.8	5038
Total N, lb (NRC, low)	.63	.899	.727	.601	.364	223
Total N, lb (NRC, high)	.63	1.030	.846	.698	.439	260
Urea + ammonium N		.408	.308	.249	.125	92
Urea + ammonium N		.500	.391	.319	.178	118
P lb (diet .40% P)	.132	.123	.115	.107	.101	40
P lb (diet .45% P)	.132	.151	.138	.126	.103	46
P lb (diet .60% P)	.132	.235	.208	.185	.151	69
K lb (diet .8% K)	.406	.296	.265	.239	.201	88
K lb (diet 1.2% K)	.406	.519	.450	.396	.302	146
Ca lb (diet .65% Ca)	.224	.242	.217	.195	.164	72
Ca lb (diet .90% Ca)	.224	.382	.333	.293	.227	108
Mg lb (diet .20% Mg)	.099	.102	.086	.073	.050	27
Mg lb (diet .35% Mg)	.099	.185	.155	.132	.088	49
Na lb (diet .35% Na)	.073	.145	.127	.112	.088	42
Cl lb (diet .55% Cl)	.182	.197	.178	.161	.138	60
Sulfur	.071					
Iron	.017					
	g/day					
Manganese	1.2					
Boron	.45					
Molybdenum	.05					
Zinc	1.14					
Copper	.28					
Cadmium	.002					
Nickel	.18					
Lead	?					

¹ Data from Van Horn et al. (1991)

N 9.4 lb actual N/ton wet manure
P 1.9 lb actual P/ton wet manure (equivalent to 4.4 lb P_2O_5)
K 3.7 lb actual K/ton wet manure
(equivalent to 4.5 lb K_2O)
Total solids 12.8%

Even if this were composition when excreted, composition when scraped and loaded usually is different due to change in moisture content and volatilization of N. It is important to take samples of manure or wastewater applied to cropland and have these analyzed at a commercial laboratory. Analyses should include total Kjeldahl N and not just nitrate N since nitrate form of N does not occur in manures. Nitrification does not occur until after manure is incorporated into soil. Major forms of N in dairy manure are organic N; urea N, the major source, is converted easily to ammonia and lost to air as gaseous ammonia.

HOW DOES MANURE MANAGEMENT SYSTEM AFFECT NUTRIENT FLOW?

After excretion, manure may be stored wet, stored after being allowed to dry, flushed with water to lagoon or holding pond, spread fresh on land, or spread in some form at later time. The longer time in storage, the greater potential for N losses to air as ammonia. The greater the dilution with water, the greater potential for nutrient losses to surface and ground waters unless included as part of an irrigation program to distribute water and nutrients to growing crops. Few manure systems on farms actually collect all feces and urine at one location for application to one particular unit of land. Separations or losses occur in many ways.

1. Flushed manure from milking parlor and feed barn may go through sand trap and be pumped over a separator screen before irrigation of land with effluent.
2. Manure is dropped in different areas such as pasture, milking parlor, cooling barns, and primary feeding area and some these separations may not be collectible for land-spreading.
3. Some gaseous loss of ammonia occurs (volatilization) which returns a variable but often controllable portion of N to the air.

Other possibilities include surface runoff and loss to groundwater. Management practices must control all of these components so that surface runoff and losses of nutrients to groundwater are minimized and do not cause violations of state water quality standards.

Choice of a manure management system depends on existing facilities. For example, if existing buildings were designed for flushing, a dry handling system would not be possible without major structural modifications. If a new dairy is being planned, then other factors can be considered. In both cases, changes in system must be compatible with other management practices on the dairy and manure nutrients must be spread in a way to recover nutrients in harvested crops or stockpiled in a way which will not pose environmental risks before being spread.

Regulatory requirements influence choice of a waste management system. For example, if surface runoff must be collected, stored, and dispersed on cropland, a liquid handling system is necessary. However, other components could still be handled as a solid or as a slurry.

Many systems exist which remove a portion of solids from manure slurries. Stationary screens are most common with many new dairies experimenting with settling basins of various shapes, depths, and capacities.

Stationary screen separators take out 20 to 30% of organic matter from flushed dairy manure. With very dilute flushed dairy manure, about 20% removal of organic solids is probably the best estimate. Dilution also assures that almost all soluble nutrients stay with the water portion. Most minerals and N are in soluble form (more than 80%).

Table 2. Composition of screened manure solids.

Nutrient ¹	% of DM
Ash	13.3 - 13.4
Nitrogen	1.2 - 1.6
P	.2 - .25
NDF	77.7 - 83.5
ADF	50.5 - 52.7
ADL	12.9 - 15.1
Cellulose (ADF-ADL)	35.4
Hemicellulose (NDF-ADF)	32.0

¹Moisture content usually about 75% (DM, 25%).

Expected composition of dairy manure fiber recovered from a screen and squeezed with a screw press is about 72.0% moisture (28% dry matter) with a nutrient content as in Table 2 (data on a 100% DM basis). Feeding value of this product will not support acceptable daily gains in growing animals. However, manure solids could be fed as an appreciable percentage of diets for cattle which need only to maintain themselves and sustain a slow rate of gain, e.g., dry cows.

Screened manure solids have been used extensively for bedding in free stalls. However, management to prepare properly is critical. An accepted practice seems to be to compost solids so that internal temperatures within the pile become high enough to kill coliform bacteria. Research has shown that even though bacteria decline to low or undetectable numbers during composting, bacteria often return in bedding material in free stalls unless the solids are dry and kept dry. Even when researchers found higher bacterial counts in composted dairy waste solids bedding than on rubber mats, there was no difference in bacterial counts on teats or in milk of cows using the two types of bedding. They concluded that with adequate composting, dairy waste solids were a suitable bedding in free stalls. Many dairymen with excellent mastitis control programs are using dry, screened manure solids for bedding in free stalls.

An alternative to removing solids from flushed manure with screening or centrifuging equipment is to design holding ponds for gravity separation (settling basins). More solids can be removed with well designed sedimentation basins (40 to 60%) than with stationary screens. The key is detention time of water carrying solids. However, sedimented solids have much higher moisture content and are not as useful as screened solids if bedding for free stalls or composting is desired. Thus, land spreading of these solids is most likely method of disposal.

Moore (1989) suggested settling basins should have a concrete bottom to allow a wheel tractor access to remove the settled solids. A slot or V notch outlet allows basin to drain dry.

and still not overtop in high rainfall events. Moore observed a settling basin design in Taiwan which could be used in dairies. Four basins were used, each 75 ft long, 25 ft wide and 18 in deep. All flow from the operation, which marketed 40,000 pigs annually, was directed into one chamber, each on a 4-day rotation. Continuing through second and third day, liquids drain down the 1/150 slope and exit basin through a stainless steel, 5 mesh screen. The fourth day, they empty basin and land-spread solids, The settling basin removed 81% of suspended solids in swine waste.

WHAT IS POTENTIAL NUTRIENT UPTAKE BY PLANTS?

One generally acceptable philosophy of land application of manures is that nutrients can be applied slightly above level of nutrients removed by crops harvested. When animal numbers are high in relation to land available, the system needs to utilize maximum application rates of environmentally sensitive nutrients such as N and P for given soil types and different cropping systems.

A long-term research project at Tifton, Georgia was designed to identify maximum application rate of flushed dairy manure nutrients when a triple cropping system was used. Flushed dairy manure nutrients were applied through a center pivot irrigation system. Cropping system included Tifton 44 bermudagrass sod in which corn was sod-planted for silage in spring and abruzzi rye was sod-planted in fall. Harvests included rye for grazing from about Dec 1 until Feb 15, rye for silage about Mar 20 (corn being planted day following), corn for silage in mid-July, low-quality bermudagrass hay about 10 days later, and high quality bermudagrass hay or grazing until rye was planted again about Nov 1.

In the Georgia experiment, large-particle manure solids were separated from liquid with an inclined stainless steel separating screen (1.0 x 6.0 mm hole size) to facilitate irrigation of effluent. Liquid portion was applied to cropping area at four rates. Actual DM and N yields of the three crops in their rotation in response to different rates of liquid manure application are shown in Table 3. Harvests of all crops yielded 11.69 tons or more of DM per acre (23,380 lb).

Due to luxury consumption of N in plants with higher N applications, particularly in rye, total N harvested in three crops continued to increase after DM yields plateaued. The N application rate reported (340, 440, 660, 880 lb N/acre) is amount of N pumped to irrigation sprinklers. Losses of N through volatilization during irrigation (e.g. 20%), surface runoff, and acceptable losses to groundwater potentially make application of 660 lb N/acre in environmental balance with a total harvest of 525 lb N. These data do not show what happened to excess N with 880 lb N application. From personal communication with Dr. Johnson, preliminary data showed nitrate level in drainage water underneath center pivot area was similar to levels under many corn fields fertilized with commercial fertilizer but was slightly above environmental standard of 10 ppm nitrate N. Due to close proximity of plots, they could not differentiate between application rates but presumably most of excess came from 880 lb N/acre applications.

The Georgia data in Table 3 show that it is possible for N removal in crops to be greater

Table 3. Yields of forage dry matter and recycled N from crops fertilized with flushed manure through center pivot.¹

Estimated annual application of N Lbs/acre	Crop, tons of DM or lb N/acre							
	T-44 bermuda		Abruzzi rye		Corn silage ²		Total	
	DM	N	DM	N	DM	N	DM	N
340	1.82	95	1.90	125	7.97	157	11.69	377
440	2.30	122	2.26	154	7.54	176	12.10	452
660	2.06	112	2.78	222	7.70	190	12.54	525
880	2.03	115	2.48	219	8.00	209	12.51	543

¹Data from Johnson et al. (1991). Fibrous solids of flushed manure were moved before irrigation with stationary manure solids separating screen.

²Mean bushels of grain/acre in silage were 175, 163, 161, and 169.

than that applied, e.g., 377 lb N harvested with 340 lb N applied. For this to happen, N must have originated from soil reserves of N carried over from previous years, from N in rainfall (often estimated at about 15 lb N/year), or from N fixation from air (not likely without legumes in system). For N budgets developed later in this publication, N in rainfall was estimated to be offset by gaseous loss of N from soil and, thus, neither were included in calculations. However, with a deficit of N in soil, gaseous losses from soil might be reduced appreciably permitting gain from rainfall to make a positive contribution. This gain might not be enough to make up the difference in plots with 340 lb N application rate. However, it could explain much of the difference in 452 lb N harvest with 440 lb N application.

Although Johnson et al. (1991) did not report P application rates, P recoveries and recoveries of several other minerals were estimated from feed composition tables (NRC, 1989). These data and data for several other example crops and systems are in Table 4. P recoveries were 55 to 60 lb per acre. P harvests are of particular interest since more acres would appear to be required to accommodate manure P than manure N. Although tempting to compare data in this table directly with estimated excretion rates to estimate acreage needed for manure disposal, factors such as volatilization of N, surface and groundwater runoff, export of some manure fractions off farm, etc. must be considered in budgeting.

Other forage crops, even legumes like alfalfa, have been proposed as good crops for consuming large quantities of manure N since legumes take up soil N in preference to fixing N from air when free N is available in soil to scavenge.

The Georgia cropping system seems to have tremendous potential for Southern US because majority of harvest is corn silage, a high-energy forage that most dairymen use for high producing cows and the sod base is bermudagrass which grows well in a warm season.

Table 4. Comparison of annual estimated uptakes of nutrients by different cropping systems with excretion rates by dairy cows.

Crop	Estimated lb harvested/acre:							
	DM	N	P	K	Ca	Mg	Na	S
DM and N data from Johnson et al., 1991; others estimated:								
#1 (340 N/acre)	23390	377	55	284	61	43	12	33
#2 (440 N/acre)	24200	452	57	302	63	44	13	34
#3 (660 N/acre)	25080	525	60	317	66	45	14	35
Estimated recoveries:								
Corn silage	16000	208	35	154	37	31	5	24
Sorghum silage	16000	154	42	163	46	43	5	23
Alfalfa	14000	448	41	358	216	34	21	43
Perennial peanut	10000	240	22	153	125	31	11	27
Bermudagrass	18000	346	40	306	58	29	24	22
Perennial peanut/rye	14000	329	30	197	131	35	22	30
Bermudagrass/rye	20000	403	43	306	57	29	23	22
Bahiagrass pasture	10000	200	25	145	46	27	10	10
Giant elephantgrass	40000	499	100					
Bermudagrass harvested, ¹								
0 N/acre	2160	30						
100 lb N/acre	7920	132						
300 lb N/acre	14220	323						
600 lb N/acre	17460	442						
900 lb N/acre	18900	554						
Amount excreted/cow/yr								
Lower estimate		223	40	88	72	27	42	26
Higher estimate		267	46	146	108	49		

¹From data cited by Staples, C.R. 1989. Proc. West Florida Dairy Prod. Seminar. FL Coop. Ext. Serv., Dairy Sci. Dept., Univ. Fl., Gainesville, 32611.

Alfalfa, perennial peanut, and giant elephantgrass systems are more hypothetical and need further testing. Winter rye, and presumably winter wheat would perform similarly, is a good luxury consumer of N and works well in rotation with corn for silage to maximize N and P uptake from applied manure.

One advantage of flushed manure systems along with irrigation, is that additional water can

be applied along with fertilizer nutrients so that full response to added nutrients is possible.

HOW DO YOU DEVELOP A MANURE NUTRIENT BUDGET?

After designing essential components of manure management system and estimating total manure nutrient excretion, the next step is to account for what happens to nutrients. If needed, one can develop alternatives to avoid nutrient leakage to environment. This includes utilization of cropping and a land application system that are in nutrient balance. If land with appropriate cropping is available to utilize all nutrients, it is important to apply manure soon after it is produced to recover maximum N. Amounts of N which plants recover are much greater than when manure is stored anaerobically before application due to gaseous losses of N to air. If storage conditions become aerobic, there is substantial additional reduction in amounts of N available to plants.

Even with tightly managed systems, there is considerable N loss through ammonia volatilization. Amount volatilized is influenced by level of N in manure (particularly part originating in urine) and by method of application. Nitrogen in urine originally is excreted in form of urea. Urease enzyme of bacterial origin is present almost everywhere so N in urea is converted readily to ammonia which is lost to the air as free ammonia unless conditions of storage are acidic. In Table 1, nearly half of manure N from cows was estimated in urea or ammonia form (mostly from urine). Most fecal N from cattle is in a more stable form.

Leaching losses also may occur. Application of manures outside growing season or in amounts which exceed crop needs may result in nitrate leaching losses of 25% or more of applied N. High utilization of N by crops can be achieved with lowered environmental risks when manures are applied at a time crops can absorb mineral-N and at rates which do not exceed crop needs.

Several example systems to illustrate how nutrients might flow through manure management systems and acreage needed to utilize manure are illustrated in Table 5. Manure excretion data for Systems 1, 2, and 3 are for 100 cows producing 50 lb milk per day. System 4 is for 100 dry cows. Yearly totals were obtained by multiplying daily data by 365. The systems are:

1. Milking cows producing 50 lb milk per day and fed diets based on NRC Low standards for protein and .40% P are confined in concrete lots, all manure flushed into holding pond for frequent irrigation of cultivated crops taking up 400 lb N and 50 lb P per acre. Solids screened to facilitate irrigation and spread on land.
2. Milking cows are producing, fed, confined, and managed as in System #1 except all manure is flushed into anaerobic lagoon with effluent from second stage of lagoon system used for frequent irrigation of same cultivated crops.
3. Milking cows producing and fed as in Systems 1 and 2 are maintained in dirt lots where 75% of manure is dropped; manure is scraped and hauled

every 3 mo; 25% of manure from milking parlor, holding areas, etc. is flushed and managed as in System #1. Surface runoff water from dirt lots is put into holding pond with flushed water.

4. Dry cows fed to meet NRC Low protein standards and .40% P are maintained on pasture. It was assumed cows harvest 5.0 ton of DM/acre/yr of nonirrigated bermudagrass which recovers 200 lb N (12.5% CP of forage) and 25 lb P. Additional feed was supplemented to provide amounts for dry cows shown in Table 1.

Anaerobic lagoons (#2) which detain flush water for a much longer time than temporary holding ponds have been used extensively. Losses of N from lagoon systems where effluent is applied through overhead irrigation are similar to dirt lot system (#3) because N volatilization is similar. Uncertain part is how much of P and other minerals accumulate in sludge at bottom of lagoon. In this example, it was estimated that 50% of P and 10% of N are complexed in sludge which needs to be periodically removed. Although lagoons reduce acreage needed for day-to-day P budgets, the P must be eventually distributed on acres needing P applications, e.g. every 3 to 10 yr depending on size of lagoon. Finding suitable acreage on which to spread these nutrients may present a problem unless the sludge is spread on farm land other than that used for regular manure spreading. Quantitative data are needed to show how much P and other minerals are retained in lagoons so that acreage requirements for regular manure disposal can be adjusted accordingly. However, it is well documented that sludge accumulates and therefore it needs to be included in nutrient budgets for dairies with anaerobic lagoons. In the four example manure management systems, these assumptions were made:

1. Manure is applied year after year to same land at same rates so carryover of nutrients from previous applications, if any, can be assumed to be equal each year.
2. Assumed losses of N through volatilization were:
 - a. 2% of N dropped on concrete before daily flushing or scraping,
 - b. 10% of N from flushed manure being held only a short time before irrigation,
 - c. 50% of N dropped in dirt lots for clean-up and spreading every 3 mo,
 - d. 40% of runoff from dirt lots which was estimated as 10% of N dropped on dirt,
 - e. 20% in the field after land-spreading N from irrigation or land spreading, and
 - f. 50% of total N dropped in pasture.
3. Runoff from flushed or scraped concrete lots was captured in a holding pond for frequent irrigation and that from dirt lots was captured in a separate holding pond which also was added to the irrigation but after longer time in storage.
4. Surface runoff losses from crop fields of N and P were assumed to be 5% of nutrients applied.
5. To account for normal and acceptable losses to groundwater, it was estimated that 20 lb N/acre and 2 lb P/acre/year pass with water moving through soil into groundwater. This amount was added to estimated uptake of N or P by crops harvested. Estimated uptake of N was 400 lb/acre for cropping systems and 200 for pasture; for P estimated

uptake was 50 lb/acre for cropping systems and 25 for pasture. Although groundwater standards have not been set for P, it was assumed that 1.0 ppm P would be acceptable and that this level would be obtained from 2 lb P/acre/yr.

Table 5 shows a N budget generated from a computer spreadsheet for the four 100-cow groups managed according to scenarios described previously and fed minimal dietary levels of N (NRC low, Table 1). Note, N produced yearly by cow groups flowed somewhat differently through the four hypothetical management systems. Predicted manure disposal acreage needed per 100 cows varied from 17 to 36 acres. Similarly using a P budget, manure disposal acreage needed varied from 71 to 129 acres. It is important to note that 38 of the 73 acres estimated with 100% use of a anaerobic lagoon system were future acres needed when sludge will be removed from the lagoon. Acres for sludge application, however, might very well be acres on another farm to which sludge could be hauled or sold to other farmers for fertilizer.

If same cows had been fed to meet NRC crude protein standards and a more typical level of P (.45% of diet DM), acreage requirements would vary from 19 to 41 acres for N budgets and 84 to 133 acres for P budgets. Direct acreage comparisons are in Table 6.

Regardless of manure management system, more acres are needed to dispose of manure with plant uptake of P as application criterion than with plant uptake of N. Level of feeding (level of production) also has a significant effect. Remember, manure management system differed between groups 1, 2, and 3 and feeding level and system were different for dry cow group, group 4.

Many more scenarios are possible than those illustrated here. Because of large variations from dairy to dairy in systems used and in feeding and production levels, it is essential that each farm be permitted to develop its own budget for nutrient flow. Tables are presented only to help individuals make estimates which are appropriate for an individual farm.

Table 6. Acres needed per 100 cows with N or P criteria.

100-cow group	N based		P based	
	NRC low	NRC high	.40% P	.45% P
Milking cows:				
100% rapid irrigation	36	41	72	85
100% anaerobic lagoon ¹	17	19	73	87
25% flushed, 75% dirt lots	22	26	71	84
Dry cows on pasture	29	35	129	133
¹ Includes future acres at annual application equivalent for sludge of:	5	6	38	44

Table 5. Manure worksheet for nitrogen: needed acreage for 100-cow groups.

Category	Diet N (NRC, low); System:				Worksheet for your dairy
	1	2	3	4	
	MY=50	MY=50	MY=50	Dry	
Number of cows per group	100	100	100	100	
% to be flushed to holding pond	100	0	25	0	
% to be flushed to anaerobic lagoon	0	100	0	0	
% to be scraped from concrete daily	0	0	0	0	
% scraped from dirt lot quarterly	0	0	75	0	
% dropped in pasture	0	0	0	100	
Lbs daily N excretion/cow	0.601	0.601	0.601	0.364	
Lbs yearly N excretion/group	21937	21937	21937	13286	
	Lbs	Lbs	Lbs	Lbs	
Volatilized N on flush floors (2%)	439	439	110	0	
N flushed for weekly irrigation	21498	0	5374	0	
N removed by solids separator screen	1306	0	326	0	
N to holding pond--irrigation weekly	20192	0	5048	0	
Volatilized N from holding pond (10%)	2019	0	505	0	
N irrigated from short-term holding	18173	0	4543	0	
N flushed to anaerobic lagoon	0	21498	0	0	
N retained in sludge (10% of N)	0	2150	0	0	
Volatilized N from lagoon (60%)	0	12899	0	0	
N irrigated from lagoon--2nd stage	0	6449	0	0	
N runoff from dirt lot (10% of original)	0	0	1645	0	
Volatilized N from dirt lot holding (40%)	0	0	658	0	
N irrigated from dirt lot holding	0	0	987	0	
Total N applied through irrigation	18173	6449	5530	0	
Volatilized N during irrigation (20%)	3635	1290	1106	0	
Volatilized N on scraped floors (2%)	0	0	0	0	
Volatilized N, pastures (50% of original)	0	0	0	6643	
Volatilized N, dirt lot (50% of original)	0	0	8226	0	
Yearly lb N hauled daily from concrete	0	0	0	0	
Yearly lb N hauled quarterly from dirt	0	0	6581	0	
Volatilized N, land-spread from concrete	0	0	0	0	
Volatilized N, land-spread from dirt lots	0	0	1316	0	
Surface runoff (5% of crop applications)	909	322	606	332	
Irrigated N available to plants	13630	5837	4148	0	
Screened solids, N available to plants	1306	0	326	0	
From concrete, N available to plants	0	0	0	0	
From dirt lots, N available to plants	0	0	4936	0	
Pasture N available to plants	0	0	0	6311	
Summary: Total N in lagoon sludge	0	2150	0	0	
Summary: Total N volatilized	6093	14627	11921	6643	
Summary: Surface runoff	909	322	606	332	
Summary: Applied N available to crops	14935	4837	9410	6311	
Total N managed (= yearly excretion)	21937	21937	21937	13286	
Acres needed/100 cows for manure for:	acres	acres	acres	acres	
Irrigation if N/acre = 400 + 20	32.5	11.5	9.9	0	
Scrapings from concrete, N/acre=400+20	0	0	0	0	
Scrapings from dirt lot, N/acre=400+20	0	0	11.8	0	
Screened solids, N/acre = 400 + 20	3.1	0	0.8	0	
Pasture if N/acre = 200 + 20	0	0	0	28.7	
Future: Lagoon sludge, N/acre=400+20	0	5.1	0	0	
Total acres needed, N basis	35.6	16.6	22.4	28.7	

Acres calculated by dividing nutrients available to plants by estimated uptake of 400 lbs N/yr for cultivated crops (pasture=200) + 20 lbs/acre groundwater passage.

Principles of nutrient budgets can best be summarized by visualizing total nutrient cycle necessary to achieve environmental balance. Figure 1 illustrates a system balanced for N which is constructed from data presented in previous tables. For this system, average dairy cows producing 50 lb milk/day/yr were chosen in which manure was flushed to a holding pond for frequent irrigation (System 1, Table 5). Irrigated N was utilized in the triple crop system of corn silage, bermudagrass hay, and rye silage (Table 3) in which 452 lb N were recovered in harvested crops. To achieve balance, manure from 3.5 cows was flushed and effluent from solids separating screen was irrigated with sprinkler irrigation heads on one acre of land. Cows consumed feed containing 1105 lb N, produced milk (7420 gallons) containing 327 lb N and 3 newborn calves with 10 lb N. The 3.5 cows excreted manure containing 768 lb N of which 15 lb N volatilized before flushing, 53 lb N were recovered in screened manure solids, 70 lb N volatilized during holding, 126 lb N volatilized during irrigation, 31 lb N were lost to surface runoff, and 20 lb N passed through to groundwater. Net recovery of 452 lb N in harvested feed was recycled to dairy cows in feed harvested from the acre to which flushed manure effluent was applied. Purchased concentrates and supplements (53% of estimated DM cows were estimated to consume) imported 653 lb N to farm. In this system, it is assumed the 53 lb N in screened manure solids (separated to facilitate irrigation) were exported from the farm after composting. Note, in this system it is estimated that 15 lb N available to the crop acre in annual rainfall is directly offset by an equal amount of gaseous N loss from soil.

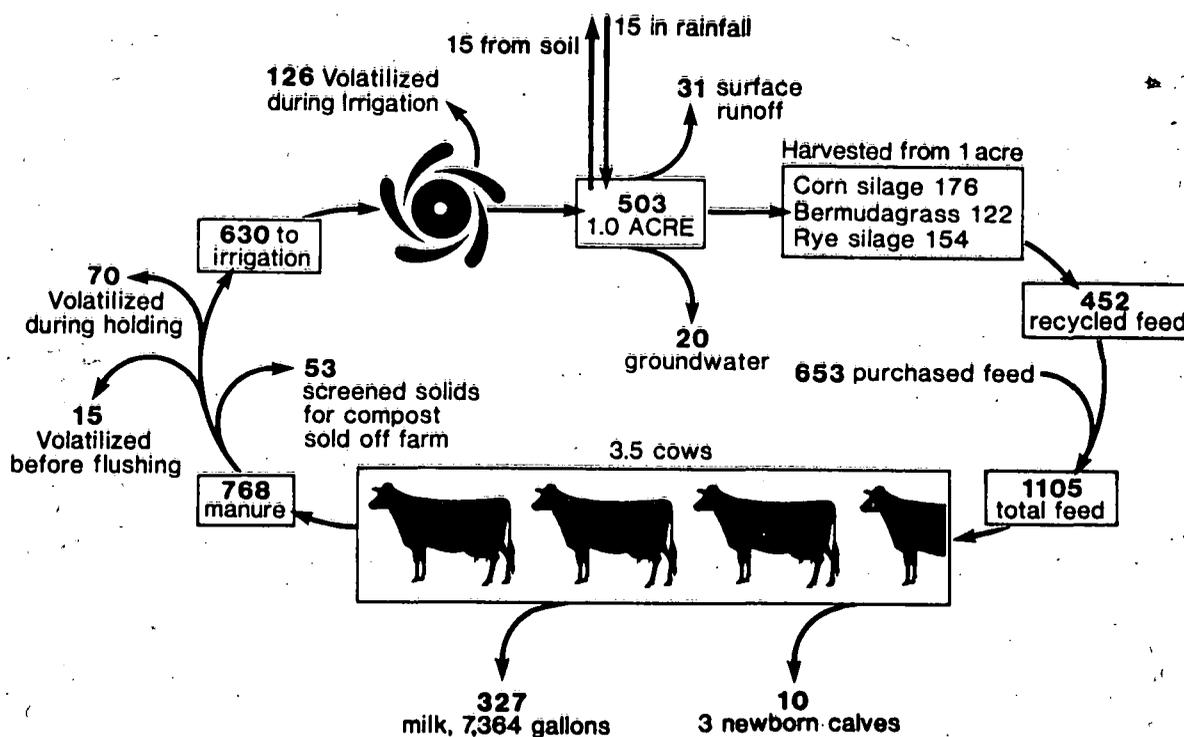


Figure 1. Example of dairy manure system where N is environmentally balanced. Numbers represent lb N. Crop N is from Table 3; excretion and losses are calculated as in Table 5, System 1.

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METHANE EMISSIONS FROM CATTLE: GLOBAL WARMING AND MANAGEMENT ISSUES

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The concentration of several trace gases in the earth's atmosphere have increased dramatically in the last one to two centuries. Several national and international groups of scientists (Kerr, 1992) conclude that these increases will lead to significant climatic shifts. Included is an increasing average global temperature from 1.5-4.5°C (3-8°F). The amount of warming is a function of the increased gas concentrations, their infrared absorbing ability and their half-life in the atmosphere. The major "greenhouse" gas causing about half of the warming is carbon dioxide, arising primarily from fossil fuel and rain forest combustions. Methane increases will likely cause about 15% and nitrous oxide, an additional 7% of the warming.

Methane concentration in the atmosphere was around 750 ppb for thousands of years, up to 200 years ago. It is presently increasing at 1% per year (Khalil and Rasmussen, 1990). The projected 1992 global concentration average is 1751 ppb. About 550 Tg (1 Tg = 1,000,000 metric tons) of methane is estimated to enter the atmosphere yearly, while about 460 Tg are consumed in the atmosphere and by soils (Table 1).

The largest single source of methane is from natural wetlands (Table 1), where organic matter decays anaerobically, producing an estimated 125 Tg annually. Although considerable uncertainty remains (i.e., termites), most authorities put modest estimates on amounts from other natural sources. About one-third of all methane is from natural sources.

The other two-thirds of methane is termed anthropogenic, or related to human activity. Approximately 145 Tg originates from energy production activities (coal, gas industries, or from landfills. Note: Fossil fuels have a triple-whammy effect on warming; CO₂, NO_x and CH₄). The remaining sources relate to agricultural activity accounting for approximately 250 Tg or 40% of all methane.

The largest agricultural source is associated with rice production (110 Tg) with a smaller amount (15 Tg) arising from biomass burning. Present best estimates suggest that the enteric or "gut" methane from livestock amounts to 75 Tg annually. Another 15 Tg may arise during manure disposal from farm animals, principally through the use of anaerobic lagoons. Livestock, thus, probably contribute about 16% of the methane entering the atmosphere. Please note, however, the rather large uncertainty range of estimates for most methane sources.

¹Professor, Postdoc, Professor Emeritus, respectively.

Table 1. Global sources and sinks of atmospheric methane^a

Sources	Tg/yr (range) ^b		Sinks	Tg/yr
Wetlands	125	(100-200)	Hydroxyl (OH)	420
Oceans, hydrates	35	(10-80)	Soils	30
Termites	20	(10-100)	Cl and O	10
Burning and other	10	(5-15)		
Natural sources total	190		Total	460
Rice	110	(25-150)		
Livestock	75	(50-110)		
Manure	15	(10-35)		
Biomass burning	15	(10-30)		
Agricultural total	215			
Gas and oil industries	70	(25-85)		
Coal mines	40	(20-43)		
Charcoal/wood	10	(5-30)		
Landfills	25	(15-70)		
Energy and waste total	145			
All sources total	550			

^aCompiled from Cicerone and Oremland, 1988; Crutzen, 1991; and NATO Workshop Proceedings, 1991 (in press).

^bTg = Teragram = 10^{12} g = million metric ton, range = range of estimates.

The origin of methane produced by animals is microbial action in their gastrointestinal tracts, which occurs to varying degrees in all animals. Major fermentative digestion allowing utilization of fibrous dietary components occurs in herbivores, particularly ruminants, which have an accentuated microbial activity. Their gut structures and diets, coupled with large body size, appetites and animal numbers results in 95% of animal methane arising from ruminants, about 80% from the bovidae family alone. Sheep and goats account for another 12%, while horses and pigs are next on the list, contributing approximately 2 and 1%. Stoichiometry of the fermentation of carbohydrate to common ratios of volatile fatty acid products results in the compulsory production of hydrogen as an intermediary byproduct. If hydrogen were allowed to accumulate, it would interfere with the thermodynamic favorability of the hydrogen production reactions and interfere with the growth of corresponding organisms, many cellulolytic species. Thus, the presence of methanogenic bacteria improves the growth and efficiency of other organisms and captures ATP from the reduction of CO_2 to CH_4 , thus furthering the amount of bacterial matter presented to the animal to improve its protein nutrition. The amount of hydrogen presented to methanogens for methane production depends on several factors. First is the amount of carbohydrate fermented, which in turn depends on a host of diet animal interactions; including amount

and type consumed; rates of carbohydrate digestion and passage, etc. The second primary factor regulating the hydrogen supply to methane is the ratio of volatile fatty acids produced, primarily the ratio of acetic acid to propionic acid. If all acetic acid is produced, then 33% of the energy of the substrate would be given off as methane gas, whereas if the ratio of acetate to propionate is 0.5, the methane production would be zero. Since A:P ratios typically vary from approximately 4 to .9, the corresponding methane loss varies widely. Alternate hydrogen sinks, i.e., microbial growth, unsaturated fatty acids, nitrates, etc., also can have some effect on methane production.

The extremes of methane loss found in the literature from sheep and cattle with functional rumens show wide variations ranging from under 2 to nearly 12% of the gross energy of the diet. As Figure 1 illustrates, lower digestibility or all forage diets are more consistent in fraction of methane loss. The extremes of both high and low losses occur with higher digestibility and higher concentrate diets. Further examination reveals that the very high fractional methane losses only occur when highly available carbohydrates are fed at limited intake. Also, the very low amounts of methane loss will only occur at very high intakes of very highly digestible diets. Only the latter commonly occurs in commercial practice, i.e., the U.S. feedlot cattle industry.

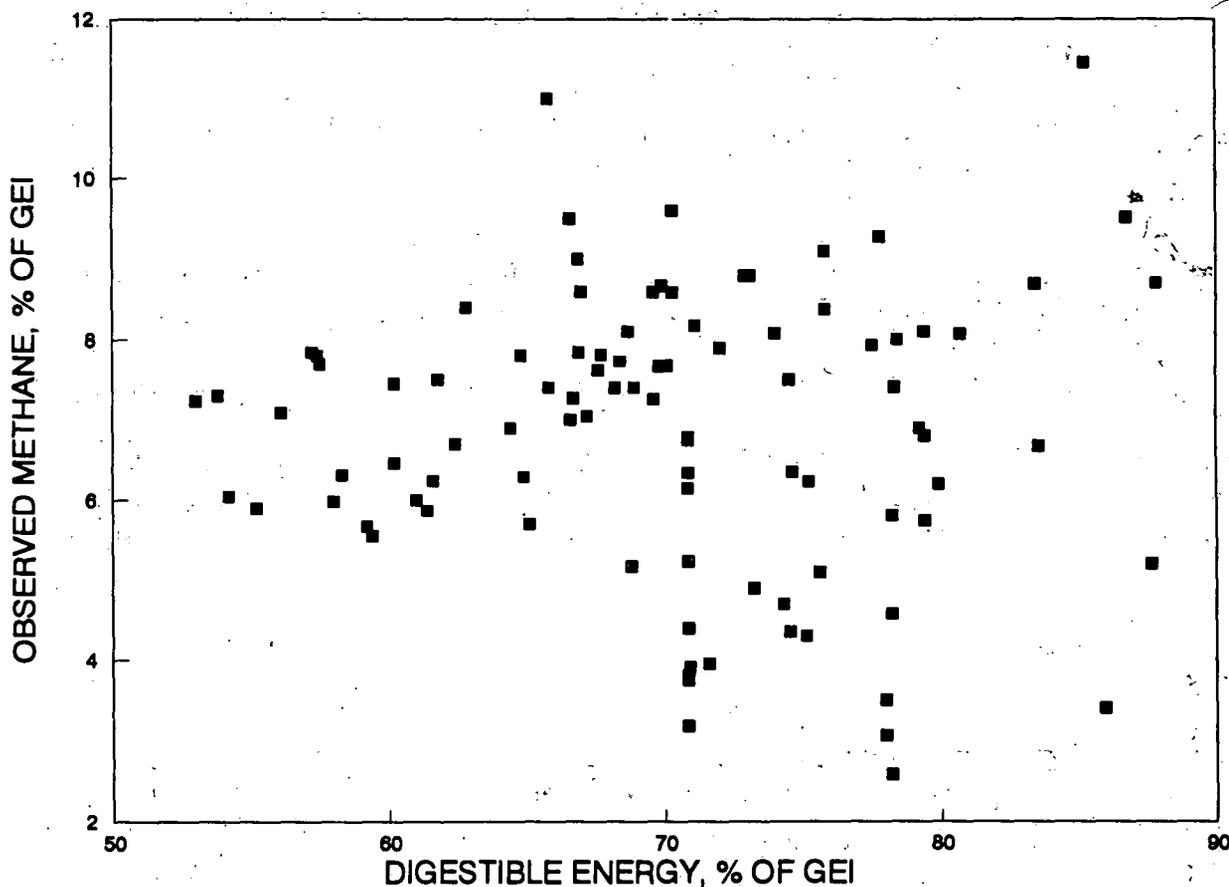


Figure 1. Observed production of methane versus digestible dietary energy. Methane = $9.6 - 0.038$ digestible energy, $R^2 = 0.03$, $P < 0.01$.

Table 2. Prediction equations of methane loss at various levels of concentrate in beef cattle diets

% Diet Conc.	CH ₄ = Equation ^a	R ²
0-20	7.8 - 9.14 GEI + .02 DE	.54
	5.5 - 2.25 LOI + .06 DE	.57
> 20-80	10.5 - 8.81 GEI - .01 DE	.22
	11.3 - 1.81 LOI - .02 DE	.27
> 80	12.2 - 9.54 GEI - .05 DE	.14
	9.9 - 1.54 LOI - .01 DE	.18
All diets	9.1 - 8.23 GEI	.18
	9.1 - 11.97 DEI	.21
	9.5 - 1.84 LOI	.31
	11.0 - 8.35 GEI - .03 DE	.20
	10.3 - 1.79 LOI - .01 DE	.31

^aGEI = daily gross energy intake (Mcal) per BW^{.75}, DEI = daily digestible energy intake (Mcal) per BW^{.75}, LOI = level of intake calculated as per Blaxter and Clapperton (1965) but using MAFF (1976) linear equation to predict fasting heat production, DE = digestible energy (percent). For all diets, n = 118; for 0 to 20% CON, n = 32; for > 20 to 80% CON, n = 64; for > 80% CON, n = 22.

Several dietary intake descriptors and digestibility were related to methane production in beef cattle using 118 treatment means from the literature. The relationship between methane and level of intake ($R^2 = 3.1$) was greater than the relationship between methane and digestible energy ($R^2 = .01$). Increasing digestibility positively affected methane losses from high forage diets, but negatively for mixtures or high grain diets. Level of energy intake was consistently negatively related to % methane loss (Table 2). Percentage losses decline about 1.8 units per increased intake expressed as multiples of maintenance or 9 units per Mcal increase in GE/W^{.75}. Considering the difficulty in calculating level of intake as a multiple of maintenance, intake energy per unit metabolic body size seems appropriate and is less confusing to apply.

The fermentability of feeds should possibly be considered in prediction equations, however, data in the literature that simultaneously quantitate ruminal fermentation fractions of feeds and methane production are virtually non-existent. Data of Wainman et al. (1984) would suggest that methane production may be greater with highly fermentable feeds, such as cassava and barley, and lower with low starch feeds, such as distiller's grains and corn gluten feed. Comparisons of beet pulp to barley, however, suggest the opposite (Beever et al., 1989). Giger-Reverdin et al. (1990) developed a prediction equation with ether extract as a variable that was negatively correlated to methane losses from feeds, consistent with data of Swift et al. (1948), Czerkawski et al. (1966), Haaland (1978) and Van der Honing et al. (1981).

Feed additives such as monensin (Joyner et al., 1979; Thorton and Owens, 1981; Benz and Johnson, 1982) and lasalocid (Delfino et al., 1988) have been demonstrated to suppress methane production, possibly through selection, against certain strains of ruminal microorganisms and altering the ruminal fermentation patterns in short term experiments. This suppression in methane production did not persist beyond 16 days in 45-day persistence experiments with feedlot cattle given monensin, lasalocid and daily rotations of the two as reported by Abo-Omar (1989) or monensin as reported by Carmean et al. (1992) when these ionophores were given as additives to 90% concentrate diets.

Utilizing these prediction equations, methane as a percentage of gross energy intake from various classes of animals fed typical diets was calculated (Table 3). Fattening cattle were projected to lose about 3.5% of diet energy as methane compared to around 6% for other classes of cattle.

Table 3. Prediction of methane loss from typical diets fed to different classes of beef cattle using various prediction equations^a

Class	Daily Gain (kg)	Daily ME intake (Mcal)	Diet DE (%)	ARC LOI ^b	% CH ₄ predicted by equation ^c	
					LOI	DE-LOI
Cow, maint.	0	16	48	1.1	7.2	5.9
Cow, lact.	0	20	56	1.5	6.5	5.5
Growing	.7	15	63	2.0	6.2	6.5
Fatten	1.4	26	84	2.6	4.4	4.2

^aNRC (1989) requirements by class. B-C equation is percentage of CH₄ = 1.30 + .112 DE + LOI (2.37 - .05 DE).

^bLevel of intake as a multiple of maintenance calculated as per Blaxter and Clapperton (1965), but using the MAFF (1975) linear equation to predict fasting heat production.

^cEquation from Table 2 to calculate CH₄ as a percent of gross energy intake.

Methane production per slaughter steer was projected for various management scenarios (Table 4). Scenarios 1 and 2 compared two typical management systems for growing and fattening cattle in the U.S. Considerably less methane per lifetime is projected for calves weaned and placed directly in the feedlot (28 kg) compared to a stocker phase preceding a feedlot phase (41 kg). Scenario 3 represents the typical Australian system (Howden, 1991) of calves finished on a 1051-day grazing period (169 kg of methane per lifetime). Scenario 4 doubles rate of gain by improving dietary energy quality from 57 to 63% digestible energy by supplementing concentrates. The results are a reduction of 43% in methane production per lifetime compared to Scenario 3. Considering these scenarios, large reductions in methane per slaughtered animal's lifetime apparently can be achieved through management strategies that improve animal performance.

In conclusion, the contribution of livestock methane emissions to global warming is small, about 2% of all greenhouse gas effects. Strategies to reduce methane losses from cattle should probably focus on improved production efficiency. These strategies are also likely to make a contribution to reduce future warming.

Table 4. Various management scenarios and estimated methane production per animal lifetime

Class	Days	Daily gain (kg)	Daily ME intake (Mcal)	Diet DE (%)	%CH ₄	CH ₄ l/d	CH ₄ /kg
<u>Scenario 1</u>							
Calf	210	---	1.2	---	6.0	34	5
Stocker	150	.7	6.5	63	6.5	199	21
Feedlot	140	1.4	8.8	84	3.5	145	14
Total							40
<u>Scenario 2</u>							
Calf	210	---	1.2	---	6.0	34	5
Feedlot	251	1.2	7.9	84	3.5	130	23
Total							28
<u>Scenario 3</u>							
Calf	180	---	1.2	---	6.0	34	4
Stocker	1051	.35	7.5	57	6.2	220	165
Total							169
<u>Scenario 4</u>							
Calf	180	---	1.2	---	6.0	34	4
Stocker	514	.7	8.2	63	6.5	249	92
Total							96

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NUTRIENT RECYCLING WITH RUMINANT MANURE APPLICATIONS

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Manure applications have raised agronomic, economic, and environmental concerns including the acute awareness of the potential problems manure might have on groundwater quality. Application of manure has traditionally been concentrated on fields that facilitate its disposal, resulting in high potential for nitrate leaching into the groundwater.

According to 1990 Minnesota Agricultural Statistic Service data, the dairy industry in Minnesota generates approximately 11 million tons of manure annually. Dairy cattle in Minnesota excrete almost 55,000 tons of nitrogen (N) per year that can serve as a nutrient source for crops. This manure also contains 22,000 tons of P_2O_5 (phosphorus (P) fertilizer equivalent) and 44,000 tons of K_2O (potassium (K) fertilizer equivalent). Although some losses of these nutrients are inevitable in handling and storage, manure can replace the need for commercial fertilizer on thousands of Minnesota's cropland acres.

More emphasis and scrutiny will be placed on manure management in the coming years. The driving force behind this emphasis will be environmental rather than agronomic or economic reasons. And as nonagricultural residents increase in rural areas, pressures to conform to existing, and possibly more restrictive, regulatory guidelines will expand.

WHOLE FARM NUTRIENT SCENARIO

As nutrients are excreted from livestock in manure, the fate of these nutrients is limited. The nutrients could be applied to cropland and, therefore, being recycled into a growing crop. This is the preferred option for manure's nutrients. The nutrients might accumulate in the soil in the field or at the barnyard--this can be due to storage system logistics (i.e. settling basins, open yard) or onto fields in which the application rate is far greater than the crop demand (i.e. field behind the barn). These fates are environmental liabilities--sooner or later these nutrients can potentially move into surface or groundwater. Another fate for N are the chemical reactions that put N into the atmosphere (i.e. volatilization, denitrification). Although this gaseous N loss is not associated with water quality, there are indications that this can have some air quality ramifications.

The environmental goal for the livestock producer is to have the nutrients contained within the manure be recycled through crops. All other options have either immediate or long-term environmental implications. Thus, the task for dairy producers is how to manage the manure on their farms so that recycling of the nutrients is accomplished rather than applying the manure to cropland at rates in which nutrients will accumulate.

A theoretically perfect system on any given farm is to have a complete nutrient balance--all nutrients staying on the farm, just moving between the fields and the barn. While this situation is not feasible, it is the scenario that one can use to exemplify the perfect recycling system.

The self-contained nutrient enterprise would not have any nutrients brought in or taken off the farm. This may sound like the demise of a crop production system, yet if all nutrients taken off each field are replaced with the manure, with no nutrient losses, production should be in equilibrium between the

animals and the crops. So, no fertilizer, no atmospheric N, or feed and feed additives would be brought onto a farm. Also, no animals or animal products, crops, manure and/or effluent, or volatile nutrients would be removed from the farm. This results in an equilibrium of nutrients on a farm.

Modern farms will not be able to achieve this self-contained nutrient system for several obvious reasons. First, milk and/or animals must be sold off-farm to provide farm income. Second, all manure handling and application systems allow some gaseous losses of nutrients to the atmosphere--regardless of how one may try to avoid them. Third, it is very likely that alfalfa will be grown and this will add atmospheric N into the soil for a net increase for the whole farm. Finally, additional nutrients will be imported onto a farm from feed or feed supplements. Figure 1 depicts the imports/exports of nutrients from a typical dairy farm.

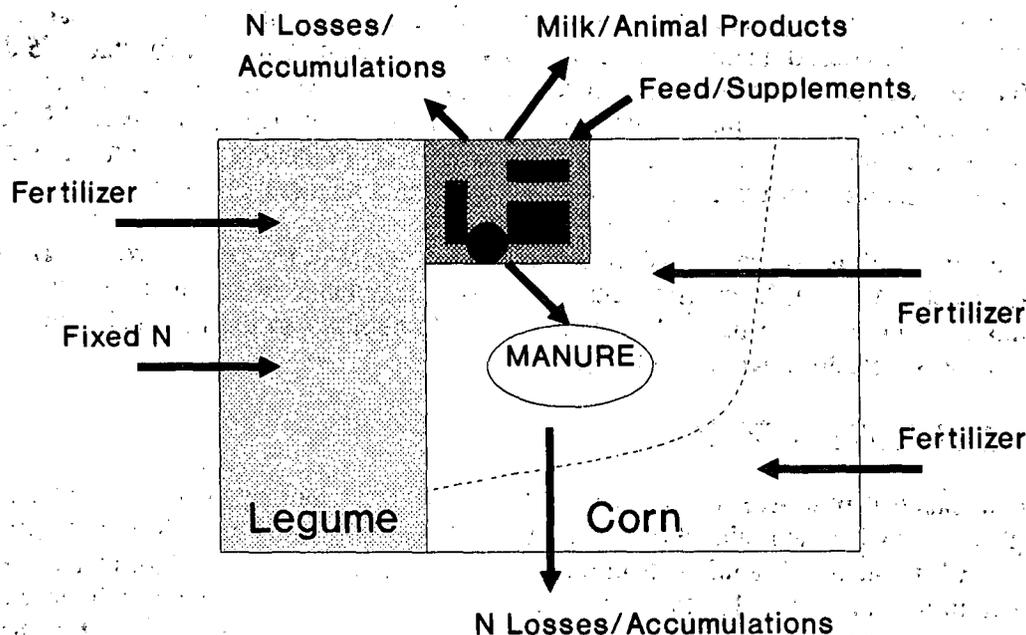


Figure 1. Simplified schematic farm set-up with fields and buildings indicating nutrient imports and exports.

In the real world, most dairy farms are having a net import of nutrients. In using a corn:alfalfa ration for a set number of cows and the current recommendations not to put manure onto alfalfa, the nutrients in the manure will be greater than the cropland needs for the nutrients. Thus, more emphasis must be placed on how to minimize the build-up of nutrients on a whole-farm basis through a complete nutrient management plan. This leads to several targeted areas of manure management that can be refined for better nutrient recycling efficiency.

1. Reduce commercial fertilizer purchases. Numerous surveys and studies have verified that legume and manure nutrient credits are underestimated, thus justifying the "insurance" use of commercial fertilizer. Nutrient credits can be quantitatively assessed with some simple analytical tests and equipment calibration so that dairy producers can confidently apply manure to all fields needing nutrients, thereby reducing/eliminating commercial fertilizer needs. Manure is generally concentrated on only a few fields due to logistical reasons, by accounting for the fertilizer savings on more distant fields the manure will have more perceived value.

2. Reduce excess nutrients in manure. This can be achieved by understanding that manure's nutrients consist of nutrients in the feed less the amount of nutrients used/retained by the animal. Animal rations are based on the nutrients used by the specie. Any feedstuff containing more of these nutrients will just add nutrients into the manure, without benefiting the animal. Therefore, feed only the ration that is required. It also is important, from a nutrient recycling perspective, to use as much of a home-grown ration as possible. This minimizes the importing of nutrients on the farm. Remember that minimizing excess nutrients in the ration can also be helped by increasing the production (meat or milk) level of the livestock.

3. Increase manure use on legumes. This practice is not normally recommended because legumes will not efficiently use the manure-N. However, alfalfa generally uses more nutrients on a per-acre basis than row crops and not including these acres for a whole-farm nutrient recycling plan would normally result in excess nutrients being applied to other crops. Also, alfalfa's N fixation amount may decrease by having manure-N applied, which would lessen the net N import on a farm. Research work in Minnesota has shown that preplant applications of manure can improve alfalfa yields compared to commercial P and K fertilizers and that the N being added was not accumulating in the soil. Therefore, it was both agronomically and environmentally beneficial to use manure on alfalfa. In the whole-farm scenario, nutrient recycling is maximized by applying manure onto alfalfa.

The whole-farm nutrient recycling issue can be improved by managing one's farm nutrients with some of the previously mentioned suggestions. However, the farm's nutrients will not be self-contained; some nutrients will still be imported and some nutrients will still be exported. Figure 2 illustrates some of the changes that can be made at the whole-farm level when efficient nutrient management is practiced.

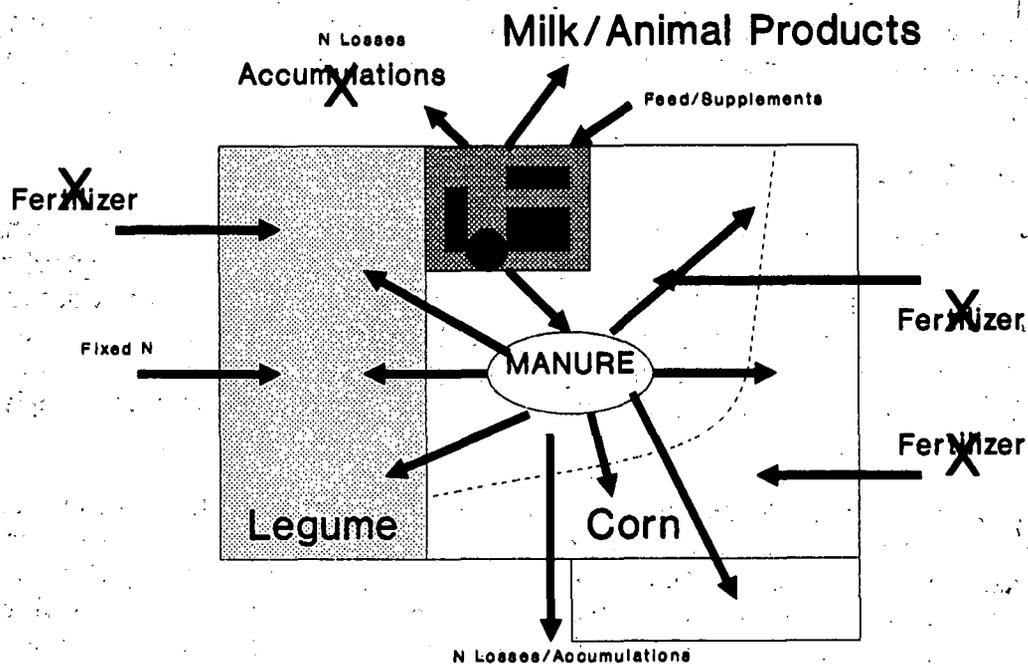


Figure 2. Simplified schematic farm set-up with fields and buildings indicating nutrient imports and exports as affected by more efficient nutrient recycling management.

MANURE MANAGEMENT PLAN COMPONENTS

Nutrient and manure management for the whole farm needs to have all of the issues considered at the same time while also considering the specific subsets of the issues. For example, nutrients and rations must be considered for each set of animals and nutrients, and crops must be considered for each field. Almost every management decision will have an effect on the nutrient cycle on the farm.

The best way to approach the nutrient recycling/environmental issue is to develop a master plan for the farm. While the issue of dealing with imports and exports of nutrients in terms of meat/milk products and feed/supplements is important, these issues are economically based such that efficiency is sought. Manure's nutrients are seldom managed with an economic perspective; thus, putting together a manure management plan can have a great immediate impact. The remainder of the discussion will focus on the manure management component of the whole-farm nutrient cycle.

A manure management plan consists of an inventory of the manure (and its nutrients) produced on an operation and the nutrient needs of the cropland. This information will then be used to make individual field decisions regarding manure application rates.

Knowing what you have

The nutrient content of the manure is affected by many factors, many of which are unique to a specific farming operation. Some of these factors include: 1) animal specie and weight, 2) type of manure handling system, 3) livestock housing and bedding system, 4) ration, 5) temperature, 6) parlor wastes, 7) rainfall dilution, and 8) other miscellaneous contamination. All of these factors affect the concentrations of N, P, K, and micronutrients.

The best method to determine nutrient supply from manure is to analytically test the manure for nutrient composition and then to multiply these results by the storage volume. This must be done for each manure storage facility and the results then combined. This method does not require numerous assumptions--yet it does require that a representative manure sample be collected and that accurate storage volumes be estimated.

Knowing what you need

Knowing the nutrient needs for an enterprise's crops requires more bookkeeping than determining the manure supply. Rather than looking at and analyzing one livestock set-up, the cropland needs are a summation of all the fields targeted (or available) for manure application. Due to previous crop, soil test values, and production potential differences for each field, nutrient needs will be unique for each field. In long-term planning, remember that the cropland needs vary from year to year due to crop rotations, nutrient credit residuals, etc., whereas the manure nutrient supply may not vary significantly from year to year.

On a field-by-field basis, determine the crop's needs for N, P, and K. Although it may be easiest to simply calculate the crop's per-acre removal rate for each nutrient and multiply by the number of acres, this technique should be avoided. For each field, use realistic yield goals, soil test information, previous cropping history, previous manure applications, and soil property information. This will represent the nutrient needs on a per-field basis, and all of the fields that will receive manure should be summed for overall nutrient need.

Matching supply and demand

On a whole-farm basis, the nutrients in the manure on the farm must be compared to the overall needs of nutrients by the crops. If the manure's nutrients for the operation are less than the operation's crop nutrient needs, supplemental commercial fertilizer will need to be purchased. This situation is common when crops are sold off the farm. However, if the manure's nutrient supply is greater than the crops' needs for an operation, no fertilizer should be purchased and alternative strategies that will either have an effect on the supply or the demand of the manure will be necessary. This can happen on farms that buy a lot of feedgrains and/or forages.

Changing supply?

Changing manure's nutrient supply is more than just changing the quantity of manure to be hauled to the field, because one can change the amount of water (thus total manure quantity) and not change the overall amount of nutrients to be land-applied. Many factors affect the quantity of nutrients in the manure. Of course, simply changing the number of animals will have a major effect on manure's nutrient production, yet this is not a realistic option for most.

While it is generally assumed that each specie of equal weight will discharge the same amount of nutrients in the manure, there is room for improvement involving nutrient feeding efficiencies. Any feedstuff and/or feed supplement added to a ration that is not being needed by that animal is simply being added to the nutrient pool of the manure. Adding extra protein or minerals "just to be sure" can create a higher analysis manure.

Changing demand?

From a practical viewpoint, it may be easier to change the cropland needs for manure's nutrients compared to changing the supply of the nutrients. For the fields currently planned to receive manure, mainly corn fields, one factor that will result in a higher need for nutrients is to increase the production level of the field. For corn acres, earlier planting, higher yielding hybrids, higher populations, better pest management, etc., all must be integrated to net a higher yield. For forages, correct soil pH, cutting schedules, varieties, etc. all need to be optimized.

Application methods that result in higher nutrient losses may be looked at as a way of changing manure demand or supply--depending on one's perspective. If manure is broadcast onto a field, N volatilization losses are inevitable and higher rates of application will be required to satisfy a given nutrient demand. While altering nutrients in the manure by handling/application methods is possible, this strategy is not widely endorsed due to the unknown air quality ramifications.

A strategy that should be receiving more attention is the off-farm hauling/marketing of manure--or acquiring more cropland either through rental or purchase agreements. This scenario is sometimes logistically difficult but must be pursued if there are not enough acres to appropriately spread all of the manure produced for an operation. The best situation is to work with nearby landowners who do not use manure on their fields. Thus an economic advantage

can be realized for these landowners, and an environmental liability can be averted for the dairy producer.

SUMMARY

Dairy farmers have a challenge to properly use the nutrients on their farms so that a build-up of nutrients does not occur, thus, not jeopardizing ground- or surface-water quality. Due to the amount of legumes grown on dairy farms and the predominance of smaller-sized farms, there is concern that there is an accumulation of nutrients, especially N, on these farms.

In the whole-farm scenario, nutrient recycling efficiency can be improved on a dairy farm by practicing some general management principles. These include the application of manure on all fields and reducing commercial fertilizer use, applying manure onto legume fields to possibly limit atmospheric N fixation by the plant and to use the P and K for this crop, and to make a ration that minimizes the excess amounts of nutrients and maximizes the amount of on-farm feedstuffs.

From strictly a manure management standpoint, manure's nutrients can be best used if a complete manure management plan is developed and implemented. Account for what nutrients are in the farm's manure and what nutrients are needed by the farm's crops. Then plan manure application rates accordingly. Although there are some methods with which to alter the manure's nutrient supply or the crop's nutrient demand, the most crucial factors are the number of livestock and the number of crop acres.

Total farm nutrient status is a combination of the manure component and the other inorganic nutrients entering or exiting a given farm. Therefore, while manure management is critical, knowing and compensating/changing the other nutrient entry points is important for environmental quality in the 1990s.

FEEDING VALUE OF FAT IN DIETS FOR FEEDLOT CATTLE

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INTRODUCTION

The feeding value of fat, as with any feedstuff, involves a consideration of much more than its energy content per se. It is also a dynamic function of acceptability or palatability, associative interactions with other ration ingredients, as well as a composite of other extra caloric effects which change in varying degrees according to the nature of the diet, level of supplementation and plane of nutrition. The objective this review is to share the results of several of our experiments evaluating the feeding value of fat for feedlot cattle.

Fat Level and Source

Concern. Intestinal digestibility of fat remains rather constant up to about 4% supplementation, averaging roughly 80%. Above 4% supplemental fat (5 to 6% total dietary fat) true digestibility of fat declines to about 56% (Palmquist and Jenkins, 1980). More dramatic reductions in digestibility occur at levels of supplementation greater than 8% (Zinn, unpublished). However, reductions in fat digestibility do not form the basis for current recommendations on safe limits for fat supplementation. The most consistent detrimental effects observed with fat supplementation are largely attributable to marked reductions in feed intake. It has been reported for levels of supplementation as low as 3%, although the majority of cases are reported for levels greater than 5% of ration dry matter (Bréthour et al., 1957; Buchanan-Smith et al., 1974; Cameron and Hogue, 1968; Cuitun et al., 1975; Dinius et al., 1975; Hatch et al., 1972; Johnson and McClure, 1972; Lofgreen, 1965; etc. Once this occurs, performance may continue to be mediocre, even after fat is removed from the diet (Hatch et al., 1972).

The basis for these effects is not understood. Indeed, it may be as much (or more) related to quality characteristics of the fat than level of supplementation, per se. Growing-finishing trials with feedlot cattle have not revealed significant ($P < .05$) or consistent differences between BVF, YG, tallow, cottonseed soap stock or soybean soap stock (Lofgreen, 1965; Brandt, 1988; Zinn, 1989a). However, a problem with comparing fat sources on the basis of animal performance is that supplemental fats usually comprise less than 8% of diet dry matter. The precision obtainable in such studies does not allow for detection of subtle (less than 10%) differences in the energy value of fat sources.

Three characteristics of fat source which may contribute to its feeding value are acceptability, total fatty acids (a measure of purity), proportion of total fatty acids as free fatty acids and iodine value (degree of unsaturation). Differences between common fat sources in acceptability have not been clearly demonstrated, although practical experience warrants some caution. For example, Brandt (1988) conducted two feeding trials involving various fat sources supplemented at 3.5% of diet dry matter. In the first trial YG supplementation resulted in a greater rate of weight gain and feed intake and less feed per unit gain than tallow supplementation. In the second trial the opposite was observed.

Trial (Zinn, 1989a,b). Two hundred twenty-eight crossbred steers (304 kg) were used in a 125-d comparative slaughter trial to evaluate the influence of level and source of supplemental fats on their feeding value for feedlot cattle. Dietary treatments consisted of a steam rolled barley-based finishing diet containing: 1) no supplemental fat; 2) 4% yellow grease (YG); 3) 4% blended animal-vegetable

fat (BVF); 4) 8% YG; 5) 8% BVF and 6) 6% BVF and 2% crude soybean lecithin. The results of this trial are shown in Tables 1-8. Increasing level of supplemental fat in the diet resulted in linear improvements ($P < .01$) in weight gain, feed conversion and NE value of the diet. Estimated NE values of YG and BVF were similar and did not appear to be influenced by level of supplementation, averaging 5.78 and 4.61 Mcal/kg for maintenance and gain, respectively. Fat supplementation resulted in linear increases in empty body fat ($P < .01$), kidney, pelvic and heart fat ($P < .01$) and marbling score ($P < .05$). Partially replacing BVF with lecithin did not influence ($P > .10$) steer performance, carcass merit or estimated NE value of the diet. It was concluded that under the conditions of this trial, the comparative feeding value (in terms of both acceptability and NE value) of supplemental fats was similar and apparently not influenced by levels of supplementation as high as 8% of diet DM.

The influence of level and source of dietary fat on characteristics of digestion was evaluated using 6 crossbred steers (315 kg) with cannulae in the rumen, proximal duodenum and distal ileum (Tables 9-18). Increasing level of fat supplementation resulted in linear decreases ($P < .01$) in ruminal and total tract digestion of OM and ADF, and intestinal digestion of fat ($P < .05$). At the 4 and 8% levels of supplementation, intestinal true digestibility of fat averaged 80.1 and 69.3%, respectively. Thus, consistent with Palmquist and Jenkins (1980), intestinal digestibility of fat remains rather constant (80%) up to about 4% supplementation (5 to 6% total dietary fat) after which it declines with increasing levels of supplementation at the rate of 3.4% for each percentage increase in level of supplementation above 4%.

Ruminal molar proportions of acetate decreased, and propionate molar proportion, as well as DE and ME values of the diet increased linearly ($P < .01$) with level of fat supplementation. The DE and ME values for fat at the 4 and 8% levels of supplementation were 8.17 and 9.76, and 7.35 and 8.72 Mcal/kg, respectively. Yellow grease supplementation resulted in greater ($P < .05$) ruminal fiber digestion and greater ruminal molar proportions of propionate than BVF. Intestinal fat digestion was similar ($P > .10$) for YG and BVF. Adding 25% lecithin to BVF resulted in greater ruminal fiber digestion and greater ruminal molar proportions of acetate; however, lecithin tended ($P < .10$) to lower the ME value of BVF.

Method of Fat Supplementation

Concern. One explanation for the detrimental effects of supplemental fat on diet digestibility is that it physically coats feed particles and thus retards digestion. Since supplemental fat has been shown to have little or no effect on the digestibility of the non-fibrous components of the diet (Robertson and Hawke, 1964; McAllan et al., 1983) it has been proposed that applying the supplemental fat directly to the grain or concentrate portion of the diet will improve its feeding value as compared to applying it to the forage component or as the last step in formulation, as is often the case. However, early studies are not supportive of this theory (Brethour et al., 1957).

Trial (Zinn, 1986a). Two hundred twenty-eight crossbred steers were used in a comparative slaughter trial to study the influence of method of fat supplementation on animal performance. Prior to initiation of the study, steers were fasted 16 hours (no feed or water). Twelve steers were selected at random for determination of initial carcass composition. The remaining 216 Steers were weighed, implanted (Synovex) and randomly assigned to 36 pens, 6 animals/pen. Three methods of fat supplementation were compared: 1) fat portion of the diet was added directly to the grain prior to adding other ration ingredients; 2) fat portion of the diet was added directly to the hay prior to adding other ration ingredients and 3) fat portion of the diet was applied as the last step in the batch mixing. Method of fat supplementation was compared at each of three levels of fat supplementation (3, 6 and 9%, table 19). Composition of experimental diets is shown in Table 19. Tallow fatty acids (acidulated tallow

soap stock), a byproduct of the rendering industry, was the source of fat used. Fatty acid composition of the fat was as follows: myristate, 3.7%; palmitate, 29%; palmitoleate, 3.7%; Stearate, 19.7%; oleate, 39.9%; linoleate, 3.9%. Experimental diets were prepared weekly and stored in plywood boxes located in front of each pen. Steers were fed twice daily. The results of the trial are shown in Table 20. All three alternatives in method of fat supplementation gave similar results when the level of fat supplementation was less than 6%. At the 9% level of supplementation, adding fat directly to the hay resulted in marked reductions in gain and efficiency ($P < .01$).

Calcium and Fat Utilization

Concern. Of the macro elements that might interact with fat none have received more research attention than calcium. Numerous trials have indicated that when calcium has been increased in fat supplemented diets digestibility (usually fiber) also increases (Grainger et al., 1961; Davison and Woods, 1963; Galbraith et al., 1971; Galbraith and Miller, 1973; Jenkins and Palmquist, 1982; Drackley et al., 1985). The benefit to added calcium appears to be related in part to its influence on solubility of nonesterified fatty acids. The process of hydrolysis of esterified fatty acids is rapid. Hawke and Silcock (1970) observed that 80% of the esterified fatty acids were nonesterified within 2 h of incubation in ruminal fluid. Calcium reacts with nonesterified fatty acids to form insoluble calcium soaps (Jenkins and Palmquist, 1982; Drackley et al., 1985; Chalupa et al., 1986; Palmquist et al., 1986). Low dietary calcium levels or low calcium solubility in the rumen may reduce the rate and/or extent of soap formation, increasing ruminal concentrations of nonesterified fatty acids. Early on, it was theorized that the role of calcium in overcoming the negative effects of supplemental fats on digestion were somehow related to ruminal concentrations of nonesterified free fatty acids (Grainger et al., 1961). Subsequent work lent support to that concept. While calcium salts of long-chain fatty acids were found to be comparatively nonreactive in the rumen (Jenkins and Palmquist, 1984; Chalupa et al., 1986), nonesterified free fatty acids were found to have a marked inhibitory effect on growth of cellulolytic bacteria (Henderson, 1973; Maczulak et al., 1981). Nevertheless, addition of calcium to fat supplemented diets has not resulted in appreciable changes in soap formation (Drackley et al., 1985; Finn et al., 1986; Palmquist et al., 1986). Supplemental fat might also influence microbial growth indirectly by depressing free ruminal calcium concentrations below that necessary to maintain optimal growth of cellulolytic bacteria. However, Palmquist et al. (1986), observed that while fat supplementation did depress ruminal free calcium concentrations, the mean concentration (.60 mM) remained higher than that considered optimal for cellulolytic activity (.25 mM, Bryant et al., 1959). Furthermore, Bock et al (1991) found that increasing the level of supplemental calcium from .6 to .9% did not influence characteristics of digestion or feedlot performance of steers fed fat supplemented diets.

Trial (Zinn, 1987). A comparative slaughter trial and a metabolism trial were conducted to evaluate the influence of calcium source on utilization of a high fat diet by feedlot steers. Treatments consisted of a 90% concentrate finishing diet containing 8% yellow grease and supplemented with 1.3% limestone or .8% calcium hydroxide. Results of the trials are shown in Tables 21-25. In trial 1, involving 54 crossbred steers (225 kg) in a 162-d comparative slaughter trial, calcium hydroxide supplementation decreased feed intake 6.2% ($P < .10$). The decreased intake was reflected in a tendency for decreased weight gain and feed conversion. Net energy value of the diet was not influenced by calcium source ($P > .20$). Treatment effects on body composition and carcass merit were small ($P > .20$) with the exception of ribeye area which was 4.4% larger in steers fed the limestone supplemented diet ($P < .01$). In trial 2, ruminal digestion of OM and N was decreased 8.1% ($P < .05$) and 6.3% ($P < .10$) with calcium hydroxide substitution for limestone. Otherwise, ruminal, intestinal and total tract digestion was not effected by calcium source ($P > .20$). Calcium source did not influence ruminal pH ($P > .20$). Ruminal concentrations of ionized calcium tended to be higher throughout the feeding interval for the

calcium hydroxide diet. At the 6 h sampling time ruminal ionized calcium concentrations for the calcium hydroxide supplemented diet exceeded that for the limestone diet by 226% ($P < .05$). Results of this study suggest that calcium source does influence the efficiency of utilization of high fat finishing diets by feedlot cattle. Palatability and cost should be the principal criterion when choosing a calcium source.

Fat by Ionophore Interaction

Concern. The basis for consideration of a supplemental fat by ionophore interaction is related to their analogous effects on end-products of ruminal fermentation. It has been proposed that the effects of ionophores on efficiency of feed utilization are mediated, in part, through changes in the nature of ruminal fermentation associated with increasing molar proportions of propionate and decreasing methane production (Raun et al., 1976; Richardson et al., 1976; Fontenot et al., 1980; Bartley et al., 1979; Fuller and Johnson, 1981; Ricke et al., 1984). Supplemental fat has been found to affect similar changes (Czerkawski et al., 1975), possibly raising the base line for the drug effect. This hypothesis is supported by a feedlot growth-performance trial of Brandt et al (1991). In the absence of supplemental fat monensin plus tylosin improved feed efficiency 7.2%. While, in the presence of supplemental fat there was no response to monensin-tylosin supplementation. Nevertheless, in a subsequent trial (Brandt, 1992) the feed efficiency response to supplemental fat and monensin plus tylosin were more nearly additive.

Trial (Zinn, 1988). Two comparative slaughter trials and a metabolism trial were conducted. Treatments consisted of: 1) 0 fat, 0 monensin; 2) 4% yellow grease, 0 monensin; 3) 0 fat, 33 mg/kg monensin and 4) 4% yellow grease, 33 mg/kg monensin. Treatments were arranged as a 2 x 2 factorial. The results of the trials are shown in Tables 26-32. Trial 1, involved 104 crossbred steers (267 kg) in a 140-d comparative slaughter trial. There were no interactions ($P > .20$) between supplemental fat and monensin on steer performance. Monensin supplementation decreased rate of weight gain ($P < .10$) and feed intake ($P < .05$), with no effect on energy value of the diet ($P > .20$). Fat supplementation increased ($P < .01$) rate of weight gain 12.5% and the NE_m and NE_g value of the diet 8.5 and 9.4%, respectively. The NE_m and NE_g value of the supplemental fat (replacement technique) was 6.40 and 4.69 mcal/kg, respectively. Fat supplementation increased ribeye area 6.5% ($P < .01$) and KPH 14% ($P < .05$). Treatment effects on components of empty body weight gain were largely the consequence of differences in rate of weight gain. Trial 2, involved 154 Holstein steers (290 kg) in a 94-d comparative slaughter trial. There were no interactions between supplemental fat and monensin ($P > .20$). Monensin supplementation did not effect rate or composition of gain ($P > .20$) but reduced ($P < .05$) feed intake and feed required per unit weight gain 3.6%, and an increased ($P < .05$) the NE_m and NE_g content of the diet 3.6 and 4.0%, respectively. Fat supplementation increased ($P < .01$) fat and energy gain 12.5 and 10.3%, respectively, and the NE_m and NE_g content of the diet 7.5 and 8.4%, respectively. The NE_m and NE_g value of the supplemental fat was 6.00 and 4.37 mcal/kg, respectively, in good agreement with trial 1. Fat supplementation increased ($P < .05$) carcass fat and KPH fat 4.3 and 11.1%, respectively. Trial 3, utilized 4 crossbred steers (220 kg) with cannulas in the rumen, proximal duodenum and distal ileum. There were no interactions between supplemental fat and monensin with respect to site of digestion ($P > .20$). Supplemental fat did not effect ($P > .20$) of OM, ADF, starch or N digestion. Intestinal digestibility of fat averaged 77.3%. Monensin increased ($P < .10$) intestinal digestibility of fat 7.4%. However, there were negative associative effects on ruminal acetate:propionate ratios and estimated methane production. It is concluded that the feeding value of feed fat is underestimated in current tables of feed standards and that the net effects of monensin on these estimates are additive.

Fat by Urea Interaction

Concern. Palatability of various feed fats has been singled out as a primary factor for explaining the occasional depressions in feedlot performance with fat supplementation. However, these effects may actually be related to protein nutrition of the animal. This is particularly evident from studies comparing urea versus natural protein in diets with supplemental fat (Jones et al., 1961; Thompson et al., 1967; Hatch et al., 1972; Buchanan-Smith et al., 1974).

Trial (Zinn, 1989). A comparative slaughter trial and a metabolism trial were conducted to evaluate the influence of N supplementation on the feeding value of yellow grease (YG). Treatments consisted of: 1) steam-flaked corn based finishing diet containing no supplemental fat, urea as source of supplemental N; 2) same as treatment 1 plus 6% YG; 3) 6% YG, urea and soybean meal (SBM) as sources of supplemental N and 4) 6% YG, urea and SBM as sources of supplemental N. Soybean meal and urea used in diets 3 and 4 replaced proportionate quantities of steam-flaked corn and urea in diet 2 so as to maintain a similar amount of ruminal available N while increasing ruminal escape N. Results of this study are shown in Tables 33-39. In trial 1, treatment effects on feedlot growth-performance were evaluated in a 149-d comparative slaughter involving 90 crossbred steers. Fat supplementation improved feed/gain (9.9%, $P < .05$) and NE value of the diet (10.3%, $P < .01$). Substituting SBM for urea resulted in a linear ($P < .05$) depression in NE value of the diet. The estimated NE value of YG averaged 5.35 and 4.30 Mcal/kg, respectively, for maintenance and gain. Trial 2 involved 4 steers (468 kg) with cannulas in the rumen and proximal duodenum. Soybean meal substitution into the diet did not increase ($P > .10$) non-ammonia N passage to the small intestine. Soybean meal substitution increased ($P < .05$) ruminal molar proportions of propionate and ADF digestion and decreased ($P < .05$) methane losses, but total tract OM digestion was decreased linearly ($P < .05$). Intestinal digestibility of yellow grease averaged 64% and was not influenced by SBM. Yellow grease supplementation increased ($P < .01$) ME, NE_m and NE_g values of the diet 3.8, 4.9 and 6.3%, respectively. It is concluded that substitution of SBM for urea in fat supplemented steam-flaked corn based diets may not improve the feeding value of the supplemental YG.

Fat Plus High-Bypass Protein

Concern. Increasing levels of protein supplementation has been found to enhance the DE value of the diet Tyrrell (1987). A primary factor which limits the feeding value of fat at higher levels of supplementation is its decreasing rate of small intestinal digestibility. Thus, it may be postulated that by simultaneously increasing the level of protein reaching the small intestine, digestibility of fat might also be enhanced.

Trial (Zinn, 1990 unpublished). A comparative slaughter trial and a metabolism trial were conducted to evaluate the influence of N supplementation using a high-bypass protein blend (HBP; 1/3 feather meal, 1/3 blood meal, 1/3 meat and bone meal) on the feeding value of yellow grease (YG). Treatments consisted of: 1) steam-flaked corn based finishing diet containing no supplemental fat, urea as source of supplemental N; 2) same as treatment 1 plus 5% YG; 3) same as 1 plus 2% HBP, and 4) same as 3 plus 5% yellow grease. The results of these trials is shown in Tables 40-49. In trial 1, treatment effects on feedlot growth-performance were evaluated in a 123-d comparative slaughter involving 68 crossbred steers. Fat supplementation improved DMI/gain (8.6%, $P < .05$) and NE value of the diet (9.6%, $P < .05$). Addition of 2% HBP did not influence ($P > .10$) feedlot performance. The estimated NE value of YG averaged 6.11 and 5.07 Mcal/kg, respectively, for maintenance and gain. Trial 2 involved 4 Holstein steers with cannulas in the rumen and proximal duodenum. The addition of 2% HBP increased ($P < .01$) the passage of feed N to the small intestine. Supplementation with HBP tended to increase the DE value of the basal (no supplemental fat) diet, apparently, by increasing

intestinal digestibility of fat. This trend was consistent with the slightly greater estimated NE values for treatment 3 observed in trial 1. However, HBP supplementation did not influence ($P>.10$) the intestinal digestibility of fat in the fat supplemented diet. DE value of the diet was increased ($P<.05$) with fat supplementation. Using the replacement technique, the DE value of YG grease was 7.49 Mcal/kg. This value corresponds to a digestibility of 79% for YG. Observed digestibility of YG was 79.6%, in good agreement with DE calculations.

Fat by Grain Type Interaction

Concern. Hale (1986) noted that the general response to supplemental fat was poorer with corn-based diets as opposed to barley-, wheat- or milo-based diets. This concept is supported, in part, by the observation that positive responses to fat supplementation (Brandt, 1988; Zinn, 1988; Zinn, 1989a) were obtained with steam rolled barley- or milo-based finishing diets, while negative responses to fat supplementation (Buchanan-Smith et al., 1972; Hatch et al., 1972; Johnson and McClure, 1972) were obtained with corn-based diets. An exception to this trend is the study of Lofgreen (1965) which involved a 70% barley-based finishing diet. However, depressed performance was only noted at the 10% level of fat supplementation.

Trial (Zinn, 1992). One hundred thirty crossbred steers (324 kg) were used in a 121-d comparative slaughter trial to evaluate the comparative feeding value of yellow grease (YG) and cottonseed oil soapstock (COS) in steam-flaked corn (SFC) or wheat (SFW) based finishing diets. Dietary treatments consisted of an 88% concentrate finishing diet containing: 1) SFC, no supplemental fat; 2) SFC, 6% YG; 3) SFC, 6% COS; 4) SFW, no supplemental fat; 5) SFW, 6% YG and 6) SFW, 6% COS. The results of this trial are shown in Tables 50-56. There were no interactions ($P>.10$) between grain type and performance response to supplemental fat. Fat supplementation increased ($P<.05$) ADG 6.4% and decreased ($P<.01$) DM/gain 10.6%. Substituting SFW for SFC did not influence ($P>.10$) ADG, but tended ($P>.10$) to increase DM/gain and decreased ($P<.05$) the NE_m and NE_g of the diet 3.4 and 4.3%, respectively. It is concluded that the feeding value of supplemental fat is similar for wheat- and corn-based finishing diets. Performance response to supplemental YG and COS was similar. The NE_m and NE_g value of YG were 6.35 and 4.93 Mcal/kg, respectively, while the corresponding values for COS were 5.69 and 4.60 Mcal/kg. Differences between the two fat sources appeared to reflect the higher percentages of moisture, impurities and unsaponifiables in COS. The NE value of SFW was roughly 96% the value of SFC.

Oleic Acid and Fat digestion

Concern. Intestinal digestibility of palmitic and stearic acid are low compared with unsaturated fatty acids such as oleic and linoleic acid. Absorption of fatty acids is dependent on the formation of bile salt micelles. The greater the surface area of the micelles, the greater the digestibility of the fat. The surface area of the micelles is enhanced by the interaction of bile salts and insoluble-swelling amphophiles such as the unsaturated fatty acids. Consequently, swelling amphophiles such as unsaturated fatty acids are thought to be helpful in the absorption on non-swelling amphophiles such as saturated fatty acids. This concept is supported by the observation that small amounts of oleic acid has measurably improved utilization of saturated fatty acids in poultry fed diets low in phospholipids (Krogdahl, 1985). In ruminants, relatively little unsaturated fatty acids escape hydrogenation in the rumen. Thus, fat digestion may be enhanced by bypassing unsaturated fatty acids to the small intestine.

Trial (Zinn, 1990 unpublished). Three Holstein calves (209 kg) with cannulas in the abomasum, proximal duodenum and distal ileum were used in a Latin square design experiment to evaluate the influence of oleic acid infusion on intestinal digestibility of fat. All calves were fed a basal diet

containing 8% tallow (DM basis). Treatments consisted of infusing 0, 68 or 160 g/d of oleic acid via the abomasal cannula. The results of the trial are shown in Table 57. Fatty acid digestion was not enhanced by increasing the proportion of oleic acid entering the small intestine. Small intestinal digestion of palmitic, stearic, oleic and linoleic acids averaged 73, 60, 90 and 92%, respectively.

Fatty-fatty esters

Concern. Can esters of long-chain fatty acids be utilized by cattle? Coconut alcohol bottoms-bottoms are a remnant from the distillation of fatty alcohols produced by the reduction and high pressure catalytic hydrogenation of coconut oil. Sometimes referred to as "stillbottoms", they contain some fatty alcohol, but are largely made up of fatty-fatty esters, which are the esters of a fatty acid and a fatty alcohol. This material has been classified as a nonfood industrial waste which may have potential as a feedstuff for livestock (NRC, 1983).

Trial (Zinn, 1989). Six crossbred steers (274 kg) with "T" cannulas in the rumen, proximal duodenum (6 cm from the pyloric sphincter) and distal ileum (20 cm from the ileal-cecal valve) were used in a crossover design experiment to evaluate the feeding value of coconut alcohol bottoms-bottoms (CABB) in a finishing diet for feedlot steers. Dietary treatments consisted of a steam-rolled barley based finishing diet supplemented with or without an additional 6% CABB. The CABB was first blended with the steam-rolled barley portion of the diet prior to incorporation of remaining dietary ingredients. Results of this trial are shown in Tables 58-61. Ruminal digestion of ADF and N was not affected ($P > .10$) by CABB supplementation. Ruminal OM digestion was depressed commensurate to the level of CABB supplemented. Total tract digestibility of OM, ADF, lipid and DE was decreased by 5.65 ($P < .01$), 29.4 ($P < .05$), 57.4 ($P < .01$) and 5.65%, respectively. Adjusting for constituent passage of the basal diet, estimated total tract digestibility of OM, DE and lipid of the supplemental CABB was 1.1, -.23 and 16.4%, respectively. It is concluded that CABB has essentially no feeding value in finishing diets for cattle.

Calcium soaps of fatty acids

Concern. Reacting fatty acids with calcium to form calcium soaps (CSFA) results in a "dry" fat form which facilitates handling and mixing. Furthermore, the CSFA are thought to be less reactive in the rumen (Chalupa et al., 1985), avoiding potential negative associative effects on digestive function. The objective of this study was to compare yellow grease and CSFA with respect to characteristics of ruminal and total tract digestion.

Trial (Zinn and Plascencia, 1992). Four Holstein steers (372 kg) with "T" cannulas in the rumen, proximal duodenum and distal ileum were used to evaluate the comparative effects of calcium soaps of fatty acids (CSFA) versus yellow grease (YG) on digestive function. Four dietary treatments were compared: 1) no supplemental fat; 2) 5% YG; 3) 5% MegaLac (ML) and 4) 5% RumInsol (RI). ML and RI are commercial preparations of CSFA and contain roughly 80% fat. The basal diet contained 55% concentrate and 45% alfalfa hay. Composition of experimental diets and trial results are shown in Tables 62-66. Ruminal pH was higher ($P < .05$) for CSFA supplemented diets than the YG diet. Ruminal propionate levels tended ($P < .10$) to be lower for the fat supplemented diets. Ruminal digestion of feed N was higher ($P < .05$) for the fat supplemented diets, reflecting the higher ruminal degradability of soybean meal which was added along with supplemental fats to maintain similar calorie:protein ratios across treatments. The addition of supplemental fat did not influence ($P > .10$) ruminal digestion of OM and ADF or ruminal microbial efficiency. Small intestinal digestibility of lipid was similar ($P > .10$) across supplemental fat sources, averaging 78.6%. Reacting fat with Ca to form calcium soaps did not prevent extensive ruminal biohydrogenation of supplemental fat. Small

intestinal fatty acid digestion was similar ($P > .10$) across treatments, averaging 84.2%. Adjusting for fatty acid contribution of the basal diet, fatty acid digestibility of the supplemental fats averaged 84.1% (84.2, 84.0 and 84.0%, respectively, for YG, ML and RI). Based on small intestinal true digestibility of supplemental fats, the expected DE values for YG, ML and RI are 8.00, 6.28 and 6.40 Mcal/kg, respectively. It is concluded that in a 55% concentrate diet the characteristics of ruminal and total tract digestion are similar for calcium soaps of fatty acids and yellow grease.

Whole cottonseed and supplemental fat

Concern. From time to time, whole cottonseed has been priced competitively (on an energy basis) with corn, and presently, large amounts are being fed to feedlot cattle in the Southwestern United States and Northwestern Mexico. Moderate to high levels of supplemental fat are also used in diet formulation in these regions and there is some concern that the feeding value of WC may not be additive with concomitant fat supplementation.

Trial (Zinn and Placencia, 1992). Four Holstein steers (155 kg) with "T" cannulas in the rumen and proximal duodenum were used in a 4 x 4 Latin square design experiment to evaluate the interaction of whole cottonseed (WC) and yellow grease (YG) on digestive function. Four treatments were compared: 1) 0% YG, 0% WC; 2) 5% YG, 0% WC; 3) 0% YG, 20% WC and 4) 5% YG, 20% WC. The YG and WC were substituted for steam-flaked corn in an 80% concentrate growing-finishing diet. Composition of experimental diets and trial results are shown in Tables 67-70. Both YG and WC depressed ruminal OM digestion ($P < .01$). However, the effects were not additive (interaction, $P < .05$). When YG was added to the non-WC supplemented diet ruminal OM digestion was depressed 6.9%. In contrast, when YG was added to the WC supplemented diet the depression was 24.0%. This interaction was also apparent ($P < .05$) in ruminal digestion of feed N and starch. Total tract digestion of OM was depressed ($P < .01$) with WC and YG supplementation, although, like ruminal digestion, the effects were non-additive ($P < .05$). In the absence of WC, YG had little influence (.8%) on OM digestion. However, in the presence of WC, YG depressed total tract OM digestion 5.7%. This interaction was also manifest ($P < .05$) in total tract digestion of ADF and GE. While there was some compensation with respect to methane energy loss, the ME (Mcal/kg) of WC was 20% lower when fed in combination with YG. Degree of ruminal biohydrogenation of unsaturated fatty acids was high for both WC and YG. Post-ruminal digestion of lipid averaged 75.5%, tending to be increased (4.3%, $P > .10$) by WC and decreased (2.9%, $P > .10$) by YG supplementation. It is concluded that the feeding value of WC is diminished in growing-finishing diets that contain moderate levels (5%) of supplemental fat. The basis for this is not so much related to depressed digestibility of fat, per se, but rather to a more general negative associative effect on ruminal and total tract digestibility of OM. While reduced digestibility was offset, to some extent, by decreased ruminal methane energy loss, the ME of WC was 20% lower when fed in combination with YG.

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Table 1. COMPOSITION OF EXPERIMENTAL DIETS FED TO STEERS

Item	Treatment					
	1	2	3	4	5	6
Ingredient composition, % of total, DM basis						
Alfalfa hay	8.00	8.00	8.00	8.00	8.00	8.00
Sudangrass hay	4.00	4.00	4.00	4.00	4.00	4.00
Steam rolled barley	58.90	58.90	58.90	58.90	58.90	58.90
Steam flaked corn	18.00	11.45	11.45	4.90	4.90	4.90
Cottonseed meal	.90	3.45	3.45	6.00	6.00	6.00
Yellow grease		4.00		8.00		
Blended fat ^a			4.00		8.00	6.00
Crude lecithin						2.00
Cane molasses	8.00	8.00	8.00	8.00	8.00	8.00
Urea	.30	.30	.30	.30	.30	.30
Trace mineral salt ^b	.50	.50	.50	.50	.50	.50
Dicalcium phosphate	.10	.10	.10	.10	.10	.10
Limestone	1.30	1.30	1.30	1.30	1.30	1.30
Vitamin A ^c	+	+	+	+	+	+

^aBlended animal-vegetable fat.

^bTrace mineral salt contained: CoSO₄, .068%; CuSO₄, 1.04%; FeSO₄, 3.57%; ZnO, .75%; MnSO₄, 1.07%; KI, .052%; and NaCl, 93.4%.

^c2,200 IU/kg diet.

Table 2. CHEMICAL ANALYSES OF SUPPLEMENTAL FAT BLENDS^a

Item	Supplemental fat source		
	YG ^b	BVF ^c	BVFL ^d
Moisture, %	.12	.86	.90
Impurities, %	.10	.59	.53
Unsaponifiables, %	.52	4.16	3.63
Iodine value	71.02	62.45	69.40
Free fatty acids, %	9.7	52.8	49.2
Total fatty acids, %	90.7	93.7	92.1
Fatty acid profile, % total			
C12:0	.7	6.3	5.7
C14:0	1.4	3.2	3.0
C16:0	20.0	27.1	26.3
C16:1	2.2	1.0	.4
C18:0	12.1	10.2	9.7
C18:1	46.8	30.9	30.7
C18:2	16.3	20.4	23.2
C18:3	.4	.8	.9

^aYellow grease.

^bBlended animal-vegetable fat.

^cBlended animal-vegetable fat (75%) plus crude corn-soy lecithin (25%).

Table 3. INFLUENCE OF LEVEL OF FAT SUPPLEMENTATION ON GROWTH PERFORMANCE OF FEEDLOT STEERS AND NET ENERGY VALUE OF THE DIET

Item	Level of fat supplementation			SD
	0%	4%	8%	
Empty body weight, kg				
Initial	306	304	304	6
Final ^a	404	412	426	11
Empty body gain				
Weight, kg/d ^a	.83	.92	1.02	.10
Energy, Mcal/d ^a	2.93	3.45	4.30	.61
Fat, kg/d ^a	.265	.313	.399	.070
Protein, kg/d ^b	.126	.135	.141	.01
Dry matter intake, kg/d	6.19	6.18	6.42	.42
Dry matter conversion ^a	7.51	6.80	6.30	.34
Diet net energy, Mcal/kg				
Maintenance ^a	1.77	1.89	2.01	.06
Gain ^a	1.14	1.25	1.35	.05

^aLinear effect, P<.01.

^bLinear effect, P<.10.

Table 4. INFLUENCE OF LEVEL OF FAT SUPPLEMENTATION ON CARCASS MERIT AND COMPOSITION OF GAIN OF FEEDLOT STEERS

Item	Level of Fat Supplementation			SD
	0%	4%	8%	
Carcass weight, kg ^a	274	280	291	8
Rib eye area, cm ²	76.8	79.3	78.6	2.8
Fat thickness, cm	1.17	1.23	1.33	.23
KPH, % ^{ab}	2.72	3.07	3.35	.26
Marbling score, degrees ^{cd}	4.09	4.21	4.35	.30
Retail yield, % ^e	50.6	50.5	49.8	.7
Empty body composition, %				
Water ^a	55.0	54.5	53.2	1.3
Protein ^a	16.6	16.4	16.1	.3
Fat ^a	24.6	25.4	27.0	1.7

^aLinear effect, P<.01.

^bKidney, pelvic and heart fat as a percentage of carcass weight.

^cLinear effect, P<.10.

^dCoded: Minimum slight = 4, minimum small = 5, etc.

^eLinear effect, P<.05

Table 5. INFLUENCE OF SOURCE OF FAT SUPPLEMENTATION ON GROWTH PERFORMANCE OF FEEDLOT STEERS AND NET ENERGY VALUE OF THE DIET

Item	Source of Fat Supplementation		SD
	Yellow grease	Blended fat ^a	
Empty body weight, kg			
Initial	305	304	6
Final	422	416	11
Empty body gain			
Weight, kg/d	.996	.944	.096
Energy, Mcal/d	4.05	3.71	.61
Fat, kg/d	.373	.339	.070
Protein, kg/d	.140	.136	.017
Dry matter intake, kg/d	6.41	6.19	.42
Dry matter conversion	6.50	6.60	.34
Diet net energy, Mcal/kg			
Maintenance	1.96	1.94	.06
Gain	1.31	1.29	.05

^aBlended animal-vegetable fat.

Table 6. INFLUENCE OF FAT SOURCE ON CARCASS MERIT AND COMPOSITION OF GAIN OF FEEDLOT STEERS

Item	Source of Fat Supplementation		SD
	Yellow grease	Blended fat ^a	
Carcass weight, kg	288	283	8
Rib eye area, cm ²	78.0	79.9	2.8
Fat thickness, cm	1.31	1.25	.23
KPH, % ^b	3.17	3.25	.26
Marbling score, degrees ^c	4.19	4.37	.30
Retail yield, %	50.0	50.4	.7
Empty body composition, %			
Water	53.6	54.1	1.3
Protein	16.2	16.3	.3
Fat	26.5	25.9	1.7

^aBlended animal-vegetable fat.

^bKidney, pelvic and heart fat as a percentage of carcass weight.

^cCoded: Minimum slight = 4, minimum small = 5, etc.

Table 7. INFLUENCE OF LECITHIN ON UTILIZATION OF A SUPPLEMENTAL VEGETABLE FAT BLEND BY STEERS: FEEDLOT CATTLE GROWTH PERFORMANCE AND NET ENERGY VALUE OF THE DIET

Item	8% Blended fat ^a : 0% Lecithin	6% Blended fat: 2% Lecithin	SD
Empty body weight, kg			
Initial	304	302	6
Final	424	420	11
Empty body gain			
Weight, kg/d	1.008	.993	.096
Energy, Mcal/d	4.22	3.85	.61
Fat, kg/d	.390	.347	.070
Protein, kg/d	.139	.145	.017
Dry matter intake, kg/d	6.33	6.22	.42
Dry matter conversion	6.31	6.29	.34
Diet net energy, Mcal/kg			
Maintenance	2.01	1.97	.06
Gain	1.36	1.32	.05

^aBlended animal-vegetable fat.

Table 8. INFLUENCE OF LECITHIN ON UTILIZATION OF SUPPLEMENTAL VEGETABLE FAT BY STEERS: CARCASS MERIT AND COMPOSITION OF GAIN

Item	8% Blended fat ^a : 0% Lecithin	6% Blended fat: 2% Lecithin	SD
Carcass ^p weight, kg	289	286	8
Rib eye area, cm ²	78.5	79.8	2.8
Fat thickness, cm	1.37	1.23	.23
KPH, % ^b	3.51	3.39	.26
Marbling score, degrees ^c	4.51	4.49	.30
Retail yield, %	49.7	50.3	.7
Empty body composition, %			
Water	53.3	54.1	1.3
Protein	16.1	16.3	.3
Fat	26.9	25.8	1.7

^aBlended animal-vegetable fat.

^bKidney, pelvic and heart fat as a percentage of carcass weight.

^cCoded: Minimum slight = 4, minimum small = 5, etc.

Table 9. INFLUENCE OF LEVEL OF FAT SUPPLEMENTATION ON CHARACTERISTICS OF DIGESTION OF A FINISHING DIET BY FEEDLOT STEERS

Item	Level of Fat Supplementation			SD ^a
	0%	4%	8%	
Intake, g/d				
Organic matter	5,284	5,297	5,284	
Starch	2,089	2,222	2,012	
Acid detergent fiber	625	598	636	
Lipid	64	257	429	
N	124	122	125	
Gross energy, Mcal/d	23.4	24.9	26.4	
Leaving abomasum, g/d				
Organic matter ^b	2,161	2,431	2,670	271
Starch	200	215	193	45
Acid detergent fiber ^b	453	484	593	61
Lipid ^b	166	326	481	35
Non-ammonia N	117	123	112	13
Microbial N ^c	95.6	102.6	85.7	12.7
Feed N	20.7	20.0	26.4	7.2
Ruminal digestion, %				
Organic matter ^b	59.1	54.1	49.5	5.1
Starch	90.3	90.3	90.4	2.2
Acid detergent fiber ^b	27.3	19.0	6.7	9.4
Feed N	83.2	83.5	78.9	5.8
Microbial efficiency ^d	31.0	36.3	34.0	7.3
Protein efficiency ^{ec}	.94	1.01	.90	.10
Leaving small intestine, g/d				
Organic matter ^f	1,077	1,096	1,241	151
Starch	40.8	41.9	39.2	13.0
Acid detergent fiber ^g	386	400	451	72
Lipid ^b	27.5	59.4	124.1	23.5
N	33.3	34.5	35.0	2.6
Small intestinal digestion, %				
Organic matter	50.3	54.2	52.9	5.0
Starch	77.3	80.6	78.7	6.8
Acid detergent fiber	13.7	16.5	23.0	12.2
Lipid ^b	83.4	81.4	74.1	5.8
N	71.2	71.3	68.2	3.4
Fecal excretion, g/d				
Organic matter ^b	794	862	1,013	70
Starch	13.2	14.6	17.1	5.8
Acid detergent fiber ^b	341	352	399	46
N ^b	26.6	28.5	30.1	1.1
Gross energy, Mcal/d ^b	4.01	4.53	5.58	.36
Total tract digestion, %				
Organic matter ^b	85.0	83.7	80.8	1.3
Starch	99.4	99.3	99.2	.3
Acid detergent fiber ^f	45.5	41.1	37.4	7.5
N ^{bh}	78.5	76.5	75.9	.9
Digestible energy, Mcal/kg ^b	3.43	3.60	3.68	.06
Metabolizable energy, Mcal/kg ^b	2.98	3.24	3.39	.07

^aStandard deviation.

^bLinear component to treatment response, P<.01.

^cQuadratic component to treatment response, P<.05.

^dMicrobial N, g/kg organic matter fermented.

^eDuodenal non-ammonia N/N intake.

^fLinear component to treatment response, P<.05.

^gLinear component to treatment response, P<.10.

^hQuadratic component to treatment response, P<.10.

Table 10. INFLUENCE OF LEVEL OF FAT SUPPLEMENTATION ON FATTY ACID PROFILE OF CHYME ENTERING AND LEAVING THE SMALL INTESTINE

Item	Level of Fat Supplementation			
	0%	4%	8%	SD ^a
Fatty acid profile, % total				
Duodenal chyme				
Lauric ^{bc}	1.14	.45	.29	.22
Myristic ^b	.49	.74	.91	.20
Palmitic ^b	20.69	24.21	25.86	1.55
Palmitoleic	.02	.11	.66	.17
Stearic ^b	70.67	69.06	66.67	2.44
Oleic	5.08	3.88	4.93	1.68
Linoleic	1.92	1.56	1.26	.95
Ileal chyme				
Lauric ^{bc}	5.58	1.89	1.87	2.22
Myristic	1.22	2.86	2.70	1.04
Palmitic	19.63	20.84	19.21	2.57
Palmitoleic ^b	.16	.09	.02	.08
Stearic ^b	68.21	74.51	77.59	3.81
Oleic ^{bc}	.16	.06	.02	.03
Linoleic ^b	5.03	2.33	1.02	1.70

^aStandard deviation.

^bLinear component to treatment response, P<.01.

^cQuadratic component to treatment response, P<.05.

Table 11. INFLUENCE OF LEVEL OF FAT SUPPLEMENTATION ON RUMINAL PH, VOLATILE FATTY ACID PROFILES AND METHANE PRODUCTION 4-H POSTPRANDIAL

Item	Level of Fat Supplementation			
	0%	4%	8%	SD ^a
Ruminal pH	6.34	6.29	6.20	.24
Ruminal concentration, mol/100 mol				
Acetate ^b	65.1	60.2	55.6	4.5
Propionate ^b	17.8	25.6	29.6	4.3
Butyrate ^c	17.1	14.2	14.9	3.1
Acetate/propionate ^b	3.74	2.46	2.04	.57
Methane production ^{bd}	.626	.541	.482	.05

^aStandard deviation.

^bLinear component to treatment response, P<.01.

^cLinear component to treatment response, P<.10.

^dMethane, mol/mol glucose equivalent fermented.

Table 12. INFLUENCE OF SOURCE OF SUPPLEMENTAL FAT ON CHARACTERISTICS OF DIGESTION OF A FINISHING DIET BY FEEDLOT STEERS

Item	Source of Fat Supplementation		SD ^b
	Yellow Grease	Blended fat ^a	
Intake, g/d			
Organic matter	5,281	5,299	
Starch	2,117	2,118	
Acid detergent fiber	626	628	
Lipid	345	340	
N	123	124	
Gross energy, Mcal/d	25.6	25.7	
Leaving abomasum, g/d			
Organic matter	2,491	2,610	271
Starch ^c	183	225	13
Acid detergent fiber	520	557	61
Lipid	400	406	35
Non-ammonia N	114	121	13
Microbial N	90.9	97.4	12.7
Feed N	23.1	23.3	7.2
Ruminal digestion, %			
Organic matter	52.8	50.7	5.1
Starch ^c	91.4	89.4	2.2
Acid detergent fiber ^c	17.2	8.6	9.4
Feed N	81.3	81.2	5.8
Microbial efficiency ^d	33.5	36.8	7.3
Protein efficiency ^e	92.7	97.8	.10
Leaving small intestine, g/d			
Organic matter	1,187	1,151	151
Starch	36.9	44.2	13.0
Acid detergent fiber	441	409	72
Lipid	95.3	88.2	23.5
N	34.8	34.7	2.6
Small intestinal digestion, %			
Organic matter ^f	51.8	55.4	5.0
Starch	79.2	80.1	6.8
Acid detergent fiber ^c	14.6	24.9	12.2
Lipid	77.1	78.4	5.8
N	68.8	70.7	3.4
Fecal excretion, g/d			
Organic matter	961	914	70
Starch	17.1	14.6	5.8
Acid detergent fiber	389	362	46
N	29.1	29.5	1.1
Gross energy, Mcal/d	5.17	4.94	.36
Total tract digestion, %			
Organic matter ^f	81.8	82.7	1.3
Starch	99.2	99.3	.3
Acid detergent fiber	37.9	40.6	7.5
N	76.3	76.2	.9
Digestible energy, Mcal/kg ^c	3.61	3.67	.06
Metabolizable energy, Mcal/kg	3.29	3.34	.07

^aBlended animal-vegetable fat.

^bStandard deviation.

^cTreatments differ, P<.05.

^dMicrobial N, g/kg organic matter fermented.

^eDuodenal non-ammonia N/N intake.

^fTreatments differ, P<.10.

Table 13. INFLUENCE OF SOURCE OF SUPPLEMENTAL FAT ON FATTY ACID PROFILE OF CHYME ENTERING AND LEAVING THE SMALL INTESTINE

Item	Source of Fat Supplementation		SD ^b
	Yellow Grease	Blended fat ^a	
Fatty acid profile, % total			
Duodenal chyme			
Lauric	.36	.39	.22
Myristic ^c	.71	.94	.20
Palmitic ^d	23.06	27.01	1.55
Palmitoleic	.12	.05	.17
Stearic ^d	69.87	65.86	2.44
Oleic	4.51	4.30	1.68
Linoleic	1.38	1.44	.95
Ileal chyme			
Lauric	1.66	2.09	2.22
Myristic	1.79	3.78	1.04
Palmitic ^d	16.86	23.19	2.48
Palmitoleic	.05	.07	.07
Stearic ^d	79.45	72.64	3.70
Oleic	.03	.05	.08
Linoleic	1.75	1.61	1.70

^aBlended animal-vegetable fat.

^bStandard deviation.

^cTreatments differ, P<.05.

^dTreatments differ, P<.01.

Table 14. INFLUENCE OF SOURCE OF SUPPLEMENTAL FAT ON RUMINAL PH, VOLATILE FATTY ACID PROFILES AND METHANE PRODUCTION 4-H POSTPRANDIAL

Item	Source of Fat Supplementation		SD ^b
	Yellow Grease	Blended fat ^a	
Ruminal pH	6.20	6.28	.24
Ruminal concentration, mol/100 mol			
Acetate	56.9	58.8	4.5
Propionate ^c	29.9	25.2	4.3
Butyrate ^c	13.1	16.0	3.1
Acetate/propionate ^d	2.04	2.46	.57
Methane production ^e	.486	.537	.05

^aBlended animal-vegetable fat.

^bStandard deviation.

^cTreatments differ, P<.05.

^dTreatments differ, P<.10.

^eMethane, mol/mol glucose equivalent fermented.

Table 15. INFLUENCE OF LECITHIN ON UTILIZATION OF SUPPLEMENTAL VEGETABLE FAT BY STEERS: CHARACTERISTICS OF DIGESTION

Item	8% Blended fat ^a 0% Lecithin	6% Blended fat 2% Lecithin	SD ^b
Intake, g/d			
Organic matter	5,293	5,285	
Starch	2,020	2,050	
Acid detergent fiber	622	623	
Lipid	427	404	
N	125	125	
Gross energy, Mcal/d	26.4	26.3	
Leaving abomasum, g/d			
Organic matter	2,740	2,540	271
Starch	222	215	13
Acid detergent fiber ^c	613	537	61
Lipid	490	461	35
Non-ammonia N	116	116	13
Microbial N	89.9	86.7	12.7
Feed N	26.1	29.1	7.2
Ruminal digestion, %			
Organic matter	48.2	51.9	5.1
Starch	89.0	89.5	2.2
Acid detergent fiber ^c	1.5	13.8	9.4
Feed N	79.1	76.6	5.8
Microbial efficiency ^d	35.8	32.1	7.3
Protein efficiency ^e	92.5	93.0	.10
Leaving small intestine, g/d			
Organic matter	1,183	1,169	151
Starch	38.5	44.7	13.0
Acid detergent fiber	420	428	72
Lipid	116.5	94.0	23.5
N	34.0	35.2	2.6
Small intestinal digestion, %			
Organic matter	56.6	53.0	5.0
Starch	82.3	78.5	6.8
Acid detergent fiber ^f	31.1	19.0	12.2
Lipid	75.9	79.3	5.8
N	70.4	69.2	3.4
Fecal excretion, g/d			
Organic matter	989	1,003	70
Starch	15.9	17.2	5.8
Acid detergent fiber	386	403	46
N	30.2	30.9	1.1
Gross energy, Mcal/d	5.42	5.42	.36
Total tract digestion, %			
Organic matter	81.3	81.0	1.3
Starch	99.2	99.2	.3
Acid detergent fiber	37.9	35.3	7.5
N	75.9	75.2	.9
Metabolizable energy, Mcal/kg ^f	3.41	3.33	.07
Digestible energy, Mcal/kg	3.72	3.69	.06

^aBlended animal-vegetable fat.

^bStandard deviation.

^cTreatments differ, P<.05.

^dMicrobial N, g/kg organic matter fermented.

^eDuodenal non-ammonia N/N intake.

^fTreatments differ, P<.10.

Table 16. INFLUENCE OF LECITHIN ON FATTY ACID PROFILE OF CHYME ENTERING AND LEAVING THE SMALL INTESTINE

Item	8% Blended fat ^a 0% Lecithin	6% Blended fat 2% Lecithin	SD ^b
Fatty acid profile, % total			
Duodenal chyme			
Lauric	.31	.46	.22
Myristic	1.00	1.10	.20
Palmitic	27.21	27.24	1.55
Palmitoleic	.09	.01	.17
Stearic	65.27	65.11	2.44
Oleic	4.85	4.50	1.68
Linoleic	1.28	1.58	.95
Ileal chyme			
Lauric	2.41	1.55	2.22
Myristic	3.65	3.19	1.04
Palmitic	21.89	20.61	2.48
Palmitoleic	.03	.07	.07
Stearic	74.17	74.73	3.70
Oleic	.03	.03	.08
Linoleic	1.12	2.69	1.70

^aBlended animal-vegetable fat.

^bStandard deviation.

Table 17. INFLUENCE OF LECITHIN ON RUMINAL PH, VOLATILE FATTY ACID PROFILES AND METHANE PRODUCTION 4-H POSTPRANDIAL

Item	8% Blended fat ^a 0% Lecithin	6% Blended fat 2% Lecithin	SD ^b
Ruminal pH	6.30	6.44	.24
Ruminal concentration, mol/100 mol			
Acetate ^c	56.4	61.9	4.5
Propionate	26.1	24.2	4.3
Butyrate ^d	17.5	13.9	3.1
Acetate/propionate	2.27	2.76	.57
Methane production ^e	.516	.560	.05

^aBlended animal-vegetable fat.

^bStandard deviation.

^cTreatments differ, P<.01.

^dTreatments differ, P<.10.

^eMethane, mol/mol glucose equivalent fermented.

Table 18. Influence of fat level and source on estimated net energy value of supplemental fat (Trials 1 and 2).

Item	Estimated NE		DE	ME
	Maintenance	Gain		
	----- Mcal/kg -----			
Yellow grease				
4% supplementation	6.406	5.047	9.757	8.166
8% supplementation	5.655	4.537	8.720	7.354
average	6.031	4.792	9.238	7.760
Vegetable blend				
4% supplementation	5.281	4.208	11.056	9.705
8% supplementation	5.781	4.646	9.224	8.216
average	5.531	4.427	10.140	8.972
Vegetable blend plus lecithin				
8% supplementation	5.239	4.172	8.277	7.903
Average for Yellow grease and vegetable blend				
4% supplementation	5.844	4.628	10.406	8.936
8% supplementation	5.718	4.592	8.972	7.785
average	5.781	4.610	9.689	8.361

TABLE 19. RATION COMPOSITION (DRY MATTER BASIS), (TRIAL 1)^a

Item, %	3% fat	6% fat	9% fat
Alfalfa hay	10.00	9.67	9.34
Sudan hay	12.00	11.60	11.21
Steam rolled wheat	35.00	33.85	32.68
Steam flaked corn	30.90	29.89	28.85
Cane molasses	7.00	6.78	6.54
Fat	3.00	6.00	9.00
Limestone	.30	.29	.28
Dicalcium phosphate	.70	.73	.81
Urea	.70	.80	.92
TM salt	.40	.39	.37
Vitamin A ^a	+	+	+
Lasalocid ^b	+	+	+

a2200 IU/kg.

b30 g/T air dry feed.

TABLE 20. INFLUENCE OF METHOD AND LEVEL OF FAT SUPPLEMENTATION ON ANIMAL PERFORMANCE AND NET ENERGY VALUE OF THE DIETS (TRIAL 1)

	Treatments									S.D.
	3% fat			6% fat			9% fat			
	On grain	On last	On hay	On grain	On last	On hay	On grain	On last	On hay	
Pen reps	4	4	4	4	4	4	4	4	4	
Weight, kg										
Initial	269	266	264	268	267	265	267	268	268	6.8
Final	470	472	463	458	466	461	438	441	433	13.2
Daily gain, kg	1.35	1.30	1.23	1.18	1.19	1.27	1.06	1.07	.96	.10
Daily feed, kg	7.44	7.21	7.10	6.86	6.74	7.12	6.33	6.53	6.09	.28
Feed/gain	5.52	5.54	5.79	5.83	5.69	5.64	5.99	6.21	6.43	.42
Net energy, mcal/kg										
Maintenance	1.69	1.69	1.74	1.66	1.74	1.71	1.74	1.67	1.74	.060
Gain	1.10	1.11	1.15	1.09	1.15	1.13	1.15	1.09	1.14	.050

Table 21. Composition of experimental diets (Trial 1 and 2)

Item	Calcium source	
	CaCO ₃	Ca(OH) 2
	----- % -----	
Alfalfa hay	8.0	8.0
Sudangrass hay	4.0	4.0
Barley, 47 lb/bu	58.9	59.4
Steam flaked corn	4.9	4.9
Cottonseed meal	6.0	6.0
Yellow grease	8.0	8.0
Cane molasses	8.0	8.0
Urea	.3	.3
Trace mineral salt ^b	.5	.5
Dicalcium phosphate	.1	.1
Limestone	1.3	--
Slaked lime	--	.8
Vitamin A ^c	+	+

^aDry matter basis.

^bTrace mineral salt contained: CoSO₄, .068%; CuSO₄, 1.04%; FeSO₄, 3.57%; ZnO, .75%; MnSO₄, 1.07%; KI, .052%; and NaCl, 93.4%.

^c2200 IU/kg

Table 22. Influence of calcium source on steer performance and diet net energy value (Trial 1)

	Calcium source		SE ^a
	CaCO ₃	Ca(OH) 2	
Pen replicates	3	3	
Empty body weight, kg			
Initial	227	223	.2
Final	377	359	.6
Gain			
Empty body, kg/d	.93	.84	.03
Protein, kg/d ^b	.135	.117	.006
Fat, kg/d	.324	.317	.018
Energy, mcal/d	3.80	3.63	.17
Feed intake, kg/d ^{bc}	6.17	5.79	.12
Feed/gain	6.67	6.93	.28
Diet NE, mcal/kg			
Maintenance	1.84	1.88	.04
Gain	1.22	1.25	.03

^aStandard error of mean.

^bMeans differ, P<.10.

^cDry matter basis.

Table 23. Influence of calcium source on body composition and carcass merit of feedlot steers fed a high fat diet (Trial 1)

	Calcium source		SE ^a
	CaCO ₃	Ca(OH) 2	
Empty body weight, kg	377	359	6
Empty body composition, % ^b			
Water	53.3	52.6	.5
Protein	16.1	16.0	.1
Fat	26.8	27.8	.7
Carcass weight, kg	255	241	4
Ribeye area, cm ^{2cd}	75.8	72.6	.4
Fat thickness, cm	1.02	1.07	.12
KPH, % ^e	2.56	2.56	.09
Yield grade	2.39	2.48	.16
Marbling score ^f	3.97	3.80	.10

^aStandard error of mean.

^bBased on carcass specific gravity.

^cTaken by direct grid reading of the eye muscle at the twelfth rib.

^dMeans differ, P<.01.

^eKidney, pelvic and heart fat as a percentage of carcass weight.

^fCoded: minimum slight = 3, minimum small = 4, etc.

Table 24. Influence of calcium source on ruminal pH and ionized calcium concentration

Item	Calcium source		SD ^a
	CaCO ₃	Ca(OH) 2	
Ruminal pH			
Time postprandial			
3 h	5.85	5.74	.10
6 h	6.05	5.99	.18
9 h	6.45	6.37	.20
12 h	6.72	6.71	.19
Avg	6.27	6.20	.12
Ionized Calcium, mM			
Time postprandial			
3 h	1.375	1.543	.586
6 h ^b	.447	1.008	.284
9 h	.147	.304	.168
12 h	.176	.217	.055
Avg	.537	.768	.181

^aStandard deviation.

^bMeans differ, P<.05.

Table 25. Influence of calcium source on characteristics of digestion of high fat finishing diets by feedlot steers (Trial 2)

	Calcium Source		SD ^a
	CaCO ₃	Ca(OH) ₂	
Observations	4	4	
Intake, g/d			
Organic matter	2664	2654	
Starch	1135	1095	
Acid detergent fiber	330	334	
Lipid	185	196	
N	63	65	
Ruminal digestion, %			
Organic matter ^b	46.7	43.2	1.2
Starch	87.7	83.1	5.6
Acid detergent fiber	20.4	18.8	5.8
Feed N ^c	73.4	68.8	2.9
Microbial efficiency ^d	35.0	34.6	4.0
Small intestinal digestion, %			
Organic matter	56.7	56.9	2.7
Starch	74.0	77.2	4.1
Acid detergent fiber	33.0	31.7	5.6
Lipid	77.2	72.0	8.1
N	71.1	70.6	2.0
Total tract digestion, %			
Organic matter	79.2	78.4	2.0
Starch	98.3	97.8	.4
Acid detergent fiber	41.9	42.3	6.1
Lipid	65.0	60.2	7.9
N	73.7	73.6	1.4

^aStandard deviation.

^bMeans differ, P<.05.

^cMeans differ, P<.10.

^dMicrobial N, g/kg organic matter fermented.

Table 26. Composition of Experimental Diets^a

Item	Experimental Diets, %			
	1	2	3	4
Alfalfa hay	8.00	8.00	8.00	8.00
Sudan-grass hay	4.00	4.00	4.00	4.00
Steam-rolled barley	58.90	58.90	58.90	58.90
Steam-flaked corn	18.00	11.45	18.00	11.45
Cane molasses	8.00	8.00	8.00	8.00
Yellow grease ^b		4.00		4.00
Cottonseed meal	.90	3.45	.90	3.45
Urea	.30	.30	.30	.30
Limestone	1.30	1.30	1.30	1.30
Dicalcium phosphate	.10	.10	.10	.10
Trace mineral salt ^c	.50	.50	.50	.50
Monensin, 33 mg/kg			+	+
Vitamin A, 2200IU/kg	+	+	+	+

^aDry-matter basis.

^bFatty acid composition: lauric, 2.94%; myristic, 2.20%; palmitic, 26.98%; palmitoleic, 6.08%; stearic, 14.60%; oleic, 42.23%; linoleic, 4.97%.

^cContained: CoSO₄, .068%; CuSO₄, 1.04%; FeSO₄, 3.57%; MnSO₄, 1.07%; KI, .052%; and NaCl, 93.4%.

TABLE 27. MAIN EFFECTS OF SUPPLEMENTAL FAT AND MONENSIN ON STEER PERFORMANCE AND DIET NET ENERGY VALUE (TRIAL 1)

Item	Treatment main effects				SE ^a
	Fat, %		Monensin, mg/kg		
	0	4	0	33	
Pen replicates	8	8	8	8	
Empty body weight, kg ^b					
Initial	268	266	266	268	.1
Final ^c	414	430	426	417	.4
Empty body gain					
Weight, kg/d ^{de}	1.04	1.17	1.14	1.06	.03
Protein, kg/d ^{fg}	.157	.174	.169	.162	.006
Fat, kg/d ^{cfh}	.332	.387	.387	.333	.016
Energy, Mcal/d ^{cfh}	3.99	4.61	4.57	4.03	.15
Feed intake, kg/d ^{hi}	6.91	6.89	7.07	6.72	.11
Feed/gain ^d	6.66	5.92	6.21	6.37	.08
Net energy of diet, MCal/kg ⁱ					
Maintenance ^{ed}	1.761	1.909	1.851	1.819	.033
Gain ^d	1.161	1.271	1.228	1.204	.025

^aStandard error of mean, n = 8

^bBased on carcass weight.

^cSupplemental fat main effect (P<.05).

^dSupplemental fat main effect (P<.01).

^eSupplemental monensin main effect (P<.10).

^fBased on carcass specific gravity of initial and final slaughter groups.

^gSupplemental fat main effect (P<.10).

^hSupplemental monensin main effect (P<.05).

ⁱDry-matter basis.

TABLE 28. MAIN EFFECTS OF SUPPLEMENTAL FAT AND MONENSIN ON CARCASS TRAITS OF FEEDLOT STEERS (TRIAL 1)

Item	Treatment main effects				SE ^a
	Fat, %		Monensin, mg/kg		
	0	4	0	33	
Carcass weight, kg	288	293	296	284	.8
Carcass components, %					
Water	51.2	50.8	49.8	52.3	1.3
Protein	15.2	15.1	14.8	15.6	.4
Fat	29.4	29.9	31.4	27.9	1.8
Ribeye area, cm ^{2b}	79.5	84.7	82.1	82.1	1.0
Fat thickness, cm	1.20	1.28	1.31	1.17	.06
KPH, % ^c	2.36	2.68	2.58	2.45	.09
Marbling score, degrees	4.96	4.86	4.96	4.86	.15
Yield, %	50.9	50.9	50.6	51.1	.2

^aStandard error of mean, n = 8.

^bSupplemental fat main effect (P<.01).

^cSupplemental fat main effect (P<.05).

TABLE 29. MAIN EFFECTS OF SUPPLEMENTAL FAT AND MONENSIN ON STEER PERFORMANCE AND DIET NET ENERGY VALUE (TRIAL 2)

Item	Treatment main effects				SE ^a
	Fat, %		Monensin, mg/kg		
	0	4	0	33	
Pen replicates	12	12	12	12	
Empty body weight, kg ^b					
Initial	333	331	333	331	2
Final	439	442	441	440	3
Empty body gain					
Weight, kg/d	1.14	1.19	1.16	1.16	.02
Protein, kg/d ^c	.148	.147	.147	.147	.004
Fat, kg/d ^{cd}	.498	.560	.528	.530	.015
Energy, Mcal/d ^{cd}	5.51	6.08	5.78	5.81	.14
Feed intake, kg/d ^{ef}	8.97	8.75	9.02	8.70	.09
Feed/gain ^{df}	7.91	7.39	7.79	7.51	.09
Net energy of diet, Mcal/kg					
Maintenance ^{edf}	1.750	1.882	1.784	1.848	.020
Gain ^{df}	1.154	1.251	1.179	1.226	.015
Maintenance coefficient ^f	.081	.081	.084	.077	.002

^aStandard error of mean, n = 12.

^bBased on carcass weight.

^cBased on carcass specific gravity of initial and final slaughter groups.

^dSupplemental fat main effect (P<.01).

^eSupplemental fat main effect (P<.10).

^fSupplemental monensin main effect (P<.05).

TABLE 30. MAIN EFFECTS OF SUPPLEMENTAL FAT AND MONENSIN ON CARCASS TRAITS OF FEEDLOT STEERS (TRIAL 2)

Item	Treatment main effects				SE ^a
	Fat, %		Monensin, mg/kg		
	0	4	0	33	
Carcass weight, kg	300	302	302	301	2
Carcass components, %					
Water	53.8	53.0	53.4	53.4	.2
Protein	16.1	15.8	16.0	15.9	.1
Fat	25.7	26.8	26.2	26.3	.3
Ribeye area, cm ²	76.1	75.4	75.4	76.2	.6
Fat thickness, cm ^b	.46	.49	.46	.48	.02
KPH, %	2.28	2.54	2.41	2.41	.08
Marbling score, degrees	3.60	3.62	3.59	3.63	.07
Yield, % ^c	51.8	51.5	51.7	51.7	.1

^aStandard error of mean, n = 12.

^bSupplemental fat main effect (P<.05).

^cSupplemental fat main effect (P<.10).

TABLE 31. MAIN EFFECTS OF SUPPLEMENTAL FAT AND MONENSIN ON CHARACTERISTICS OF DIGESTION

	Supplemental fat ^a , %		Supplemental monensin, mg/kg		SD ^b
	0	4	0	33	
Observations	8	8	8	8	
Ruminal digestion, %					
Organic matter ^c	55.5	51.2	53.4	53.3	2.8
Starch	90.3	91.3	90.7	90.9	2.7
Acid detergent fiber	16.9	14.5	18.8	12.6	10.6
Feed N	56.0	55.1	56.0	55.2	8.5
Microbial efficiency ^{dc}	25.1	28.0	27.5	25.6	2.7
Small intestinal digestion, %					
Organic matter ^c	47.3	49.6	49.0	47.9	2.1
Starch ^c	76.8	71.3	75.3	72.8	5.3
Acid detergent fiber	3.6	9.7	4.9	8.3	10.6
N ^f	74.0	73.3	74.8	72.5	2.2
Lipid ^f	81.3	79.1	77.3	83.0	5.5
Total tract digestion, %					
Organic matter	80.8	79.3	80.3	79.9	2.2
Starch	99.1	99.0	99.1	99.0	.20
Acid detergent fiber	31.8	29.3	32.8	28.4	5.8
N	74.6	74.6	74.2	75.0	3.2
Lipid ^{fg}	41.4	73.6	50.6	64.5	14.3

^aYellow grease.

^bStandard deviation.

^cFat significant (P<.05).

^dMicrobial N, g/kg organic matter fermented.

^eFat effect significant (P<.10).

^fMonensin effect significant (P<.10).

^gFat effect significant (P<.01).

TABLE 32. MAIN EFFECTS AND INTERACTIONS OF SUPPLEMENTAL FAT AND MONENSIN ON RUMINAL pH, VFA PROFILES AND ESTIMATED METHANOGENSIS

	Main effects				SD ^b
	Supplemental fat ^a , %		Supplemental monensin, mg/kg		
	0	4	0	33	
Average for feeding interval					
Ruminal pH	5.86	6.00	5.96	5.91	.28
Ruminal concentrations, mol/100mol					
Acetate ^{cd}	50.9	49.6	52.0	48.5	3.0
Propionate ^{efg}	39.9	42.6	38.7	43.8	3.0
Butyrate	9.2	7.8	9.3	7.7	1.9
Acetate/propionate ^{fg}	1.35	1.17	1.40	1.12	.19
Methane ^{fg}	.366	.335	.383	.318	

^aYellow grease.

^bStandard deviation.

^cSignificant supplemental fat by monensin interactions (P<.10).

^dSignificant monensin effect (P<.01).

^eSignificant supplemental fat effect (P<.05).

^fSignificant supplemental fat by monensin interactions (P<.05).

^gSignificant monensin effect (P<.05).

^hSignificant monensin effect (P<.01).

ⁱSignificant supplemental fat by monensin interactions (P<.01).

^jMethane, mol/mol glucose equivalent fermented.

^kSignificant monensin effect (P<.10).

Table 33. COMPOSITION OF EXPERIMENTAL DIETS FED TO STEERS
(Trials 1 and 2)^a

Item	Treatments			
	1	2	3	4
	%			
Alfalfa hay	6.38	6.00	6.00	6.00
Sudangrass hay	6.38	6.00	6.00	6.00
Steam flaked corn	76.56	71.96	69.09	65.26
Soybean meal			3.06	7.22
Yellow grease		6.00	6.00	6.00
Cane molasses	7.45	7.00	7.00	7.00
Limestone	1.64	1.54	1.54	1.54
Urea	1.06	1.00	.81	.48
Trace mineral salt ^b	.53	.50	.50	.50
Vitamin A ^c	+	+	+	+
Lasalocid ^d	+	+	+	+
Nutrient composition ^e				
Net energy, Mcal/kg				
Maintenance	2.10	2.34	2.33	2.33
Gain	1.44	1.64	1.64	1.63
Crude protein, %				
Total	13.6	12.8	13.5	14.2
Rumen degradable ^f	9.6	9.0	9.2	9.3
Rumen bypass	4.0	3.8	4.3	4.9
Ether extract, %	3.5	9.3	9.2	9.1
Calcium, %	.78	.73	.74	.76
Phosphorus, %	.29	.27	.28	.30

^aDry matter basis.

^bTrace mineral salt contained: CoSO₄, .068%; CuSO₄, 1.04%; FeSO₄, 3.57%; ZnO, .75%; MnSO₄, 1.07%; KI, .052%; and NaCl, 93.4%.

^c2200 IU/kg.

^d32 mg/kg.

^eBased on tabular values for individual feed ingredients (NRC, 1984) with exception of supplemental fat which was assigned NE_m and NE_g values of 6.03 and 4.79, respectively (Zinn, 1988b).

^fBased on the following estimates for ruminal degradability of dietary crude protein: alfalfa hay, 70%; sudangrass hay, 65%; steam flaked corn, 50%; soybean meal, 60%; cane molasses, 100% and urea, 100%.

Table 34. PROFILE OF YELLOW GREASE FED TO STEERS
(TRIALS 1 AND 2)

Item	
Moisture, %	.5
Impurities, %	.05
Unsaponifiabiles, %	1.16
Total fatty acids, %	94.7
Free fatty acids, %	13.1
Iodine value	75.5
Fatty acid profile, %	
C12	.2
C14	1.8
C15	.6
C16	23.9
C16:1	5.1
C17	.2
C18	11.1
C18:1	43.1
C18:2	14.0

Table 35. INFLUENCE OF PROTEIN SUPPLEMENTATION ON FEEDLOT GROWTH PERFORMANCE AND ESTIMATED NET ENERGY VALUE OF FAT SUPPLEMENTED DIETS FED TO STEERS (TRIAL 1)

Item	Treatment				SD
	1	2	3	4	
Empty body weight, kg					
Initial	273	274	275	272	.8
Final	458	476	471	468	24
Empty body gain, kg/d	1.25	1.36	1.33	1.32	.11
Dry matter intake, kg/d	7.34	7.02	7.12	7.19	.42
Dry matter conversion ^a	5.88	5.19	5.41	5.45	.27
Diet net energy, Mcal/kg					
Maintenance ^{bc}	1.94	2.19	2.14	2.09	.05
Gain ^{bc}	1.29	1.51	1.47	1.42	.05

^aTreatment 1 versus treatments 2, 3 and 4 (fat effect), $P < .05$.

^bTreatment 1 versus treatments 2, 3 and 4 (fat effect), $P < .01$.

^cLinear component for treatments 2, 3 and 4 (protein effect), $P < .05$.

Table 36. INFLUENCE OF PROTEIN SUPPLEMENTATION ON CARCASS MERIT AND EMPTY BODY COMPOSITION OF FEEDLOT STEERS FED FAT SUPPLEMENTED DIETS (TRIAL 1)

Item	Treatment				SD
	1	2	3	4	
Carcass weight, kg	314	328	324	321	17
Dressing percentage ^a	64.8	66.3	66.0	64.8	.9
Rib eye area, cm ²	83.8	86.1	84.6	82.0	4.5
Fat thickness, cm	.98	1.14	1.10	.97	.25
KPH, % ^{bc}	2.28	2.78	2.68	2.51	.33
Marbling score, degrees ^d	3.86	3.91	3.86	3.95	.23
Retail yield, %	51.2	50.6	50.7	50.8	.8
Empty body composition, %					
Water	54.0	52.6	52.6	53.1	1.4
Protein	16.3	15.9	15.9	16.1	.4
Fat	26.0	27.8	27.9	27.1	1.9

^aLinear component for treatments 2, 3 and 4 (protein effect), P<.10.

^bTreatment 1 versus treatments 2, 3 and 4 (fat effect), P<.10.

^cKidney, pelvic and heart fat as a percentage of carcass weight.

^dCoded: Minimum slight = 3, minimum small = 4, etc.

Table 37. INFLUENCE OF PROTEIN SUPPLEMENTATION ON CHARACTERISTICS OF DIGESTION OF FAT SUPPLEMENTED DIETS FED TO STEERS (TRIAL 2)

Item	Treatment				SD
	1	2	3	4	
Intake, g/d					
DM	5,782	5,788	5,827	5,827	
OM	5,477	5,485	5,518	5,521	
Starch	2,596	2,402	2,389	2,354	
ADF	431	439	445	443	
Lipid	158	442	470	453	
N (total)	125	119	126	132	
N (non-urea)	97.3	92.6	104.6	119.7	
GE, Mcal/d	24.1	26.0	26.4	26.4	
Leaving abomasum, g/d					
OM ^a	2,544	3,224	3,132	3,283	195
Starch ^b	462	579	586	595	66
ADF ^{cd}	340	398	375	349	27
Lipid ^{ae}	217	502	562	548	14
Non-ammonia N ^c	115	123	120	132	8
Microbial N ^{bd}	79.9	85.1	89.2	96.7	5.0
Feed N	36.0	37.7	31.1	35.7	6.8
Ruminal digestion, % intake					
OM ^a	68.1	56.7	59.4	58.0	3.3
Starch ^a	82.2	75.9	75.5	74.7	2.8
ADF ^d	21.0	9.4	15.7	21.3	6.3
Feed N					
Total	71.1	68.3	75.3	73.0	5.2
Non-urea ^d	63.0	59.3	70.3	70.1	6.1
Microbial efficiency ^{ag}	21.5	27.8	27.3	31.0	2.4
Protein efficiency ^{ch}	.93	1.03	.96	1.00	.06
Fecal excretion, g/d					
OM ^{ad}	695	841	927	950	51
Starch ^c	12.3	19.8	18.2	26.3	7.8
ADF ^b	226	242	250	257	16.5
Lipid ^{aij}	50.3	140.5	190.6	167.2	18.5
N ^{bd}	26.1	27.8	29.9	32.5	1.9
GE, Mcal/d ^{adk}	3.58	4.77	5.47	5.43	.31
Post-ruminal digestion, % leaving abomasum					
OM ^d	72.6	73.8	70.5	71.0	1.9
Starch	97.3	96.4	96.9	96.0	1.3
ADF ^d	32.8	39.2	33.1	26.1	5.4
Lipid ^c	77.0	72.1	66.1	69.5	5.7
N	78.6	78.3	76.4	76.6	1.3
Post-ruminal digestion, % intake					
OM ^a	33.8	43.4	40.0	42.3	3.2
Starch ^a	17.3	23.3	23.8	24.2	2.8
ADF ^{ad}	26.5	35.4	28.0	20.6	6.5
Lipid ^{ae}	105.1	81.8	79.1	84.1	2.6
N	76.6	85.2	76.8	80.6	5.7
Total tract digestion, %					
OM ^{ad}	87.3	84.7	83.2	82.7	.9
Starch ^c	99.5	99.2	99.2	98.9	.3
ADF	47.5	44.9	43.8	41.9	3.7
Lipid	68.3	68.2	59.4	63.1	8.4

Table 37 Continued

N ^a	79.1	76.6	76.2	75.4	1.5
DE, Mcal/kg ^{ci}	3.55	3.67	3.60	3.60	.05
ME, Mcal/kg ^{ad}	3.10	3.26	3.20	3.19	.04
NE _m ^{ad}	2.11	2.25	2.20	2.19	.03
NE _g ^{ad}	1.44	1.56	1.52	1.51	.03

^aTreatment 1 versus treatments 2, 3 and 4 (fat effect), P<.01.

^bTreatment 1 versus treatments 2, 3 and 4 (fat effect), P<.05.

^cTreatment 1 versus treatments 2, 3 and 4 (fat effect), P<.10.

^dLinear component for treatments 2, 3 and 4 (protein effect), P<.05.

^eLinear component for treatments 2, 3 and 4 (protein effect), P<.01.

^fQuadratic component for treatments 2, 3 and 4 (protein effect), P<.01.

^gMicrobial N, g/kg OM fermented.

^hDuodenal non-ammonia N/N intake.

ⁱLinear component for treatments 2, 3 and 4 (protein effect), P<.10.

^jQuadratic component for treatments 2, 3 and 4 (protein effect), P<.05.

^kQuadratic component for treatments 2, 3 and 4 (protein effect), P<.10.

Table 38. INFLUENCE OF PROTEIN SUPPLEMENTATION ON RUMINAL PH, AMMONIA, VFA PROFILES AND METHANE PRODUCTION 4 H POSTPTANDIAL (TRIAL 2)

Item	Treatment				SD
	1	2	3	4	
Ruminal pH	6.06	6.17	6.17	6.01	.18
Ruminal ammonia, mg/dl	5.56	4.68	6.68	4.79	2.11
Ruminal VFA, mol/100 mol					
Acetate ^a	68.8	70.8	67.1	65.2	3.3
Propionate ^b	21.6	19.5	21.8	24.5	2.7
Butyrate	9.6	9.7	11.1	10.3	1.3
Methane production ^{bc}	.62	.65	.61	.57	.04

^aLinear component for treatments 2, 3 and 4 (protein effect), P<.10.

^bLinear component for treatments 2, 3 and 4 (protein effect), P<.05.

^cMethane, mol/mol glucose equivalent fermented.

Table 39. INFLUENCE OF PROTEIN SUPPLEMENTATION ON THE ESTIMATED ENERGY VALUE OF YELLOW GREASE (TRIALS 1 AND 2)

Item	Treatment		
	2	3	4
Trial 1			
NE, Mcal/kg fat			
Maintenance	6.11	5.35	4.60
Gain	4.96	4.35	3.58
Trial 2			
DE, Mcal/kg fat	5.55	4.51	4.71
ME, Mcal/kg fat	5.76	4.86	4.93
NE, Mcal/kg fat			
Maintenance	4.44	3.69	3.60
Gain	3.44	2.84	2.73

Table 40. COMPOSITION OF EXPERIMENTAL DIETS FED TO STEERS^a

Item	Treatments			
	1	2	3	4
			%	
Alfalfa hay	6.00	6.00	6.00	6.00
Sudangrass hay	6.00	6.00	6.00	6.00
Steam flaked corn	51.43	46.43	49.43	44.43
Steam flaked wheat	20.00	20.00	20.00	20.00
Cassava pellets	10.00	10.00	10.00	10.00
Yellow grease		5.00		5.00
Blood meal			.66	.66
Feather meal			.67	.67
Meat and bone meal			.67	.67
Cane molasses	3.00	3.00	3.00	3.00
Sodium bicarbonate	.75	.75	.75	.75
Limestone	1.47	1.47	1.47	1.47
Urea	.95	.95	.95	.95
Trace mineral salt ^b	.40	.40	.40	.40
Vitamin A ^c	+	+	+	+
Nutrient composition ^d				
Net energy, Mcal/kg				
Maintenance	2.07	2.25	2.06	2.24
Gain	1.41	1.57	1.40	1.56
Crude protein, %				
Total	12.5	12.0	13.8	13.3
Rumen degradable ^e	8.8	8.6	9.2	9.0
Ether extract, %	2.7	7.5	2.8	7.6
Calcium, %	.80	.80	.88	.88
Phosphorus, %	.29	.27	.32	.31

^aDry matter basis.

^bTrace mineral salt contained: CoSO₄, .068%; CuSO₄, 1.04%; FeSO₄, 3.57%; ZnO, .75%; MnSO₄, 1.07%; KI, .052%; and NaCl, 93.4%.

^c2200 IU/kg.

^dBased on tabular values for individual feed ingredients (NRC, 1984) with exception of supplemental fat which was assigned NE_m and NE_g values of 6.03 and 4.79, respectively (Zinn, 1988).

^eBased on the following estimates for ruminal degradability of dietary crude protein: alfalfa hay, 70%; sudangrass hay, 65%; steam flaked corn, 50%; steam flaked wheat, 85%; cassava pellets, 77%; cane molasses, 100%; feather meal, 40%; blood meal, 17%; meat and bone meal, 37% and urea, 100%.

Table 41. COMPOSITION OF YELLOW GREASE USED IN TRIALS 1 AND 2^a

Yellow grease	
Moisture, %	.56
Impurities, %	.50
Unsaponifiabiles, %	.24
Iodine value	72.0
Free fatty acids, %	8.0
Fatty acid profile, %	
C14:0	1.1
C16:0	17.8
C16:1	2.5
C18:1	58.2
C18:2	19.5
C18:3	.9

^aAnalysis provided by Baker Commodities Inc., Los Angeles, CA.

Table 42. INFLUENCE OF PROTEIN SUPPLEMENTATION ON THE COMPARATIVE FEEDING VALUE OF YELLOW GREASE IN A GROWING-FINISHING DIET FOR FEEDLOT CATTLE

Item	Treatments				SD
	1	2	3	4	
Pen replicates	4	4	4	4	
Live weight, kg					
Initial ^b	352	351	350	351	26
Final ^c	480	497	485	495	28
Weight gain, kg/d					
First 56-d	1.09	1.26	1.12	1.17	.20
Overall (123-d)	1.04	1.21	1.10	1.18	.15
DMI, kg/d					
First 56-d	6.61	6.62	6.61	6.41	.69
Overall (123-d)	6.69	6.79	6.77	6.91	.62
DMI/gain					
First 56-d	6.08	5.32	5.93	4.53	.46
Overall (123-d)	6.45	5.68	6.15	5.84	.36
Diet NE, Mcal/kg ^d					
Maintenance	1.94	2.22	2.03	2.13	.13
Gain	1.29	1.53	1.37	1.46	.12

^aDM basis.

^bInitial weight reduced 4% to adjust for digestive tract fill.

^cCarcass adjusted final weight.

^dEnergy retention was based on carcass specific gravity.

Table 43. TREATMENT EFFECTS ON ON CARCASS MEASUREMENTS

Item	Treatments				SD
	1	2	3	4	
Carcass weight, kg	309	321	313	319	18
Carcass composition, %					
Water	51.3	49.0	50.6	49.7	1.8
Fat	29.2	32.5	30.3	31.6	2.5
Protein	15.3	14.5	15.0	14.7	.6
Dressing percentage	64.5	64.7	64.9	64.1	.8
Rib eye area, cm ²	82.7	79.2	81.9	81.0	4.0
Fat thickness, cm	1.14	1.53	1.31	1.39	.39
KPH, % ^a	2.73	2.89	2.77	2.83	.37
Marbling score, degrees ^{bc}	4.04	4.35	4.72	3.60	.28
Retail yield, %	50.6	49.0	50.1	49.6	1.3
Liver Abscess, %	0	0	0	0	0

^aKidney, pelvic and heart fat as a percentage of carcass weight.

^bCoded: Minimum slight = 3, minimum small = 4, etc.

^cInteraction of protein and yellow grease supplementation, P<.01.

Table 44. MAIN EFFECT OF PROTEIN SUPPLEMENTATION ON FEEDLOT PERFORMANCE OF GROWING-FINISHING STEERS

Item	High-bypass protein blend		SD
	-	+	
Pen replicates	8	8	
Live weight, kg			
Initial ^a	351	350	26
Final ^b	488	490	28
Weight gain, kg/d			
First 56-d	1.17	1.15	.20
Overall (150-d)	1.11	1.13	.15
DMI, kg/d			
First 56-d	6.61	6.51	.69
Overall (150-d)	6.74	6.84	.62
DMI/gain			
First 56-d	5.70	5.73	.46
Overall (150-d)	6.07	6.00	.36
Diet NE, Mcal/kg ^c			
Maintenance	2.08	2.08	.14
Gain	1.41	1.41	.12

^aInitial weight reduced 4% to adjust for digestive tract fill.

^bCarcass adjusted final weight.

^cEnergy retention was based on carcass specific gravity.

Table 45. MAIN EFFECTS OF PROTEIN SUPPLEMENTATION ON CARCASS MEASUREMENTS

Item	High-bypass protein blend		SD
	-	+	
Carcass weight, kg	315	316	18
Carcass composition, %			
Water	50.2	50.1	1.8
Fat	30.9	30.9	2.5
Protein	14.9	14.9	.6
Dressing percentage	64.6	64.5	.8
Rib eye area, cm ²	80.9	81.4	4.0
Fat thickness, cm	1.34	1.35	.39
KPH, % ^a	2.81	2.80	.37
Retail yield, %	49.8	49.9	1.3
Liver Abscess, %	0	0	0

^aKidney, pelvic and heart fat as a percentage of carcass weight.

Table 46. MAIN EFFECT OF YELLOW GREASE SUPPLEMENTATION ON FEEDLOT PERFORMANCE OF GROWING-FINISHING STEERS

Item	Yellow grease, %		SD
	0	5	
Pen replicates	8	8	
Live weight, kg			
Initial ^a	351	351	26
Final ^b	481	495	28
Weight gain, kg/d			
First 56-d	1.11	1.21	.20
Overall (150-d)	1.06	1.18	.15
DMI, kg/d			
First 56-d	6.61	6.51	.69
Overall (150-d)	6.73	6.85	.62
DMI/gain			
First 56-d ^c	6.01	5.42	.46
Overall (150-d) ^d	6.37	5.82	.36
Diet NE, Mcal/kg ^e			
Maintenance ^d	1.98	2.17	.14
Gain ^d	1.33	1.50	.12

^aInitial weight reduced 4% to adjust for digestive tract fill.

^bCarcass adjusted final weight.

^cTreatments differ, P<.10.

^dTreatments differ, P<.05.

^eEnergy retention was based on carcass specific gravity.

Table 47. MAIN EFFECTS OF YELLOW GREASE SUPPLEMENTATION ON CARCASS MEASUREMENTS

Item	Yellow grease, %		SD
	0	5	
Carcass weight, kg	311	320	18
Carcass composition, %			
Water	50.9	49.3	1.8
Fat	29.8	32.0	2.5
Protein	15.1	14.6	.6
Dressing percentage	64.7	64.3	.8
Rib eye area, cm ²	82.3	80.1	4.0
Fat thickness, cm	1.22	1.46	.39
KPH, % ^a	2.75	2.86	.37
Retail yield, %	50.4	49.3	1.3
Liver Abscess, %	0	0	0

^aKidney, pelvic and heart fat as a percentage of carcass weight.

Table 48. INFLUENCE OF PROTEIN AND FAT SUPPLEMENTATION ON RUMINAL PH, VFA PROFILES AND METHANE PRODUCTION 4 H POSTPRANDIAL (Trial 2)

Item	Treatments				SD
	1	2	3	4	
Ruminal pH	5.90	5.90	5.81	5.95	.11
Ruminal VFA, mol/100 mol					
Acetate	55.1	60.7	60.1	60.2	3.6
Propionate	27.3	24.5	26.5	25.3	3.8
Butyrate ^{ab}	17.7	14.8	13.4	14.5	1.8
Methane production ^c	.50	.55	.53	.54	.05

^aSupplemental protein main effect, P<.05.

^bSupplemental protein by fat interaction, P<.10.

^cMethane, mol/mol glucose equivalent fermented.

Table 49. INFLUENCE OF PROTEIN AND FAT SUPPLEMENTATION ON CHARACTERISTICS OF RUMINAL AND TOTAL TRACT DIGESTION (Trial 2)

Item	Treatments				SD
	1	2	3	4	
Intake, g/d					
OM	6,695	6,950	6,890	7,065	
ADF	587	461	543	636	
N	144	133	153	160	
lipid	243	564	250	590	
GE, Mcal/d	29.9	32.5	30.8	33.5	
Leaving abomasum, g/d					
OM ^a	3,108	2,930	2,998	2,469	257
ADF ^b	369	342	396	436	36
Non-ammonia N ^b	149	129	156	162	16
Microbial N	57.9	58.8	55.2	56.0	13.4
Feed N ^{ac}	91.5	70.3	100.6	111.4	13.5
lipid ^d	261	556	270	619	111
GE, Mcal/d ^{ad}	15.7	16.3	15.4	19.3	1.2
Ruminal digestion, %					
OM ^{ae}	62.2	66.3	64.5	58.1	2.1
ADF ^a	37.1	25.9	27.0	31.5	4.9
Feed N	36.3	47.2	34.0	30.4	8.5
GE ^a	47.7	49.7	50.1	42.5	3.5
Fecal excretion, g/d					
OM	825	839	729	895	153
ADF	266	294	249	295	47
N	35.0	30.1	30.4	34.6	5.2
Lipid ^d	83.8	135.0	65.4	145.7	26.1
GE, Mcal/d	4.3	4.6	3.8	4.9	.8
Postruminal digestion, % duodenal					
OM	73.2	71.0	75.9	74.1	3.8
ADF ^b	16.1	10.4	37.7	31.5	14.1
N	77.7	77.1	81.0	79.2	3.1
Lipid	67.7	75.4	75.7	74.8	4.6
GE	72.5	71.4	75.8	74.2	4.0
Small intestinal digestion, % intake					
OM	34.1	30.1	32.9	36.4	2.3
ADF ^b	17.5	10.3	27.1	22.1	8.3
N	83.7	78.4	86.0	83.7	9.6
Total tract digestion, %					
OM	87.7	87.9	89.4	87.3	2.2
ADF ^{fg}	54.6	36.2	54.2	53.6	8.8
N	75.6	77.4	80.0	78.4	3.4
GE	85.6	85.8	87.8	85.3	2.4
DE, Mcal/kg ^h	3.60	3.84	3.73	3.82	.1

^aSupplemental protein by fat interaction, P<.05.

^bSupplemental protein main effect, P<.05.

^cSupplemental protein main effect, P<.01.

^dSupplemental fat main effect, P<.01.

^eSupplemental protein by fat interaction, P<.01.

^fSupplemental fat main effect, P<.10.

^gSupplemental protein by fat interaction, P<.10.

^hSupplemental fat main effect, P<.05.

Table 50. COMPOSITION OF EXPERIMENTAL DIETS FED TO STEERS (Trials 1 and 2)

Item	Treatments					
	1	2	3	4	5	6
Ingredient Composition, % ^a						
Alfalfa hay	8.00	8.00	8.00	8.00	8.00	8.00
Sudangrass hay	4.00	4.00	4.00	4.00	4.00	4.00
Steam flaked corn	79.24	69.54	69.54	9.70		
Steam flaked wheat				70.24	70.24	70.24
Yellow grease		6.00			6.00	
Cottonseed oil soapstock			6.00			6.00
Cottonseed meal		3.70	3.70		3.70	3.70
Cane molasses	6.00	6.00	6.00	6.00	6.00	6.00
Limestone	1.56	1.56	1.56	1.56	1.56	1.56
Urea	.70	.70	.70			
Trace mineral salt ^b	.50	.50	.50	.50	.50	.50
Vitamin A ^c	+	+	+	+	+	+
Nutrient composition ^{ad}						
Net energy, Mcal/kg						
Maintenance	2.13	2.33	2.33	2.01	2.21	2.21
Gain	1.47	1.64	1.64	1.36	1.53	1.53
Crude protein, %						
Total	12.0	12.7	12.7	13.1	13.8	13.8
Rumen degradable ^e	7.5	7.8	7.8	9.1	9.3	9.3
Rumen escape ^e	5.4	5.7	5.7	4.2	4.5	4.5
Ether extract, %	3.6	9.3	9.3	2.0	7.6	7.6
Calcium, %	.75	.75	.75	.77	.77	.77
Phosphorus, %	.29	.32	.32	.37	.40	.40

^aDM basis.

^bTrace mineral salt contained: CoSO₄, .068%; CuSO₄, 1.04%; FeSO₄, 3.57%; ZnO, .75%; MnSO₄, 1.07%; KI, .052%; and NaCl, 93.4%.

^c2200 IU/kg.

^dBased on tabular values for individual feed ingredients (NRC, 1984) with exception of supplemental fat which was assigned NE_m and NE_g values of 6.03 and 4.79, respectively (Zinn, 1988).

^eBased on the following estimates for ruminal degradability of dietary crude protein: alfalfa hay, 70%; sudangrass hay, 65%; steam flaked corn, 45%; cottonseed meal, 45%; cane molasses, 100% and urea, 100%.

Table 51. CHEMICAL ANALYSES OF SUPPLEMENTAL FATS (Trials 1 and 2)

Item	Supplemental fat source	
	Yellow grease	Cottonseed oil soapstock
Moisture, %	.5	1.4
Impurities, %	.05	4.9
Unsaponifiabiles, %	1.16	3.46
Iodine value	75.5	102.6
Free fatty acids, %	13.1	54.8
Total fatty acids, %	94.7	85.7
Fatty acid profile, % total		
C12:0	.2	.4
C14:0	1.8	.9
C16:0	24.1	21.5
C16:1	5.1	1.4
C18:0	11.2	6.0
C18:1	43.4	26.5
C18:2	14.1	40.2
C18:3	.1	3.1

Table 52. INFLUENCE OF FAT SUPPLEMENTATION ON 121-D GROWTH-PERFORMANCE OF FEEDLOT STEERS AND NET ENERGY VALUE OF THE DIET (Trial 1)

Item	Treatments ^a			SD
	No fat	6% YG	6% COS	
Pen replicates	10	10	10	
Initial weight, kg				
Live ^b	324	323	323	.2
Empty body	292	292	292	.2
Final weight, kg				
Live ^{cd}	481	492	488	.13
Empty body ^d	452	462	458	.11
Gain				
Live weight, kg/d ^e	1.30	1.41	1.38	.11
Empty body				
Weight, kg/d ^e	1.33	1.43	1.40	.10
Water, kg/d	.62	.63	.60	.07
Fat, kg/d, kg/d ^e	.48	.55	.56	.08
Protein, kg/d	.19	.20	.19	.02
Energy, Mcal/d ^e	5.57	6.26	6.36	.74
DM intake, kg/d ^e	7.82	7.42	7.61	.38
ME intake, Mcal/d ^e	22.4	23.1	23.4	1.2
DM conversion				
Live weight ^f	6.05	5.28	5.54	.40
Empty body weight ^f	5.91	5.23	5.47	.33
Diet NE, Mcal/kg				
Maintenance ^f	1.91	2.13	2.09	.07
Gain ^f	1.27	1.45	1.43	.07

^aTreatment main effects for: no supplemental fat (No fat); supplemental yellow grease (6% YG) and supplemental cottonseed oil soapstock (6% COS).

^bLive weight reduced 4% to adjust for digestive tract fill.

^cCarcass weight/average dressing percentage.

^dNo fat versus 6% YG and 6% COS, P<.10.

^eNo fat versus 6% YG and 6% COS, P<.05.

^fNo fat versus 6% YG and 6% COS, P<.01.

Table 53. INFLUENCE OF FAT SUPPLEMENTATION ON CARCASS MERIT OF FEEDLOT STEERS (Trial 1)

	Treatments ^a			SD
	No fat	6% YG	6% COS	
Carcass weight, kg ^b	309	317	314	8
Carcass specific gravity ^b	1.0554	1.0530	1.0519	.0041
Carcass composition, %				
Water ^b	52.2	51.3	50.9	1.5
Protein ^b	15.5	15.2	15.1	.5
Fat ^b	28.0	29.3	29.9	2.2
Dressing percentage ^c	63.7	65.1	64.6	.9
Rib eye area, cm ² ^{bd}	83.5	87.8	84.8	3.6
Fat thickness, cm	.99	1.07	1.13	.19
KPH, % ^{bef}	2.05	2.23	2.36	.31
Marbling score, degrees ^g	3.88	3.98	3.90	.35
Retail yield, %	51.4	51.5	51.0	.6
Abscessed liver, %	5.0	0	0	4.6

^aTreatment main effects for: no supplemental fat (No fat); supplemental yellow grease (6% YG) and supplemental cottonseed oil soapstock (6% COS).

^bNo fat versus 6% YG and 6% COS, P<.10.

^cNo fat versus 6% YG and 6% COS, P<.01.

^d6% YG versus 6% COS, P<.10.

^eInteraction between grain type and supplemental fat, P<.10. With the wheat based diet %KPH averaged 2.05, 2.00 and 2.05 for the no fat, 6% YG and 6% CSS diets, respectively. With the corn based diet %KPH averaged 2.08, 2.45 and 2.68 for the no fat, 6% YG and 6% CSS diets, respectively.

^fKidney, pelvic and heart fat as a percentage of carcass weight.

^gCoded: Minimum slight = 4, minimum small = 5, etc.

Table 54. CHARACTERISTICS OF STEAM-FLAKED CORN AND WHEAT (Trial 1 and 2)

Item	Steam-flaked	
	Corn	Wheat
Dry matter, % ^a	83.0	87.0
N, % (DM basis)	1.47	2.47
Starch, % (DM basis)	72.3	65.0
Density, kg/l ^{ab}	.30	.36
Amyloglucosidase reactive starch, % of total starch	12.5	11.2

^aMeasurement taken on grain as it exited the rollers.

^b.30 kg/liter = 23 lb/bu, .36 kg/liter = 28 lb/bu.

Table 55. INFLUENCE OF REPLACING STEAM-FLAKED CORN WITH STEAM-FLAKED WHEAT ON 121-D GROWTH-PERFORMANCE OF FEEDLOT STEERS AND NET ENERGY VALUE OF THE DIET (Trial 1)

Item	Steam-flaked		SD
	Corn	Wheat	
Pen replicates	15	15	
Initial weight, kg			
Live ^a	323	323	2
Empty body	292	292	2
Final weight, kg			
Live ^b	489	484	13
Empty body	459	455	11
Gain			
Live weight, kg/d	1.39	1.34	.11
Empty body			
Weight, kg/d	1.40	1.36	.10
Water, kg/d	.62	.62	.07
Fat, kg/d, kg/d	.55	.51	.08
Protein, kg/d	.19	.19	.02
Energy, Mcal/d	6.26	5.87	.74
DM intake, kg/d	7.63	7.61	.38
ME intake, Mcal/d	23.3	22.6	1.2
DM conversion			
Live weight	5.53	5.72	.40
Empty body weight	5.46	5.62	.33
Diet NE, Mcal/kg			
Maintenance ^c	2.08	2.01	.07
Gain ^c	1.41	1.35	.07

^aLive weight reduced 4% to adjust for digestive tract fill.

^bCarcass weight/average dressing percentage.

^cTreatments differ, P<.05.

Table 56. INFLUENCE OF REPLACING STEAM-FLAKED CORN WITH STEAM-FLAKED WHEAT ON CARCASS MERIT OF FEEDLOT STEERS (Trial 1)

Item	Steam-flaked		SD
	Corn	Wheat	
Carcass weight, kg	315	312	8
Carcass specific gravity	1.0525	1.0544	.0041
Carcass composition, %			
Water	51.2	51.8	1.5
Protein	15.2	15.4	.5
Fat	29.5	28.6	2.2
Dressing percentage	64.5	64.4	.9
Rib eye area, cm ²	84.9	85.8	3.6
Fat thickness, cm	1.08	1.05	.19
KPH, % ^{abc}	2.40	2.02	.31
Marbling score, degrees ^d	3.95	3.89	.35
Retail yield, % ^e	51.1	51.5	.6
Abscessed liver, %	1.6	0	4.6

^aTreatments differ, $P < .01$.

^bInteraction between grain type and supplemental fat, $P < .10$. With the wheat based diet %KPH averaged 2.05, 2.00 and 2.05 for the no fat, 6% YG and 6% CSS diets, respectively. With the corn based diet %KPH averaged 2.08, 2.45 and 2.68 for the no fat, 6% YG and 6% CSS diets, respectively.

^cKidney, pelvic and heart fat as a percentage of carcass weight.

^dCoded: Minimum slight = 4, minimum small = 5, etc.

^eTreatments differ, $P < .10$.

Table 57. INFLUENCE OF OLEIC ACID INFUSION INTO THE ABOMASUM ON SMALL INTESTINAL DIGESTIBILITY OF LONG-CHAIN FATTY ACIDS^a

Item	Oleic Acid Infusion, g/d			SD ^a
	0	68	106	
Small intestinal digestion, %				
Total fatty acids	72.0	78.8	69.2	12.8
Myristic	88.7	90.6	83.7	10.4
Palmitic	74.9	80.6	62.6	16.1
Stearic	62.5	69.4	49.5	16.7
Oleic	89.7	88.7	92.1	10.4
Linoleic	92.5	90.5	93.1	6.2

^aMeasured in Holstein steers (209 kg) with cannulas in the abomasum, proximal duodenum and distal ileum. Dry matter intake was 4.1 kg/d.

Table 58. COMPOSITION OF EXPERIMENTAL DIETS^a

Item	Control	Coconut Bottoms
	%	
Alfalfa hay	8.24	7.83
Sudangrass hay	4.02	3.82
Steam rolled barley	57.92	54.01
Steam flaked corn	18.83	17.89
Cottonseed meal	.90	.85
Coconut bottoms ^b		6.00
Cane molasses	7.44	7.07
Urea	.30	.28
Dicalcium phosphate	.10	.10
Limestone	1.30	1.23
Trace mineral salt ^c	.50	.47

^aDry matter basis.

^bCoconut alcohol bottoms-bottoms.

^cTrace mineral salt contained: CoSO₄, .068%; CuSO₄, 1.04%; FeSO₄, 3.57%; ZnO, .75%; MnSO₄, 1.07%; KI, .052%; and NaCl, 93.4%.

TABLE 59. INFLUENCE OF COCONUT ALCOHOL BOTTOMS-BOTTOMS SUPPLEMENTATION ON RUMINAL PH, VOLATILE FATTY ACID PROFILES AND ESTIMATED METHANE PRODUCTION 4-H POSTPRANDIAL

Item	Control	Coconut Bottoms	SD ^a
Ruminal pH	6.16	6.33	.22
Ruminal concentration, mol/100 mol			
Acetate	68.4	66.5	5.5
Propionate	23.0	25.3	6.0
Butyrate	8.6	8.3	2.2
Acetate/propionate	3.10	2.84	.88
Methane production ^b	.604	.572	.080

^aStandard deviation.

^bMethane, mol/mol glucose equivalent fermented.

TABLE 60. INFLUENCE OF COCONUT ALCOHOL BOTTOMS-BOTTOMS ON CHARACTERISTICS OF DIGESTION OF A FINISHING DIET BY FEEDLOT STEERS

Item	Control	Coconut Bottoms	SD ^a
Intake, g/d			
Organic matter	4534	4810	
Acid detergent fiber	495	498	
Lipid	71	375	
N	102	100	
Gross energy, Mcal/d	20.8	24.8	
Leaving abomasum, g/d			
Organic matter ^b	1893	2130	214
Acid detergent fiber	398	365	55
Lipid ^c	137	455	34
Non-ammonia N	101	103	15
Microbial N	67.6	73.8	14.1
Feed N	33.0	29.4	10.3
Ruminal digestion, %			
Organic matter	58.2	55.7	4.5
Acid detergent fiber	19.6	26.6	9.9
Feed N	67.6	70.5	10.3
Microbial efficiency ^d	26.0	28.1	7.0
Leaving small intestine, g/d			
Organic matter ^e	900	1139	140
Acid detergent fiber	325	351	63
Lipid ^c	24.3	280.9	26.9
N	28.3	28.8	2.7
Small intestinal digestion, %			
Organic matter	52.5	46.3	6.1
Acid detergent fiber	17.6	1.1	22.7
Lipid ^c	82.2	38.0	6.2
N	71.8	71.7	3.3
Fecal excretion, g/d			
Organic matter ^c	684	957	77
Acid detergent fiber ^e	274	341	36
Lipid ^c	28.8	283.0	34.3
N	24.8	25.4	3.0
Gross energy, Mcal/d ^c	4.50	8.01	.67
Total tract digestion, %			
Organic matter ^c	84.9	80.1	1.6
Acid detergent fiber ^e	44.6	31.5	9.7
N	75.7	74.6	3.0
Digestible energy, Mcal/kg	3.36	3.27	.13
Metabolizable energy, Mcal/kg	2.93	2.87	.13

^aStandard deviation.

^bTreatments differ, P<.10.

^cTreatments differ, P<.01.

^dMicrobial N, g/kg organic matter fermented.

^eTreatments differ, P<.05.

TABLE 61. INFLUENCE OF COCONUT ALCOHOL BOTTOMS-BOTTOMS SUPPLEMENTATION ON CHARACTERISTICS OF FATTY ACID DIGESTION IN THE SMALL INTESTINE

Item	Control	Coconut Bottoms	SD ^a
Entering the small intestine, g/d			
Total fatty acids ^b	73.26	107.51	.11
Myristic	6.15	6.67	6.11
Palmitic ^c	16.38	19.27	2.41
Palmitoleic	.04	.05	.03
Stearic ^b	43.77	77.90	12.95
Oleic ^c	5.87	2.70	2.87
Linoleic	1.03	.93	.74
Leaving the small intestine, g/d			
Total fatty acids ^b	7.66	31.27	8.07
Myristic	6.15	6.67	6.12
Palmitic ^b	1.97	5.16	1.35
Palmitoleic	.01	.03	0.01
Stearic ^b	4.45	24.29	6.55
Oleic	.50	.47	.30
Linoleic ^d	.25	.65	.24
Small intestinal digestion, %			
Total fatty acids ^b	89.5	71.2	7.1
Myristic	88.3	83.7	12.0
Palmitic ^b	87.8	73.2	6.8
Palmitoleic	63.4	41.7	21.5
Stearic ^b	89.8	68.7	8.5
Oleic	90.4	83.2	7.5
Linoleic	75.7	30.1	141.0

^aStandard deviation.

^bTreatments differ, P<.01.

^cTreatments differ, P<.10.

^dTreatments differ, P<.05.

Table 62. COMPOSITION OF EXPERIMENTAL DIETS FED TO STEERS^a

Item	Treatments			
	Control	YG	ML	RI
Ingredient composition, %				
Alfalfa hay	45.00	44.71	44.71	44.71
Dry rolled corn	40.26	31.91	31.91	31.91
Soybean meal	6.25	9.93	9.93	9.93
Yellow grease		5.00		
Megalac			5.00	
RumInsol				5.00
Cane molasses	7.00	6.96	6.96	6.96
Dicalcium phosphate	.60	.60	.60	.60
Trace mineral salt ^b	.50	.50	.50	.50
Chromic oxide	.40	.40	.40	.40

^aDry matter basis.

^bTrace mineral salt contained: CoSO₄, .068%; CuSO₄, 1.04%; FeSO₄, 3.57%; ZnO, .75%; MnSO₄, 1.07%; KI, .052%; and NaCl, 93.4%.

Table 63. FATTY ACID PROFILE OF SUPPLEMENTAL FATS

Item	Supplemental fats		
	YG	ML	RI
Fatty acids, %			
C14:0	1.9	1.8	1.9
C16:0	24.3	51.2	50.8
C16:1	3.3		
C18:0	12.5	4.6	4.9
C18:1	41.6	34.7	34.5
C18:2	15.5	7.4	7.6
C18:3	.9	.3	.3

Table 64. COMPARATIVE EFFECTS OF YELLOW GREASE, MEGALAC AND RI ON CHARACTERISTICS OF DIGESTION IN CATTLE

Item	Treatments				SD
	Control	YG	ML	RI	
Intake, g/d					
OM	5,546	5,566	5,549	5,548	
ADF	988	990	993	1,007	
Lipid	83	351	294	291	
N	151	163	166	160	
Gross energy, Mcal/d	25.0	27.1	26.6	26.4	
Leaving abomasum, g/d					
OM	3,437	3,192	3,706	3,366	475
ADF	671	700	787	773	171
Lipid ^a	158	415	397	371	52
Non-ammonia N ^b	163	145	156	140	11
Microbial N	76.7	71.2	75.5	69.6	6.1
Feed N ^c	86.8	73.4	80.9	69.9	10.7
Ruminal digestion, %					
OM	51.9	55.4	46.8	51.9	7.9
ADF	32.0	29.2	20.7	23.3	17.9
Feed N ^b	42.6	54.9	51.2	56.2	6.7
Microbial efficiency ^d	26.9	23.1	30.4	24.6	6.2
Protein efficiency ^{ae}	1.08	.89	.94	.87	.07
Leaving small intestine, g/d					
OM ^p	1,778	1,496	1,644	1,493	130
ADF	588	509	505	539	76
Lipid ^b	44.5	90.1	75.2	82.6	18.1
N ^b	53.3	47.2	50.5	45.6	2.9
Small intestinal digestion, %					
OM ^p	47.7	53.2	55.1	55.4	4.8
ADF	11.5	26.3	32.7	29.9	19.5
Lipid ^a	71.3	78.3	80.3	77.3	9.5
N	67.2	67.3	67.7	67.3	2.9
Fecal excretion, g/d					
OM	1,570	1,492	1,479	1,424	265
ADF	568	554	446	523	83
N	52.6	48.6	48.5	51.0	6.2
Gross energy, Mcal/d	8.07	7.99	7.69	7.61	1.28
Total tract digestion, %					
OM	71.7	73.2	73.3	74.3	4.8
ADF	42.4	43.9	55.0	48.1	8.4
N ^c	65.2	70.1	70.8	68.1	3.9
DE, Mcal/kg ^b	2.82	3.16	3.12	3.13	.21
ME, Mcal/kg ^b	2.57	2.90	2.89	2.87	.18

^aControl versus Yellow grease, Megalac and RumInsol, P<.01.

^bControl versus Yellow grease, Megalac and RumInsol, P<.05.

^cControl versus Yellow grease, Megalac and RumInsol, P<.10.

^dMicrobial N, g/kg OM fermented.

^eDuodenal non-ammonia N/N intake.

Table 65. COMPARATIVE DIGESTION OF YELLOW GREASE, MEGALAC AND RI FATTY ACIDS IN THE SMALL INTESTINE OF CATTLE.

Item	Treatments				SD
	Control	YG	ML	RI	
Leaving abomasum, g/d					
C16:0 ^{ab}	34.1	83.2	117.4	118.6	13.5
C18:0 ^{ac}	82.1	160.4	127.8	137.7	15.5
C18:1 ^{ad}	23.7	68.6	79.6	60.1	11.2
C18:2 ^{ef}	10.4	12.6	19.4	13.6	3.5
Total fatty acids ^a	150.4	328.2	345.1	333.8	30.8
Leaving distal ileum, g/d					
C16:0 ^g	6.5	13.8	23.9	17.5	7.5
C18:0 ^g	11.1	29.7	20.4	26.8	10.0
C18:1 ^e	3.0	5.0	6.6	5.2	1.9
C18:2 ^h	2.0	1.7	3.1	2.6	.8
Total fatty acids ^g	22.9	50.9	54.0	52.2	16.5
Small intestinal digestion, %					
C16:0	80.6	82.8	79.2	84.7	8.6
C18:0	87.6	81.9	83.0	79.5	8.1
C18:1	87.2	92.7	91.1	90.1	4.0
C18:2	79.9	86.2	82.8	78.0	8.2
Total fatty acids	85.1	84.6	83.5	83.5	6.1

^aControl versus supplemental fat, P<.01.

^bYellow grease versus Megalac and RumInsol, P<.01.

^cYellow grease versus Megalac and RumInsol, P<.05.

^dMegalac versus RumInsol, P<.05.

^eControl versus supplemental fat, P<.10.

^fMegalac versus RumInsol, P<.10.

^gControl versus supplemental fat, P<.05.

^hYellow grease versus Megalac and RumInsol, P<.10.

Table 66. INFLUENCE OF LEVEL OF FAT SUPPLEMENTATION ON RUMINAL PH, VFA PROFILES AND METHANE PRODUCTION 4 H POSTPRANDIAL

Item	Treatments				SD
	Control	YG	ML	RI	
Ruminal pH ^a	6.29	6.08	6.74	6.56	.37
Ruminal VFA, mol/100 mol					
Acetate	64.1	65.4	66.1	68.3	4.1
Propionate ^b	18.6	16.0	18.1	15.9	1.6
Isobutyrate	1.4	1.4	1.6	1.4	.4
Butyrate	12.7	10.7	11.1	11.0	1.8
Isovalerate ^c	1.8	5.1	1.8	2.1	2.6
Valerate	1.4	1.3	1.3	1.3	.2
Methane production ^d	.62	.66	.64	.67	.03

^aYellow grease versus Megalac and RumInsol, P<.05.

^bControl versus Yellow grease, Megalac and RumInsol, P<.10.

^cYellow grease versus Megalac and RumInsol, P<.10.

^dMethane, mol/mol glucose equivalent fermented.

Table 67. COMPOSITION OF EXPERIMENTAL DIETS FED TO STEERS

Item	Treatments			
	1	2	3	4
Ingredient composition, % (DM basis)				
Alfalfa hay	20.00	20.00	20.00	20.00
Steam-rolled barley	43.00	43.00	43.00	43.00
Steam flaked corn	25.00	20.00	5.00	
Whole cottonseed ^a			20.00	20.00
Yellow grease ^b		5.00		5.00
Cané molasses	10.00	10.00	10.00	10.00
Limestone	1.20	1.20	1.20	1.20
Trace mineral salt ^c	.40	.40	.40	.40
Chromic oxide	.40	.40	.40	.40

^aWhole cottonseed contained 4.0% ash, 4.1% N, 36.6% ADF and 18.1% ether extract (DM basis).

^bYellow grease contains 91.5% total fatty acids, 15.0% free fatty acids, 1.1% MIU (moisture, impurities and unsaponifiables) and an iodine value of 65.1.

^cTrace mineral salt contained: CoSO₄, .068%; CuSO₄, 1.04%; FeSO₄, 3.57%; ZnO, .75%; MnSO₄, 1.07%; KI, .052%; and NaCl, 93.4%.

Table 68. INFLUENCE OF WHOLE COTTONSEED AND SUPPLEMENTAL FAT ON CHARACTERISTICS OF RUMINAL AND TOAL TRACT DIGESTION

	No Cottonseed		20% Cottonseed		Main effects				SD
	No	5%	No	5%	Cottonseed		Fat ^a		
	Fat	Fat	Fat	Fat	0%	20%	0%	5%	
Intake, g/d									
DM	3,644	3,661	3,711	3,723	3,653	3,717	3,678	3,692	
OM	3,428	3,448	3,479	3,498	3,438	3,488	3,453	3,473	
ADF	432	453	651	686	442	668	541	570	
N	64	63	85	83	64	84	74	73	
Starch	1,270	1,185	997	794	1,227	895	1,133	989	
Lipid	66	216	161	300	141	231	114	258	
GE, Mcal/d	14.9	16.0	15.8	16.7	15.4	16.3	15.3	16.3	
Leaving abomasum, g/d									
OM ^{bcd}	1,633	1,801	1,927	2,365	1,717	2,146	1,780	2,083	114
ADF ^{be}	357	403	574	683	380	629	466	543	56
Starch ^{bd}	154.9	147.5	95.8	125.2	151.2	110.5	125.4	136.3	16.4
Lipid ^{abcd}	101	220	192	349	160	271	146	284	19
N ^b	73.2	75.6	88.8	93.4	74.4	91.1	81.0	84.5	5.2
Non-ammonia N ^b	70.7	72.9	85.2	89.6	71.8	87.4	77.9	81.3	4.9
Microbial N ^{bf_g}	44.7	45.3	56.8	48.5	45.0	52.7	50.8	46.9	3.2
Feed N ^{bc_g}	26.0	27.7	28.4	41.0	26.8	34.7	27.2	34.4	3.6
Ruminal digestion, %									
OM ^{bc_g}	65.4	60.9	60.9	46.3	63.2	53.6	63.2	53.6	3.4
ADF	17.2	10.9	11.7	5.1	14.1	6.1	14.5	5.7	10.0
Feed N ^{eg}	59.6	56.2	66.5	50.6	57.9	58.6	63.0	53.4	5.2
Starch ^{eg}	87.8	87.6	90.4	84.2	87.7	87.3	89.1	85.9	1.9
MN efficiency ^{bf_h}	20.0	21.5	27.0	30.2	20.8	28.6	23.5	25.9	2.1
N efficiency ^{fi_j}	1.10	1.15	1.00	1.08	1.13	1.04	1.05	1.12	.06
Post-ruminal digestion, % leaving abomasum									
OM	54.6	57.2	54.8	56.7	55.9	55.8	54.7	57.0	3.8
ADF ^f	17.6	27.4	25.4	29.4	22.5	27.4	21.5	28.4	5.9
N	69.7	71.0	71.7	71.5	70.3	71.6	70.7	71.2	4.2
Starch	94.3	95.8	95.7	96.2	95.1	95.9	95.0	96.0	1.5
Lipid	75.6	72.4	77.8	76.5	74.0	77.2	76.7	74.5	8.1
Fecal excretion, g/d									
OM ^{bc_g}	747	773	866	1,021	760	944	807	897	39

Table 2. Continued

ADF ^{beg}	295	293	421	482	294	452	358	387	14
N ^k	22.2	21.9	24.9	26.6	22.0	25.7	23.5	24.2	2.0
Starch ^j	9.4	6.7	4.3	4.6	8.0	4.4	6.8	5.6	3.0
Lipid ^c	24.1	60.8	42.0	82.9	42.4	62.4	33.0	71.8	20.0
GE, Mcal/d ^{bcd}	3.69	4.01	4.37	5.32	3.85	4.85	4.03	4.67	.27
Total tract digestion, %									
OM ^{bcg}	78.2	77.6	75.1	70.8	77.9	73.0	76.7	74.2	1.2
ADF ^g	31.6	35.3	35.2	29.8	33.5	32.5	33.4	32.6	3.2
N ^k	65.5	65.3	70.6	68.1	65.4	69.3	68.0	66.7	3.0
Starch	99.3	99.4	99.6	99.4	99.3	99.5	99.4	99.4	2.2
DE, Mcal/kg ^{fgj}	3.07	3.26	3.08	3.07	3.17	3.08	3.08	3.16	.08
ME, Mcal/kg ^c	2.38	2.62	2.40	2.50	2.50	2.45	2.39	2.56	.08

^aYellow grease.

^bCottonseed main effect, P<.01.

^cSupplemental fat main effect, P<.01.

^dCottonseed by supplemental fat interaction, P<.10.

^eSupplemental fat main effect, P<.05.

^fSupplemental fat main effect, P<.10.

^gCottonseed by supplemental fat interaction, P<.05.

^hMicrobial N, g/kg OM fermented.

ⁱDuodenal non-ammonia N/N intake.

^jCottonseed main effect, P<.10.

^kCottonseed main effect, P<.05.

INFLUENCE OF COTTONSEED AND SUPPLEMENTAL FAT ON RUMINAL pH, VFA PROFILES AND METHANE PRODUCTION 4 HOURS POSTPRANDIAL

	No Cottonseed		20% Cottonseed		Main effects				SD
	No	5%	No	5%	Cottonseed		Fat ^a		
	Fat	Fat	Fat	Fat	0%	20%	0%	5%	
Ruminal pH ^b	6.37	6.50	6.71	7.13	6.43	6.92	6.54	6.81	.38
Ruminal VFA, mol/100 mol									
Acetate ^c	57.8	55.4	60.3	55.6	56.6	57.9	59.1	55.5	2.1
Propionate ^d	30.9	33.3	28.8	32.8	32.1	30.8	29.8	33.1	2.7
Butyrate	11.3	11.3	10.9	11.6	11.3	11.3	11.1	11.4	1.6
Acetate/propionate ^e	1.91	1.72	2.10	1.71	1.81	1.90	2.00	1.71	.21
Methane production ^{ce}	.48	.45	.51	.45	.47	.48	.50	.45	.03

^aYellow grease.

^bCottonseed main effect, P<.05.

^cSupplemental fat main effect, P<.05.

^dSupplemental fat main effect, P<.10.

^eMethane, mol/mol glucose equivalent fermented.

Table 70. INFLUENCE OF COTTONSEED AND SUPPLEMENTAL FAT ON PROFILE OF FATTY ACIDS LEAVING THE ABOMASUM

	No Cottonseed		20% Cottonseed		Main effects				SD
	No	5%	No	5%	Cottonseed		Fat ^a		
	Fat	Fat	Fat	Fat	0%	20%	0%	5%	
Dietary, % total									
C14:0	13.3	4.5	6.6	2.2	8.9	4.4	9.9	3.3	
C16:0	32.5	24.5	30.6	32.9	28.5	31.8	31.5	28.7	
C18:0	5.2	10.0	3.9	8.8	7.6	6.4	4.6	9.4	
C18:1	21.1	32.6	12.2	23.6	26.9	17.9	16.7	28.1	
C18:2	27.8	27.1	46.7	31.4	27.4	39.1	37.3	29.2	
Leaving abomasum, % total									
C14:0	1.0	1.0	.8	1.0	1.0	.9	.9	1.0	.1
C16:0 ^{bcd}	26.9	30.0	31.1	31.7	28.4	31.4	29.0	30.8	1.0
C18:0 ^e	42.5	44.0	54.8	46.8	43.2	50.8	48.6	45.4	6.7
C18:1 ^f	21.8	19.6	10.2	15.7	20.7	13.0	16.0	17.7	5.7
C18:2 ^{bd}	7.8	5.0	3.1	4.5	6.4	3.8	5.4	4.8	1.2

^aYellow grease.

^bCottonseed main effect, P<.01.

^cSupplemental fat main effect, P<.01.

^dCottonseed by supplemental fat interaction, P<.05.

^eCottonseed main effect, P<.10.

^fCottonseed main effect, P<.05.

THE INFLUENCE OF GENETICS ON FEEDLOT PERFORMANCE OF CATTLE

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INTRODUCTION

As with any business, most feedlot owners/managers determine which type of management and nutritional program will work best given the local environment and available resources which should enable them to receive the best price from packer buyers as often as possible. Either immediately or over time, the owner/manager will also determine what types of cattle work best given their management and nutrition program as well as the high bid. Because each of these factors can vary considerably from one feeder and packer combination to the next, more than one breedtype is necessary in the beef industry. There is no one best breed or breed cross to fit every situation.

Performance of an animal in the feedlot or any other phase of production can be explained by two factors that determine what the final product (carcass composition) will be. The two factors are genetics and environment. Together, these will determine the phenotype of the animal at each stage of life. Considerable control of the environment of the feedlot animal is possible. Management of the animal prior to and during the feeding period as well as the diet supplied in the feedlot are all part of the environmental component of the calf's final phenotype (carcass). In contrast, an animal's genetic potential for performance in the feedlot and ultimately its carcass composition are determined at conception. Thus, the only control the feedlot owner/manager has on genetics is take into account the genetic make-up of cattle prior to purchase. Thereafter, the environment provided will determine whether the animal can fully express its genetic potential.

This paper will review research, published since 1970, concerning the influence of genetics or breed composition on performance in the feedlot. The main reason for reviewing only research published since 1970 is an attempt to avoid presenting results conducted with cattle-types completely different than those available today. Cattle have changed considerably in the last 25 years; therefore, even the results of those studies included in this paper from the early 1970s should be used with caution as they often used data collected from cattle fed in the 1960s.

TISSUE GROWTH

General characteristics affecting tissue development and growth in young cattle can also be considered breed specific. Figure 1 provides several figures depicting factors which affect an animal's proportion of muscle, fat and bone. Figure 1a shows the rapid rate of muscle growth compared to bone, whereas fat starts out as a smaller proportion of tissue growth but increases dramatically as the animal enters the feedlot phase of production. Females have a higher percentage of body fat in most species and that is certainly true for cattle, but it is not a breed specific characteristic and is included here only for completeness. Maturity type is a factor in

how soon increased fat deposition begins to occur (Figure 1c). English cattle breeds are normally classified as being earlier maturing breeds compared to Continental breeds. Dairy breeds such as Holstein (Ho) are known to be lighter muscled than beef breeds at the same live weight (Figure 1d). Ho also tend to have much less fat and a greater proportion of bone than beef breeds at similar weights. Specific breeds can also be characterized as heavily- (i.e., Charolais (C) and Simmental (S)) or double-muscled (i.e., Belgian Blue), resulting in a more rapid rate of muscle growth and dramatically slower rate of fat deposition.

SIGNIFICANCE OF BREED EFFECTS

Numerous studies have published comparisons of least-squares means by breedtype for various traits. Analyses of variance results for the model used gives an indication of the significance of the overall effect of breedtype or breed of sire. Long et al. (1979) reported a significant breedtype effect ($P < .05$) for weight gain between the age intervals 270 to 360 d, 360 to 450 d, and 450-540 d. Kempster et al. (1988) tested the effect of sire breed in a 16-mo feedlot system and found it to be significant for lean tissue growth rate and efficiency of lean gain as well as seven other carcass traits. Brown et al. (1991) and Urick et al. (1991) both reported significant breed of sire effects for average daily gain (ADG), feed intake (FI) and feed efficiency or conversion (FCONV). Six breed combinations in a study by Smith et al. (1976) were significantly different for feed efficiency, ADG, relative growth rate (RGR) and weight. Fredeen et al. (1972) reported feeding 174 hybrid bulls (involving Angus (A), Hereford (H), and Ho dams and A, H, Brown Swiss, C, and Shorthorn sires) and finding generally nonsignificant breed of sire differences except for growth rate in the feedlot. However, with so many breed combinations, the number of progeny per breedtype were limited, resulting in large standard errors. Comerford et al. (1988) did not find a significant sire breed effect for ADG of male and female progeny from a four breed diallel study involving S, Limousin (L), Polled Hereford (PH) and Brahman (B) cattle. Sire breed was significant for all postweaning growth characteristics measured by Baker and Lunt (1990): final weight, weight per day of age, carcass weight per day of age, days on feed and feed intake.

The fact that cattle type within a breed has changed dramatically over time is proof that producers have taken advantage of within breed variation. Brown et al. (1988) and Urick et al. (1991) tested sire within breed of sire and reported it as a significant ($P < .05$) source of variation in progeny ADG, FI and FCONV. Comerford et al. (1988) also indicated sire within breed of sire was significant for ADG.

BREED DIFFERENCES UNDER FEEDLOT CONDITIONS

Individual Studies

Perhaps the most comprehensive study of the influence of genetics or more specifically, biological type was started by the U.S. Meat Animal Research Center (MARC) in 1970 as the Germ Plasm Evaluation in Cattle project. The project was designed for characterization of breeds representing diverse biological types by breeding various purebred bulls to A, H and A x H reciprocal crosses (control group) in four cycles from 1970 to 1990.

Table 1 shows how researchers at MARC grouped various breed types into seven biological types based on the four production characteristics listed. The number of Xs is used to indicate level of performance or age at puberty. Hence, additional Xs imply higher performance for a particular trait or older age at puberty. Note that grouping these breeds in this manner was done during the design of this experiment in the late 1960s. The point being that the cattle in some of these breeds have changed dramatically since then.

Previous research has shown there can be as much variation within a breed as between breeds. Table 2 shows considerable variation in postweaning performance among progeny of sire breeds within specific biological types. S, Maine-Anjou (MA) and C steers had the highest ADG, as well as the heaviest carcasses. Overall ranking of these breeds for feed efficiency (FE) varies depending on what final end point is used. However, H-Ax steers were most efficient when evaluated on USDA Choice or fat trim. Because many packer buyers bid cattle based on percent of fed cattle in a pen grading Choice, these two end points are perhaps more important. The two breed groups of Continental European cattle were very efficient during the weight period of 545 to 1,036 lb because of their ability to gain faster, but may not have graded very high at that weight. HA, South Devon (SD), Tarentaise (T), Pinzgauer (P), L and B crosses were intermediate for efficiency during the same weight period.

In comparison to HAx steers, Jersey- (Jx), Red Poll- (RP) and Sahiwal- (Sw) cross steers gained more slowly and had lower final weights, whereas Bx, SDx, Tx and Px steers had final weights 1 to 3% higher than AHx steers (Cundiff et al., 1982). The Continental breeds had final weights 4 to 9% heavier than HAx steers.

Correlations between 452-d weight and feed efficiency were measured using four end points: 0 to 238 days on feed; 545 to 1,036 lb; 0 d to small amount of marbling; and 0 d to 18.9% fat trim end points, -.78, -.91, -.17 and .40, respectively. The first two correlations imply the larger-frame, faster-gaining breed groups were more efficient in time- and weight-constant intervals because of taking fewer days to reach those end point which translates into fewer days of maintenance.

Smith et al. (1976) reported C and S cross steers as having heavier initial and final weights, ADG and RGR than HAx, SDx (except RGR) and Lx steers during a 180-d test period (Table 3). All steers were fed a diet that varied between 89 and 60% corn silage and 7.5 to 33% concentrate as the feeding period progressed. HAx and Lx steers were similar for weight and ADG, but were outperformed by SDx for ADG and RGR. Jx and SDx steers were the lightest at the start of the test, but by the end of the test SDx had heavier weights than Jx, HAx and Lx steers because they had significantly ($P < .05$) higher ADGs.

Table 4 shows the results of 140-d postweaning feedlot tests of 2,007 bulls representing H, A, C, PH, SG, S, MA, B and Bm individually fed a 33% cottonseed or soybean meal diet (Chewning et al., 1990). MA, C and S bulls had significantly ($P < .05$) higher ADG than the other breeds followed by A and PH. MA and C were also the most efficient at converting feed to gain. Bm bulls had the lowest ADG and feed intake and worst feed conversion (similar to Br) than all other breeds. So it is not surprising they performed the worst of all nine breeds.

Table 1 shows how researchers at MARC grouped various breed types into seven biological types based on the four production characteristics listed. The number of Xs is used to indicate level of performance or age at puberty. Hence, additional Xs imply higher performance for a particular trait or older age at puberty. Note that grouping these breeds in this manner was done during the design of this experiment in the late 1960s. The point being that the cattle in some of these breeds have changed dramatically since then.

Previous research has shown there can be as much variation within a breed as between breeds. Table 2 shows considerable variation in postweaning performance among progeny of sire breeds within specific biological types. S, Maine-Anjou (MA) and C steers had the highest ADG, as well as the heaviest carcasses. Overall ranking of these breeds for feed efficiency (FE) varies depending on what final end point is used. However, H-Ax steers were most efficient when evaluated on USDA Choice or fat trim. Because many packer buyers bid cattle based on percent of fed cattle in a pen grading Choice, these two end points are perhaps more important. The two breed groups of Continental European cattle were very efficient during the weight period of 545 to 1,036 lb because of their ability to gain faster, but may not have graded very high at that weight. HA, South Devon (SD), Tarentaise (T), Pinzgauer (P), L and B crosses were intermediate for efficiency during the same weight period.

In comparison to HAx steers, Jersey- (Jx), Red Poll- (RP) and Sahiwal- (Sw) cross steers gained more slowly and had lower final weights, whereas Bx, SDx, Tx and Px steers had final weights 1 to 3% higher than AHx steers (Cundiff et al., 1982). The Continental breeds had final weights 4 to 9% heavier than HAx steers.

Correlations between 452-d weight and feed efficiency were measured using four end points: 0 to 238 days on feed; 545 to 1,036 lb; 0 d to small amount of marbling; and 0 d to 18.9% fat-trim end points, -.78, -.91, -.17 and .40, respectively. The first two correlations imply the larger-frame, faster-gaining breed groups were more efficient in time- and weight-constant intervals because of taking fewer days to reach those end point which translates into fewer days of maintenance.

Smith et al. (1976) reported C and S cross steers as having heavier initial and final weights, ADG and RGR than HAx, SDx (except RGR) and Lx steers during a 180-d test period (Table 3). All steers were fed a diet that varied between 89 and 60% corn silage and 7.5 to 33% concentrate as the feeding period progressed. HAx and Lx steers were similar for weight and ADG, but were outperformed by SDx for ADG and RGR. Jx and SDx steers were the lightest at the start of the test, but by the end of the test SDx had heavier weights than Jx, HAx and Lx steers because they had significantly ($P<.05$) higher ADGs.

Table 4 shows the results of 140-d postweaning feedlot tests of 2,007 bulls representing H, A, C, PH, SG, S, MA, B and Bm individually fed a 33% cottonseed or soybean meal diet (Chewning et al., 1990). MA, C and S bulls had significantly ($P<.05$) higher ADG than the other breeds followed by A and PH. MA and C were also the most efficient at converting feed to gain. Bm bulls had the lowest ADG and feed intake and worst feed conversion (similar to Br) than all other breeds. So it is not surprising they performed the worst of all nine breeds.

Urlick et al. (1991) reported results on postweaning growth, feed consumption and carcass characteristics of 259 individually fed F₁ steers out of Hereford dams bred to Angus (A), Red Poll (RP), Pinzgauer (P), S, and Tarentaise (T) sires (Table 5). These steers were fed an ad libitum 2.62 Mcal energy/kg DM corn silage and cracked barley diet. Sequential slaughter was used to enable adjustment to different end points. Feed intake and conversion were adjusted to age-, weight- and fat-depth-constant end points. Statistical analysis of Tx steer data appears to be incorrect and will not be discussed. No significant differences were observed among breeds for relative growth rate. Initial weight, daily gain and 382-d weight were similar for Ax, RPx, and Px steers. Sx steers gained faster and had heavier initial and 382-d weights than Ax, RPx, and Px steers. Ax steers had high feed intake and poor feed conversion at the 382-d and 400 kg end points. Their intake was considerably less at the 12.7 mm backfat end point, resulting in the best feed conversion rate. Sx cross steers ate more ($P < .05$) than RPx and Px steers but had comparable feed conversion rates at each end point. Overall, Sx steers outperformed Ax, RPx, and Px steers.

ADG of AxSG, SG x SG and Gelbvieh x A were greater than A x A (Gotti and Benyshek, 1988). The heaviest slaughter weights were observed for A x SG and straightbred SG.

Baker and Lunt (1991) slaughtered calves when they reached 1.0 cm fat thickness at the 12th rib. There was a sire breed significant difference for all postweaning growth characters. Final weight, days on feed and FI for A were 440 kg, 141 d and 8.94 kg/d, respectively. The same values for C and P calves were 483 kg, 475 kg; 188 d, 197 d; and 9.27 kg/d, 9.84 kg/d, respectively.

Feedlot Performance by Interval of Measurement

Bull test data generally consist of numerous measurements which can be used to divide up the entire test period to enable evaluation of animals during different segments of the feedlot period. Brown et al. (1991) divided 140 d test data into periods 1 to 84 d, 84 to 112 d and 112 to 140 d. ADG, FI and FCONV were then analyzed within each time interval. Comparison of least-squares means over the entire interval is given in Table 4 (Chewning et al., 1990). Data from 1,830 individually fed bulls representing 13 breeds ($n > 25$) were used. In general, bulls of all breeds gained more rapidly at the earlier test intervals, suggesting bulls reach the inflection point on their growth curve prior to day 112 of the test. FI increased considerably from the first interval to the second; however, FI was close to the same, or less during day 112 to day 140 compared to day 84 to day 112. This would normally be attributed to increased deposition of fat during the 84 to 112 d interval. FCONV data shows a continual increase in kilogram feed required per kilogram of gain. The FCONV mean for MA more than doubled from the first interval to the last and numerous other breed means for FCONV approached a two-fold increase. Brown et al. (1991) cites Gregory et al. (1962), Hedrick et al. (1972) and Dikeman (1973) as having shown efficiency of feed utilization decreases as cattle approach slaughter. Increased maintenance due to additional size and weight is also a factor. Comparison of breed means for each trait published by Chewning et al. (1990) is discussed in a previous section.

As was mentioned earlier, Long et al. (1979) reported significant breedtype differences in weight and gain for bulls from a five-breed diallel among A, B, H, Ho and J breeds during periods defined by age: 270 d, 360 d, 450 d and 540 d. Table 6 shows weight and gain in weight for

each breedtype. Note that bulls from each breed group were being slaughtered at target weights, resulting in a continual decrease in sample size for comparison as the study progressed. In comparing straightbred bull performance, Holsteins weighed the most and gained the fastest through 630 d of age. Jersey bulls were the lightest and slowest gaining. The gain from period to period was quite variable for both pure- and crossbred bulls, but dropped considerably for all bulls remaining after 540 d. Using data on gain from 270 to 630 d, H × Ho, A × H and A × Ho considerably out-gained other breedtypes. H × J and Ho × J had the poorest gains through 630 d.

Efficiency of Growth at Different End Points

Efficiency of growth can be measured over different intervals which can influence how breed types are perceived to perform. Smith et al (1976) analyzed breed group means for cumulative metabolizable energy per unit of gain for 0 to 217 d on feed, 240 to 470 kg and 0 d to 5% longissimus fat. These end points were chosen because Koch et al. (1976) used them and found 5% longissimus fat corresponded to a marbling score of average small which is equivalent to a quality grade of Choice. Breed groups of steers evaluated were HH + AA, HAx, Jx, SDx, Lx, Cx and Sx. Cx and Jx were the most and least efficient ($P < .05$), respectively, for the age- and weight-constant intervals of measurement given. Lx were least efficient and HAx most efficient for 0 d to 5% longissimus fat. Sx steers were as efficient as Cx steers for the 240 to 470 kg and 0 d to 5% longissimus fat intervals, but Sx steers were not significantly more or less efficient than other breed groups which were all intermediate to Cx and Jx.

Age-constant evaluation of efficiency gives an advantage to breed groups that gain rapidly relative to weight being maintained (Smith et al., 1976). They cite Klosterman (1972) for reporting that less mature breed groups are favored in an evaluation of weight-constant efficiency because of their leaner composition of gain. Smith and co-workers suggest the fast-growing breeds benefit from their leaner composition of gain, i.e., L.

Composition of gain is obviously a factor in the ranking of breed groups for efficiency when evaluated to a certain amount of fat as with the 0 d to 5% longissimus fat interval. Charolais and especially L are promoted on their leanness, making them poor prospects for ranking well in efficiency to a fat level that would generally require longer feeding periods than for other breeds like A, H and J. Smith et al. (1976) reported number of days required to reach 5% longissimus accounted for 74% of breed group variation in fat constant feed efficiency.

Biological vs Economic Efficiency

Up to this point, this paper has reviewed literature involving comparisons of various breedtypes for biological differences in feedlot performance. While biological efficiency is important, the feedlot owner/manager must also be concerned with economic efficiency of performance to be able to maintain a viable feeding business. Several studies reviewed in this paper measured biological efficiency of gain at three different intervals of measurement: constant age (440 d), weight (288 kg carcass weight) or fat (low Choice) end points. Economic efficiency can be measured at the same end points using input costs. Lamb et al. (1992) simulated an integrated beef production system using five breeds: A, C, H, L and S. These breeds were used to compare simulated feedlot performance of progeny resulting from three mating systems: purebreeding and

two- and three-breed rotational crossbreeding. Biological efficiency was measured as megacalories of ME per kilogram of gain and economic efficiencies were measured as input costs per kilogram of lean weight and input costs per kilogram of carcass weight. Caution is suggested in using these results as this simulation (as with most) was based on analyses of data from previous research which may have involved breedtypes different than what we have today. Input costs included purchase price and feed and non-feed costs. Carcass value was lowered when a carcass did not fit into the 272 to 318 kg carcass weight range.

Current System. Because many packer buyers still buy fed cattle based on an estimate of what percent of a pen will grade Choice, measuring input costs per kilogram of carcass weight most closely reflects how cattle are currently bought. Lamb et al. (1992) indicated biological efficiencies for all slaughter end points improved with crossbreeding. Because most feeders probably sell at constant weight or fat end points, only those will be discussed here. However, it is important to minimize number of days on feed for those end points. Improvement in biological efficiency due to crossbreeding was 14 to 20% and 8 to 12% at the weight and fat end points, respectively (Table 7). At a weight constant end point, Cx and Sx cattle were most efficient for all three breeding systems because of their ability to gain faster during pre- and postweaning phases of production. Breed combinations involving A were most efficient for the fat end point due to their ability to deposit fat earlier.

Comparisons based on economic efficiency measured as input costs per kilogram of carcass weight (Table 8) showed C and S purebreds and crossbreds ranked higher than A and H and their crosses at all slaughter end points (Lamb et al., 1992). Increases in economic efficiency for weight and fat end points as a result of crossbreeding ranged from 5 to 22%. Improvement in economic efficiency occurred on average from the purebred mating system to the three-way crosses, but some purebreds were more efficient than some crossbreds.

Value-Based Marketing. The National Cattlemen's Association set up a Value-Based Marketing Task Force which determined the goal of the beef industry should be to improve production efficiency by reducing excess trimmable fat by 20% and increasing lean production by 6% by 1995, without diminishing the eating qualities of beef. Results of the 1991 National Beef Quality Audit indicate the beef industry is not making much progress in that direction. Consumers still say they want leaner beef, but the industry is slow to change the product on a large scale, primarily due to the way fed cattle are bought by packers. Should value-based marketing, payment based on individual carcass value, be implemented to a greater extent, economic efficiency will need to be measured by input costs per kilogram of lean weight or input costs per carcass value (Tables 9 and 10).

In Table 9, C and S purebreds and crossbreds were more efficient when ranked on input costs per kilogram of lean weight (Lamb et al., 1992). Advantages of crossbreds over purebreds at weight and fat end points ranged from 4 to 9%. C purebreds were more efficient than all crossbreds at weight (except CL) and fat end points (Lamb et al., 1992). Finally, when feedlot efficiency is measured on an input costs per carcass value basis, C and S crosses involving A and H were generally more efficient than other crosses.

Effect of Heterosis on Feedlot Performance

Most animal scientists and producers know one of the biggest advantages to crossbreeding is the resulting heterosis or hybrid vigor. The amount of heterosis varies depending on the breed combinations and is simply the superior performance of progeny above the average performance of the respective parent breeds. Gregory et al. (1978) reported significant ($P < .01$) effects in their study of 584 steers from a four-breed diallel involving Red Poll (RP), Brown Swiss (BS), A and H. Effect of heterosis for weight at 200 d was 12.7 kg, 312 d - 15.6 kg and 424 d - 15.2 kg for all crossbreds minus purebreds. Most heterotic effect on ADG occurred during the preweaning period. Smith et al. (1976) also reported a nonsignificant heterosis effect for ADG during the feedlot phase of production for steers; however, the amount of observed heterosis for initial weight, 405-d weight and RGR was significant. Gotti and Benyshek (1988) indicated 3.4% heterosis for ADG was significant ($P < .05$) in comparing SG and A. Comerford et al. (1988) also reported on heterosis ranging from .5 to 9.8% for ADG when comparing S, L, PH and B. Only the 9.8% heterosis value for H and B crossbred progeny was significant ($P < .05$).

Breed Influence Under Different Environments

As an example, B and other *Bos indicus* cattle are known to originate from warm climate countries and are highly adapted to that type of environment. Numerous crosses with B have become quite popular, even in northern climates. If B cross cattle are going to be used in Northern climates, they should probably be less than 25% B. Boyles and Riley (1991) tested crossbred B calves under feedlot conditions in a Northern U.S. (North Dakota) winter with temperatures ranging from -9 to 26 C. Only ten A and ten F_1 B x A calves were fed for a 184 d, but the results clearly indicated the crossbred calves performed poorly. Although final weight, FCONV, and FI were the same, 90% of the A steers graded Choice while only 10% of the B steers graded Choice.

HERITABILITIES AND CORRELATIONS

Table 11 and 12 are provided to indicate how heritable feedlot measures of performance are in relation to other growth and carcass characteristics and how feedlot performance correlates to those other traits. There are not very many recent heritability (h^2) or correlation estimates available from the literature for feedlot performance measures, probably due to the difficulty in obtaining accurate trait measurements for large numbers of cattle in typical feedlot conditions. The average h^2 value for ADG in Table 11 is .41. Brown et al. (1988) reported the only recent estimate of relative growth rate to be .21. Estimates for feed conversion efficiency ranged from .14 to .45 which is the weighted average of numerous studies prior to 1977. Feed intake is moderately heritable (.45) whereas final weight has a h^2 of only .25 (MacNeil et al., 1991).

Table 12 shows ADG has a high positive correlation to FI and final weight as would be expected and a moderate to high negative correlation to feed conversion. MacNeil et al. (1991) reported the correlation between feed intake and conversion to be .31, implying those animals that eat more are not always more efficient. Feed intake and final weight are very highly correlated while FCONV and final weight are essentially uncorrelated traits according to MacNeil et al. (1991).

SUMMARY

Genetics or breedtypes do influence tissue development differently and specific breedtypes may be chosen to fit a particular feedlot system. Not only is breed of sire a significant effect for most measures of feedlot performance, but sire within breed is also quite variable and a significant factor. Several studies indicated the performance of crossbred animals is superior to straightbred animals. Continental European breeds (and crosses) were most often ranked the highest for weight, gain and feed intake traits. They are also generally more efficient at converting feed to gain over weight-constant end points. English breeds and their crosses tended to rank higher than some of the Continental breeds when efficiency was measured to a fat-constant endpoint. Jersey and Brahman-based breed groups generally performed the worst under typical U.S. feedlot conditions. Feed efficiency does decrease as the feeding period progresses. That fact along with the cost associated with increased feed costs suggests the need to minimize days on feed, while ensuring a quality product is produced. Price discounts can be severe if a pen of animals do not grade the required percentage Choice or do not fit in the "box". Hence, economic efficiency is important to consider in addition to biological efficiency. It is also important to realize some breeds can tolerate different climates from which they originated better than others. Feedlot measures of performance are low to moderately heritable and have low to moderate correlations with other traits, but moderate to high correlations with feedlot characteristics.

Actual performance of the various breedtypes reported on here depends on so many variables as well as the criteria for evaluation, it is not wise to indicate any one breed or group of breeds that are without a doubt best for most situations. Larger frame, later maturing cattle are favored over smaller, earlier maturing, but slower gaining cattle when evaluated on a live-weight-gain³ basis and plenty of feed is available. However, if time on feed is limited and a fat-constant end point is used, the more moderate types of cattle will work better.

FUTURE BREED INFLUENCE

Producers are becoming more aware of the technologies available to improve their operations. It will become increasingly important for feedlot owners/managers to determine what kind of end product they want to offer the packer and then decide what breedtype of cattle will allow them to meet that goal. Niche marketing is increasing, but will probably really escalate after widespread value-based marketing is in place. Eventually, the retail operators will get tired of trimming off the excess 5 billion lb of fat at a cost of over \$3 billion to produce. At that point, they will hopefully put pressure on packers to supply them with trimmed beef or beef that is naturally quarter-inch trim. Packers would then see the benefit of buying cattle without all the excess "white bark". In turn, feeders will want the type of genetic potential in cattle they buy to feed which will allow them to finish in a reasonable amount of time with limited waste fat. Those producers making selection decisions today with that possibility in mind for the near future will be ready to take advantage of value-based marketing when it arrives.

Technologies already available to the production and feedlot phase of the beef industry include ultrasound and EPDs. Both growth and carcass EPDs are available and are the most accurate indicator of genetic merit. Under the current system, there is currently little reward to those

producers collecting carcass data. More data is needed to improve accuracy of EPD prediction for carcass traits (Woodward et al, 1992).

Other developments include on-going research into instrument grading possibilities. Marker-assisted selection is also in the research stage, but could be available for use in the near future (Beever et al., 1990). Individual electronic animal identification is already available, but needs to be refined so that the cost is more affordable for the average producer/feeder.

Implementation or greater use of some of these technologies will help to shape the future of the beef industry in general and perhaps the feeding segment specifically.

Table 1. Breed Crosses Grouped into Seven Biological Types on the Basis of Four Major Criteria^{ab}.

Breed group	Growth Rate & Mature Size	Lean to Fat Ratio	Age at Puberty	Milk Production
Jersey (J)	x	x	x	xxxxx
Hereford-Angus (HA)	xx	xx	xxx	xx
Red Poll (RP)	xx	xx	xx	xxx
Devon (D)	xx	xx	xxx	xx
South Devon (SD)	xxx	xxx	xx	xxx
Tarentaise (T)	xxx	xxx	xx	xxx
Pinzgauer (P)	xxx	xxx	xx	xxx
Brangus (Br)	xxx	xx	xxxx	xx
Santa Gertrudis (SG)	xxx	xx	xxxx	xx
Sahiwal (Sw)	xx	xxx	xxxxx	xxx
Brahman (B)	xxxx	xxx	xxxxx	xxx
Brown Swiss (BS)	xxxx	xxxx	xx	xxxx
Gelbvieh (G)	xxxx	xxxx	xx	xxxx
Holstein (Ho)	xxxx	xxxx	xx	xxxxxx
Simmental (S)	xxxxx	xxxx	xxx	xxxx
Maine-Anjou (MA)	xxxxx	xxxx	xxx	xxx
Limousin (L)	xxx	xxxxx	xxxx	x
Charolais (C)	xxxxx	xxxxx	xxxx	x
Chianina (Ch)	xxxxx	xxxxx	xxxx	x

^aAdapted from Cundiff et al., 1988.

^bIncreasing number of x's indicate relatively higher levels of performance and older age at puberty.

Table 2. Breed Group Means for Postweaning Growth and Feed Efficiency to Time, Weight, Grade, and Fat-Trim End Points^a.

Breed group	Number of Steers	Post-Weaning ADG (kg/d)	452-day weight (kg)	452-day weight ratio ^b	Feed efficiency (Mcal ME/kg gain)			
					Time	Weight	USDA Choice	Fat trim
					0 to 238 days	545 to 1,036 lb	0 days to small marbling	0 days to 18.9% fat trim
Jersey-X	132	1.01	446	94	23.98	25.87	24.33	22.95
Hereford-Angus-X	508	1.09	476	100	23.08	23.47	23.19	22.15
Red Poll-X	111	1.00	453	95	24.99	25.28	25.39	24.95
South Devon-X	94	1.17	492	103	22.77	22.88	23.58	22.64
Tarentaise-X	103	1.08	480	101	23.65	24.13	25.06	24.44
Pinzgauer-X	176	1.11	481	101	22.97	23.32	23.69	23.85
Sahiwal-X	154	1.00	454	96	24.29	25.96	25.41	24.16
Brahman-X	153	1.09	486	102	23.82	24.20	25.98	24.16
Brown-Swiss-X	154	1.12	494	104	22.79	21.27	23.85	24.64
Gelbvieh-X	111	1.16	507	107	22.37	20.79	24.02	24.44
Simmental-X	176	1.22	519	109	22.79	21.89	24.64	25.23
Maine-Anjou-X	109	1.20	515	108	22.48	20.57	24.22	26.05
Limousin-X	173	1.05	471	99	22.33	22.55	25.83	25.74
Charolais-X	176	1.21	520	109	22.04	20.81	24.07	25.54
Chianina-X	119	1.13	500	105	22.86	21.69	26.69	29.24

^aAdapted from Cundiff et al., 1982.

^bRatio relative to Hereford-Angus crosses

Table 3. Breed Group Means For Live Weights and Growth Rates of Steers[†].

Breed group ^a	Number	Weight, kg		Avg daily gain, kg	Rel. growth rate ^c
		Initial	405-day ^b		
HH	66	214.	419.	1.14	.375
AA	84	225.	420.	1.08	.348
Heterosis		10.**	11.**	.01	-.012**
HAx	204	230. ^d	430. ^d	1.12 ^d	.350 ^d
Jx	132	221. ^e	408. ^e	1.04 ^e	.342 ^{de}
SDx	94	227. ^{de}	443. ^f	1.20 ^f	.374 ^f
Lx	173	233. ^d	428. ^d	1.08 ^{de}	.339 ^e
Cx	176	246. ^f	470. ^g	1.24 ^g	.361 ^g
Sx	176	239. ^g	463. ^g	1.25 ^g	.371 ^f
H dams	501	226.	437.	1.17	.369 ^g
A dams	604	236.	438.	1.12	.345

[†]Adapted from Smith et al., 1976.

^aH = Hereford, A = Angus, J = Jersey, SD = South Devon, L = Limousin, C = Charolais, S = Simmental; HA = Hereford sires by Angus dams; HAx = HA + AH; Jx = JH + JA, et cetera.

^bWeight after 180 days on test.

^cRelative growth rate is percentage change in body weight per day.

^{d,e,f,g}Means in the same column that do not have at least one common superscript differ significantly ($P < .05$). Means without superscripts not included in the Duncan's Multiple Range test of significance.

** $P < .01$.

Table 4. Breed Least-Squares Means for Average Daily Gain (ADG), Feed Conversion (FCONV), Feed Intake (FI), and Daily Feed Intake as a Percentage of Body Weight (FIP) of Beef Bulls During 140-d Postweaning Feedlot Tests^a.

Breed	No.	ADG	Order ^a	FCONV	Order	FI	Order	FIP
		kg/d		feed/gain		kg/d		%/d
Maine-Anjou	55	1.67 ^b	8	6.73 ^d	2	11.10 ^c	3	2.91 ^{cd}
Charolais	232	1.66 ^b	9	6.68 ^d	3	11.00 ^c	7	2.83 ^c
Simmental	357	1.64 ^b	5	7.10 ^c	1	11.58 ^b	6	2.86 ^{de}
Angus	528	1.48 ^c	3	7.46 ^b	4	10.95 ^c	1	3.06 ^b
P. Hereford	469	1.45 ^{cd}	5	7.10 ^c	6	10.26 ^d	2	2.94 ^c
Santa Gertrudis	66	1.42 ^{de}	4	7.29 ^{bc}	6	10.26 ^d	9	2.65 ^f
Hereford	177	1.43 ^{de}	5	7.10 ^c	8	10.15 ^d	3	2.91 ^c
Brangus	98	1.39 ^e	2	7.48 ^b	5	10.27 ^d	5	2.90 ^{cd}
Beefmaster	46	1.28 ^f	1	7.59 ^b	9	9.65 ^e	8	2.66 ^f

^aAdapted from Chewning et al. (1990).

^{b,c,d,e,f}Means within the same column and period without a common superscript differ ($P < .05$).

^aOrder given to help reader see how each breed performed for each trait; 1 does not necessarily mean best performance.

Table 5. Growth Traits, Intake and Feed Conversion of Angus-, Pinzgauer-, Red Poll-, Simmental- and Tarentaise-Sired Steers From Hereford Dams[†].

Item	Breed of sire				
	Angus	Red Poll	Pinzgauer	Simmental	Tarentaise
Number	63.	56.	56.	58.	26.
Initial wt, kg	177. ^{ab}	167. ^a	174. ^a	188. ^b	186. ^{ab}
Daily gain, g/d	1011. ^a	1008. ^a	1042. ^a	1123. ^b	1040. ^{ab}
382-d Wt, kg	375. ^{ab}	365. ^a	378. ^{ab}	408. ^c	390. ^{bc}
Relative growth rate, %/d	.585 ^a	.617 ^a	.610 ^a	.608 ^a	.569 ^a
Feed intake, Mcal					
382 d	3,487. ^a	3,382. ^b	3,386. ^b	3,492. ^a	3,476. ^a
400 kg	3,804. ^a	3,855. ^a	3,642. ^b	3,361. ^c	3,457. ^d
12.7 mm Backfat	1,585. ^a	2,832. ^b	3,576. ^c	3,357. ^d	3,636. ^b
Feed conversion, Mcal/kg					
382 d	17.3 ^a	16.8 ^{ab}	16.2 ^{bc}	15.8 ^c	16.3 ^{bc}
400 kg	17.7 ^a	17.3 ^{ab}	16.5 ^{bc}	15.7 ^c	16.3 ^{bc}
12.7 mm Backfat	14.9 ^a	16.2 ^b	16.4 ^b	15.7 ^{ab}	16.5 ^b

[†]Adapted from Urick et al., 1991.

^{a,b,c,d}Means in the same row with a common superscript are not different ($P > .05$).

Table 6. Breedtype Least-Squares Means for Weight (kg) and Absolute Growth Rate for Weight (g/d) of Bulls^a.

Breedtype	Number at start	Weight, kg					Gain in weight, g/d				
		270 days	360 days	450 days	540 days	630 days	270 to 360 days	360 to 450 days	450 to 540 days	540 to 630 days	270 to 630 days
Angus	13	257	344	404	472	530	954	883	730	850	803
Brahman	29	240	307	368	425	473	746	693	719	608	684
Hereford	56	217	299	383	457	508	914	962	869	657	832
Holstein	33	267	353	441	523	585	983	1005	1003	885	915
Jersey	11	179	241	302	374	402	681	589	755	447	625
Angus × Brahman	18	290	366	443	513	542	841	828	744	644	784
Angus × Hereford	11	267	357	428	514	583	999	1000	988	685	899
Angus × Holstein	35	263	341	418	512	571	900	953	919	798	885
Angus × Jersey	31	230	310	392	487	530	879	883	937	712	807
Brahman × Hereford	25	272	351	435	509	563	888	846	807	864	845
Brahman × Holstein	30	302	378	450	537	570	852	816	961	806	791
Brahman × Jersey	30	252	324	394	452	538	807	754	816	715	782
Hereford × Holstein	36	271	358	444	531	604	972	947	952	731	918
Hereford × Jersey	24	215	297	371	452	478	873	870	896	544	740
Holstein × Jersey	22	244	320	416	502	523	854	875	1004	420	765
Overall	404	251	330	406	484	533	876	860	873	691	805

^aAdapted from Long et al., 1979.

Table 7. Biological Efficiencies (Mcal ME/kg gain) in the Feedlot for Slaughter End Points Simulated^a

	440 d		Weight		Fat	
Purebreds	C ^b	16.79	C	15.43	A	16.87
	S	17.10	S	16.79	C	18.90
	A	17.13	L	18.32	H	18.98
	L	17.60	A	18.40	S	19.17
	H	18.03	H	19.54	L	21.80
Average		17.33		17.70		17.76
2 Breed Rotations	AS	16.02	CS	13.98	AS	16.20
	AC	16.26	AC	14.14	AC	16.41
	LS	16.46	CL	14.36	AH	16.49
	CS	16.56	CH	14.59	HS	17.33
	HS	16.56	AS	15.15	CH	17.53
	CL	16.57	LS	15.58	AL	18.06
	CH	16.68	HS	15.68	CS	18.15
	AL	17.08	AL	17.02	LS	19.01
	AH	17.44	HL	17.53	CL	19.02
HL	17.62	AH	17.61	HL	19.37	
Average		16.73		15.56		17.76
3 Breed Rotations	ALS	16.01	ACS	13.71	AHS	15.88
	ACS	16.13	CLS	14.00	ACH	16.05
	AHS	16.20	CHS	14.04	ACS	16.52
	ACL	16.21	ACL	14.18	ALS	17.03
	ACH	16.33	ACH	14.36	ACL	17.13
	HLS	16.39	CHL	14.44	CHS	17.29
	CLS	16.42	ALS	15.04	AHL	17.55
	CHS	16.46	AHS	15.23	HLS	17.86
	CHL	16.51	HLS	15.39	CHL	17.96
AHL	17.29	AHL	16.95	CLS	18.43	
Average		16.40		14.73		17.17

^aAdapted from Lamb et al., 1992.

^bA = Angus, C = Charolais, H = Hereford, L = Limousin and S = Simmental.

Table 8. Economic Efficiency (\$/kg carcass weight) in the Feedlot for Slaughter End Points Simulated^a.

	440 d		Weight		Fat	
Purebreds	C ^b	2.04	C	1.91	C	1.83
	S	2.13	S	2.05	S	1.90
	A	2.25	A	2.13	L	2.06
	L	2.27	L	2.16	A	2.17
	H	2.29	H	2.19	H	2.21
Average		2.20		2.09		2.03
2 Breed Rotations	AC	1.80	AC	1.82	AC	1.84
	CH	1.81	CH	1.84	CL	1.84
	AS	1.83	CL	1.87	AS	1.85
	HS	1.84	AS	1.89	CS	1.85
	CL	1.85	CS	1.92	CH	1.86
	CS	1.86	HS	1.93	LS	1.87
	LS	1.88	LS	1.95	HS	1.89
	AL	2.00	AL	2.06	AL	2.01
	HL	2.03	HL	2.10	HL	2.06
	AH	2.05	AH	2.13	AH	2.18
Average		1.90		1.95		1.93
3 Breed Rotations	ACH	1.75	ACH	1.82	ACL	1.82
	ACL	1.77	ACL	1.83	ACS	1.84
	ACS	1.77	CHL	1.85	ALS	1.84
	AHS	1.77	ACS	1.86	CLS	1.84
	ALS	1.78	AHS	1.88	CHL	1.85
	CHL	1.78	CHS	1.88	ACH	1.86
	CHS	1.78	ALS	1.89	CHS	1.86
	HLS	1.80	CLS	1.89	AHS	1.87
	CLS	1.80	HLS	1.91	HLS	1.87
	AHL	1.95	AHL	2.06	AHL	2.05
Average		1.80		1.89		1.87

^aAdapted from Lamb et al., 1992.

^bA = Angus, C = Charolais, H = Hereford, L = Limousin and S = Simmental.

Table 9. Economic Efficiency (\$/kg lean weight) in the Feedlot for Slaughter End Points Simulated^a.

	440 d		Weight		Fat	
Purebreds	C ^b	3.99	C	3.55	C	3.62
	S	4.08	S	3.87	S	3.83
	L	4.31	L	4.03	L	4.21
	A	4.61	A	4.46	A	4.43
	H	4.62	H	4.49	H	4.49
Average		4.32		4.08		4.12
2 Breed Rotations	CL	3.50	CL	3.54	AC	3.75
	CS	3.55	AC	3.65	CS	3.75
	AC	3.56	CH	3.65	CL	3.76
	CH	3.56	CS	3.66	CH	3.79
	LS	3.56	LS	3.73	AS	3.82
	HS	3.60	AS	3.83	LS	3.85
	AS	3.64	HS	3.87	HS	3.89
	AL	3.93	AL	4.14	AL	4.18
	HL	3.95	HL	4.18	HL	4.27
	AH	4.18	AH	4.50	AH	4.52
Average		3.70		3.88		3.96
3 Breed Rotations	ACL	3.42	ACL	3.61	ACL	3.76
	CLS	3.42	CLS	3.62	ACS	3.77
	CHL	3.43	CHL	3.63	CLS	3.79
	CHS	3.45	ACS	3.69	ALS	3.81
	HLS	3.46	CHS	3.70	CHL	3.81
	ACS	3.47	ACH	3.72	CHS	3.81
	ALS	3.47	ALS	3.75	ACH	3.82
	ACH	3.48	HLS	3.78	HLS	3.87
	AHS	3.53	AHS	3.87	AHS	3.88
	AHL	3.86	AHL	4.22	AHL	4.26
Average		3.50		3.76		3.86

^aAdapted from Lamb et al., 1992.

^bA = Angus, C = Charolais, H = Hereford, L = Limousin and S = Simmental.

Table 10. Economic Efficiency (\$/\$ weight value) in the Feedlot for Slaughter End Points Simulated^a.

	440 d	457 d	Weight	Fat
Purebreds				
C ^b	.86	S .78	C .75	C .90
S	1.01	C .82	S .82	H .91
L	1.08	L .87	L .87	S .94
A	1.12	A .94	A .87	L 1.02
H	1.13	H 1.01	H .90	A 1.08
Averages	1.04	.88	.84	.97
2 Breed Rotations				
AS	.76	AS .78	AC .75	AC .83
AC	.77	CH .80	CH .76	AS .84
HS	.77	HS .80	CL .76	CH .85
AL	.78	AC .81	AS .78	HS .86
CH	.78	AL .81	CS .78	AL .91
AH	.80	LS .81	HS .80	CL .91
HL	.81	CL .83	LS .80	CS .92
LS	.85	HL .83	AL .85	HL .93
CL	.86	CS .87	HL .87	LS .93
CS	.88	AH .89	AH .89	AH 1.08
Averages	.81	.82	.80	.91
3 Breed Rotations				
AHS	.77	AHS .78	ACH .75	ACH .71
ALS	.78	ALS .78	ACL .75	AHS .72
ACH	.79	ACH .79	CHL .76	AHL .78
ACL	.80	HLS .79	ACS .77	ACL .83
ACS	.80	AHL .80	CHS .77	ACS .83
HLS	.80	CHL .80	CLS .77	ALS .83
CHL	.81	ACL .81	AHS .78	CHL .84
CHS	.81	ACS .84	ALS .78	CHS .84
AHL	.84	CHS .85	HLS .79	HLS .85
CLS	.89	CLS .86	AHL .86	CLS .91
Averages	.81	.81	.78	.81

^aAdapted from Lamb et al., 1992.

^bA = Angus, C = Charolais, H = Hereford, L = Limousin and S = Simmental.

Table 11. Heritability Estimates from Several Literature Sources.

	Source ^a				
	1	2	3	4	5
Birth weight	.45	.43			
Weaning weight	.24				
ADG	.34	.57	.35	.38	
RGR			.21		
Feed efficiency	.45		.14	.26	
Feed intake				.45	
Final weight				.25	
Fat thickness		.41		.52	
Marbling		.40			.23
Cutability		.63			.18

^a1) Woldehawariat et al., 1977; 2) Koch et al., 1982; 3) Brown et al., 1988; 4) MacNeil et al., 1991; 5) Woodward et al., 1992.

Table 12. Genetic Correlations Among Selected Growth and Carcass Traits

Trait	Source ^a	Trait							
		1	2	3	4	5	6	7	8
1. Birth weight									
2. Weaning weight	1	.54							
3. ADG	1	.51	.32						
	2	.61							
4. Feed intake	4			.73					
5. Feed conversion	3			-.84					
	4			-.43	.31				
6. Final weight	1	.60	.71	.82					
	4			.94	.94	-.03			
7. Fat thickness	2	-.27		.05					
	4			-.20	.09	.30	.00		
8. Marbling	2	.31		.15				.16	
	5	.05	.33						
9. Cutability	2	.05	-.13					-.74	-.37
	5	.14							-.12

^a1) Woldehawariat et al., 1977; 2) Koch et al., 1982; 3) Brown et al., 1988; 4) MacNeil et al., 1991; 5) Woodward et al., 1992.

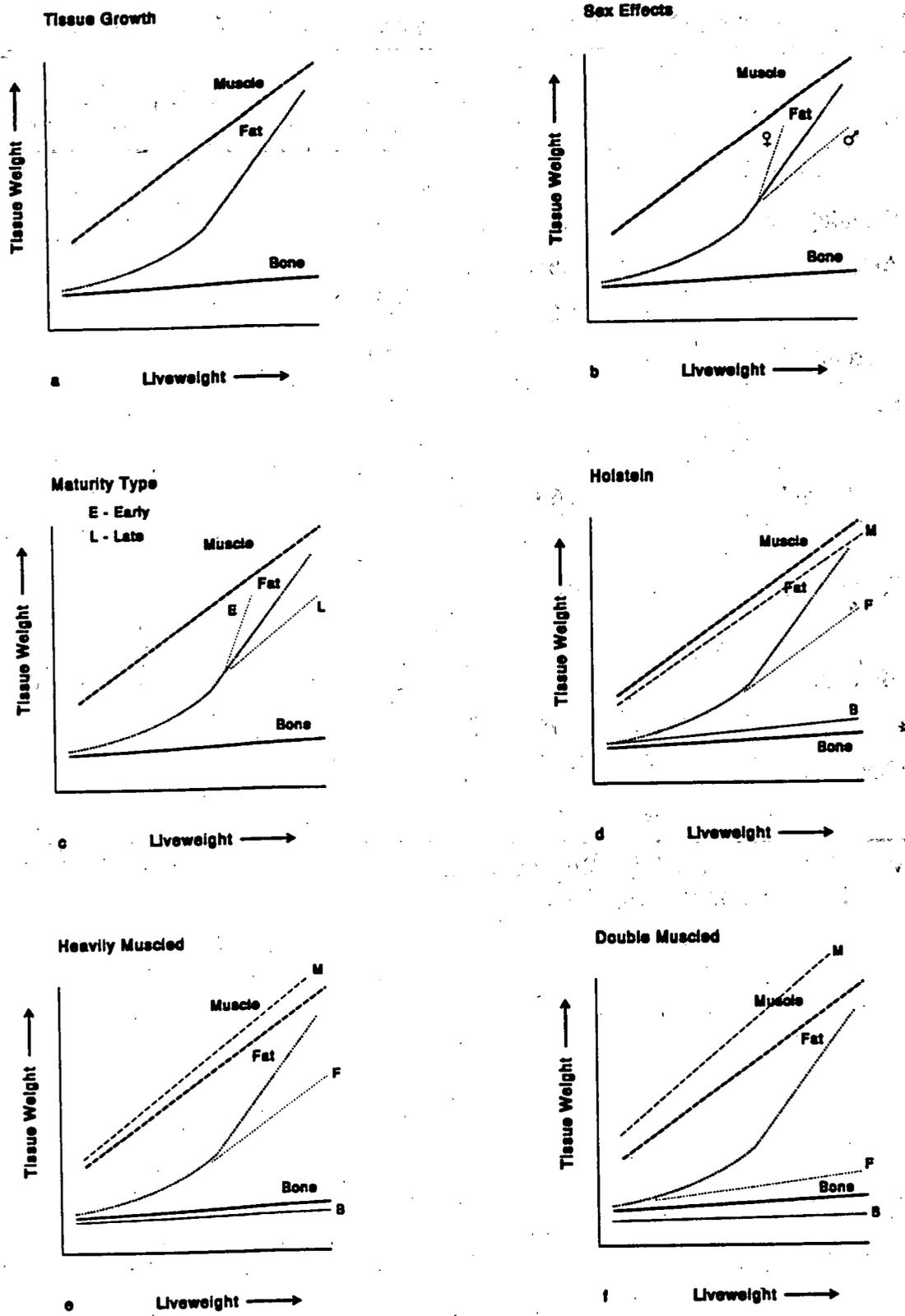


Figure 1. Schematic representation of factors influencing tissue growth relative to live weight in cattle. Adapted from Berg and Walters (1983).

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NUTRITIONAL CONTROL OF GROWTH

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INTRODUCTION

Animal growth is elegantly regulated by complex interactions among many hormones and growth factors which are under nutritional, genetic and physiological control. The animal will be unable to reach its potential for growth if nutritional status, specific hormonal interactions or a number of other factors is limiting. One of the most interesting aspects of growth regulation is the interplay between nutrition and hormonal factors and how they work in concert to control animal growth. For example, nutrients can regulate the hormonal environment, while the hormonal environment can regulate the priority for lean tissue growth which will influence rate of lean gain, and can subsequently alter nutrient requirements (Figure 1). This discussion will

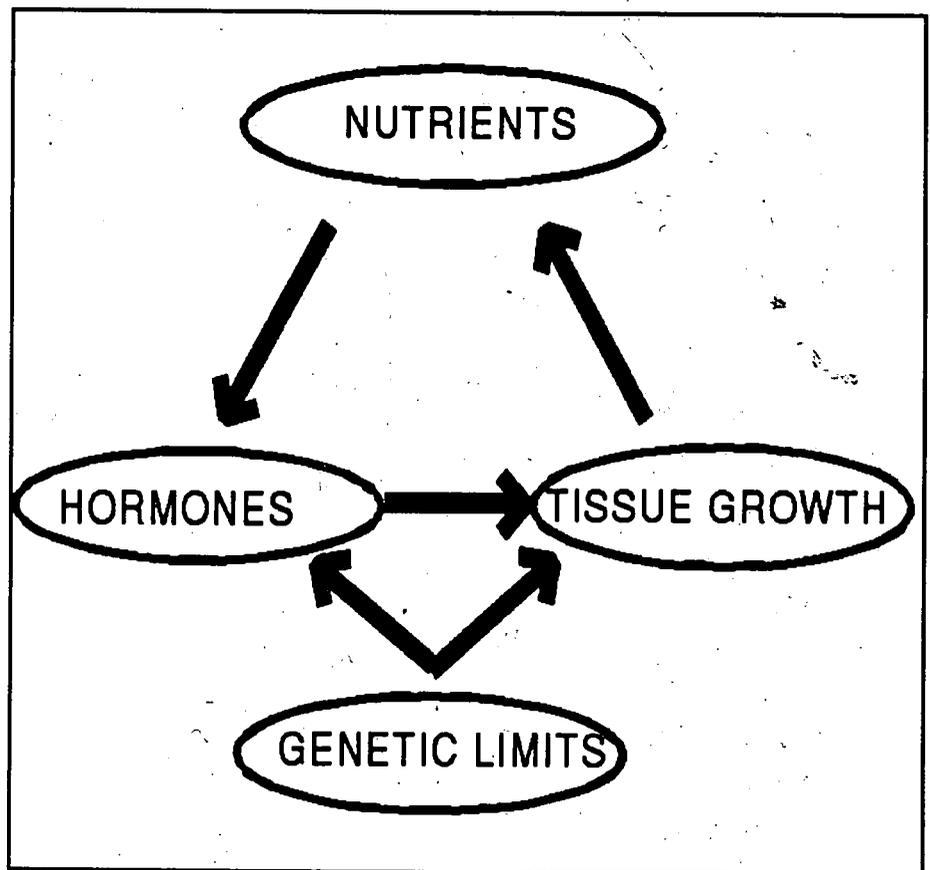


Figure 1: *Nutritional regulation of growth.*

focus on nutrient-hormonal interactions and their involvement in the biology underlying the nutritional control of animal growth.

Whole Animal Growth

In order to discuss the nutritional regulation of growth, it is first necessary to understand the nature of growth and development. Swine and other farm animals follow a classical sigmoidal growth curve with respect to body weight gain as shown in Figure 2

(Widdowson, 1983). This curve can be divided into different phases which represent very different potentials for lean gain. Initially

animals exhibit a slower growth rate due to the stress of birth and a brief lag later on just after weaning. This lag phase is followed by an accelerated growth period which represents the rapid growth observed in young growing pigs. As animals approach sexual maturity growth rate begins to decline and the animal begins to lay down proportionately more fat than muscle. Finally a plateau is reached which represents mature body weight. The growth curve of swine differs from the curve shown in Figure 2 in that sexual maturity is reached at approximately 30 percent of mature body compared with seventyfive to ninety percent in most other species.

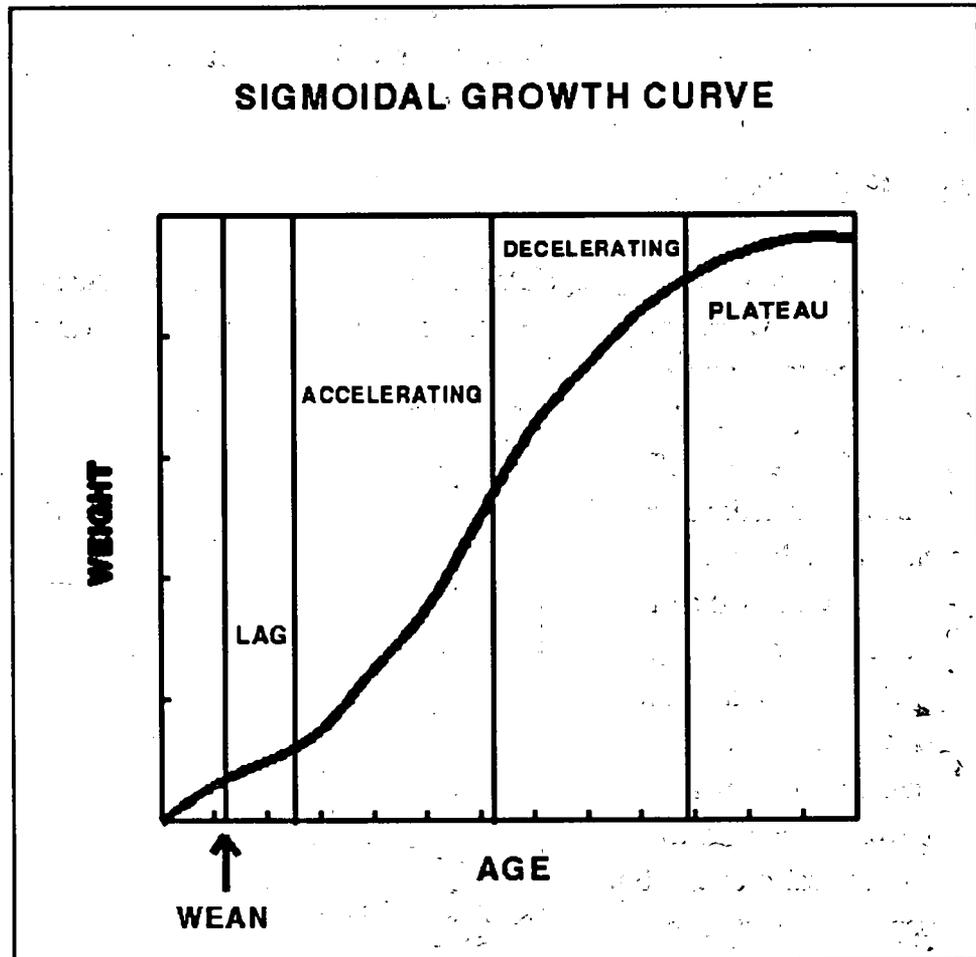


Figure 2: Classical sigmoidal growth curve exhibited by most species. Swine reach sexual maturity at ~30% of mature weight.

It has been shown that at comparable body weights, genotypes which exhibit a larger body size at maturity tend to grow faster and have leaner carcasses than those with smaller mature body weights (Black 1983). Genotypes which exhibit a higher lean growth rate reach their maximum protein or lean mass at heavier weights than genotypes which have lower lean gain potential (Schinckel 1991). Thus, contemporary genetics with high potentials for lean gain may have larger mature lean body size. Larger mature lean body size should be an important parameter to include in selection indexes to improve the lean gain potential in different genotypes.

The rate of lean gain will increase with increased feed consumption until the maximum lean growth potential for the animal is reached. After this point, fat accretion increases in much greater proportion. Pigs with higher lean growth potentials increase their lean gain in response to higher levels of increased feed consumption compared with lower lean gain potential animals. This is because the genetically superior animals have a higher priority for lean growth over a longer period of time. However, this improved lean gain potential cannot be fully realized unless the appropriate nutrient supply is provided.

The whole body growth curve is really a composite of the different growth curves of all the tissues which make up the animal. Therefore, in order to understand animal growth further, we must also understand what controls the growth of the major tissues which make up the whole animal.

Tissue Growth

Different tissues have their own separate growth curves and priorities for growth. In fairly general terms, the order of tissue priority for growth and thus the priority for nutrients is Neural > Skeletal > Muscle > Adipose as shown in Figure 3 (Hammond, 1961). These tissue priorities are reflected in the different potentials for lean tissue growth observed in the various phases of the whole body growth curve. These general tissue growth priorities are the reason that the early and accelerated growth phases of whole body growth represent largely lean tissue accretion, whereas the later phases of growth represent proportionately more adipose tissue accretion. Thus, animals marketed at earlier ages, though lower in total body weight, are leaner than animals marketed at later ages.

The most efficient phase of lean tissue accretion is during the exponential or rapid growth phase of the animal. We can take advantage of this by marketing animals as soon as possible after they leave the accelerated growth phase and by selecting animals that have an extended

accelerated growth phase. On a gross basis, this is considered the most efficient part of the animal's growth curve. Yet if we consider the energetic efficiency of tissue growth instead of the gross efficiency, lean tissue accretion and maintenance are quite inefficient compared with adipose tissue. There are many reasons for this. The major component of lean tissue is protein, and protein has a great deal of water associated with it. For example, a gram of muscle contains only about 0.25 grams of protein. The remaining 0.75 grams is largely made up of the water associated with the protein. In addition to this, protein accretion in tissues is a highly inefficient process as is the maintenance of lean tissue. It has been shown that for

every 1 gram of protein accretion in the whole body of the pig, 1.5-2 grams of protein must be synthesized (Reeds, 1989). This indicates that nearly half of the protein synthesized in the young pig is degraded for various reasons which leaves only half of it available for lean growth.

Despite this energetic inefficiency, the young animal has a tremendous capacity for lean tissue growth which may be limited mainly by its maximum ability to consume nutrients. Increasing the protein intake above maintenance in the

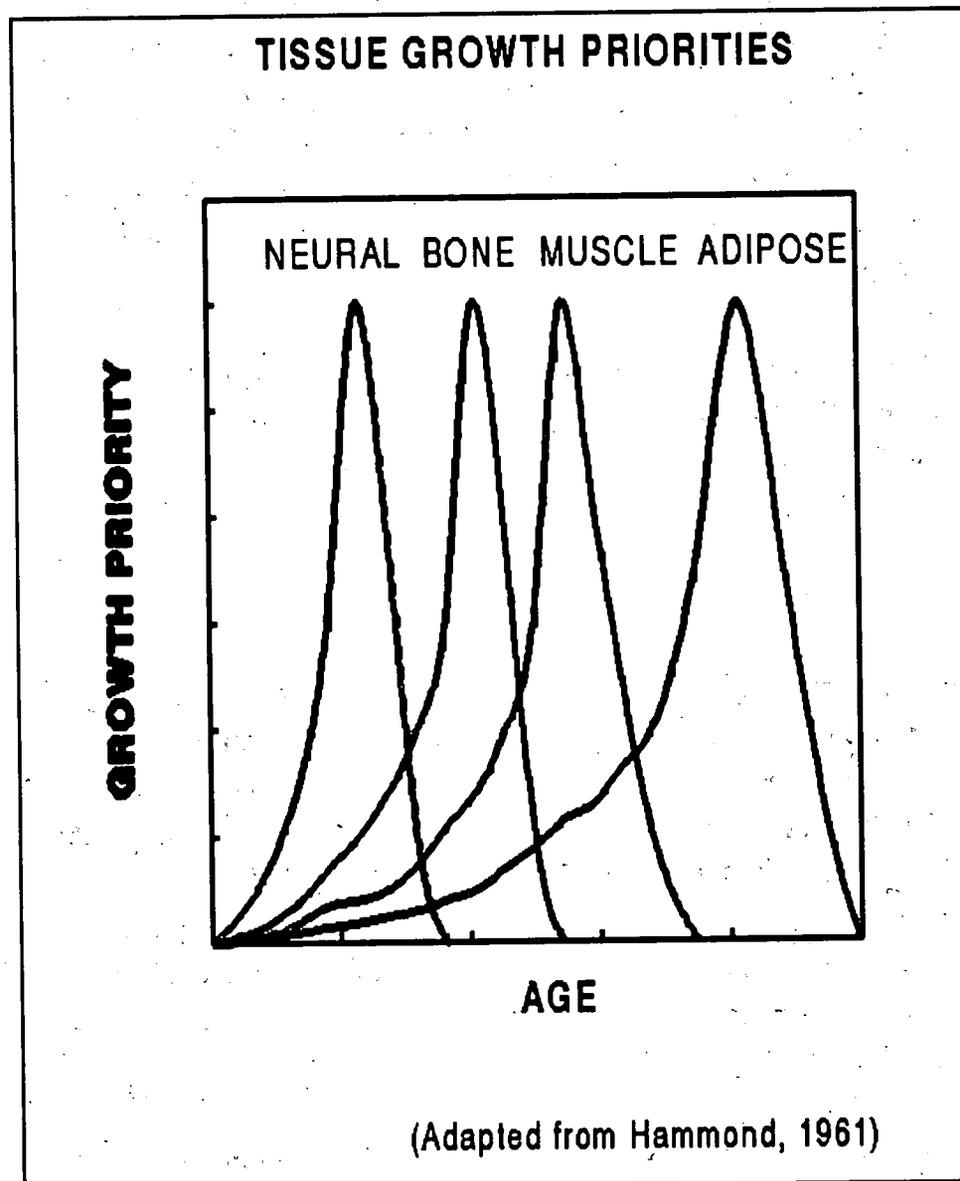


Figure 3: General tissue growth priorities which affect lean gain potential during different phases of growth.

young animal significantly increases lean gain whereas increasing protein intake above maintenance in the mature animal has little effect on lean gain (Reeds and Fuller, 1983). Thus, the stage of growth and the tissue priorities characteristic of these growth phases are determining factors in the nutritional control of growth.

Nutrition and Growth

Nutrition is one of the most important factors that influences whether maximum growth is attained. An optimal level of nutrition can be defined as one that enables an animal to take full advantage of its genetic potential for growth. Since maximal growth of lean tissues is genetically regulated, this potential cannot be exceeded through "super" or "excess" nutrition, however it can be inhibited by inadequate nutrient intake.

In light of our understanding of tissue growth priorities, it is logical that nutrient requirements will vary with the stage of development due to the characteristic tissue priority for that growth phase. From a practical sense we need to attempt to take these different growth stages into account when formulating diets for pigs at different stages of production. However, in order to make sure that pigs are receiving the appropriate nutrient supply for their growth stage and lean gain potential, we must know the quantity of specific nutrients being consumed. Therefore, we must measure the feed intake of our animals so that diets can be adjusted to supply the needed nutrients.

A complicating factor is that as the potential for lean gain increases in our herds, the priorities for lean tissue growth also change. This means that we must constantly be concerned with providing the necessary amino acids and energy to allow the animal to take advantage of its lean gain potential, and making sure that the nutrient supply keeps up with current and future genetic improvement of our animals.

In addition to genetic improvement, tissue growth priorities can be altered by various growth promotants as well. For example, growth hormone (GH), beta-agonists and sex steroids all function by generally increasing the priority for lean tissue growth through various biological mechanisms. Keeping males intact vastly increases their potential for lean gain by increasing the priority for muscle growth compared with gilts and especially barrows. Thus the amino acid requirements for different sexes differs during all growth phases. In the same way feeding animals beta-agonists or injecting them with porcine somatotropin (pST) vastly alters lean gain potential and thus the nutrient requirements to support the increased lean tissue growth (Easter, 1987).

In addition to the priority and pattern of tissue growth, the rate at which an animal grows also has a strong impact on the fate of the nutrients that are consumed. The faster an animal grows, the larger proportion of the nutrients go for tissue accretion whereas in the slower growing animal, more of its nutrients go toward tissue maintenance.

At different stages of growth, the relative rates of lean and fat accretion can be affected by nutritional plane and amino acid adequacy (Black 1983). In finishing pigs, a uniform reduction in nutrient intake by limit feeding decreases the rate of adipose tissue deposition to a greater extent than lean tissue. This produces a leaner carcass compared with animals that are full fed to similar body weights. However, animals fed diets limited or deficient in specific nutrients such as amino acids are fatter than full fed animals at similar body weights (Black, 1988).

The degree of lean and fat tissue accretion as well as the priority for tissue growth is primarily dependent upon the rate of cellular proliferation and the net rate of protein and fat accretion. These processes of cell proliferation and tissue accretion are intimately controlled by hormones and growth factors. Many of these hormones and growth factors are nutritionally regulated which is reflected in the profound effects of nutrient status on lean and fat tissue accretion.

Hormone- Nutrient Interactions

There are numerous hormones and growth factors which under nutritional, physiological and genetic control regulate animal growth. A partial list of these hormones and growth factors and their general effect on whole animal growth is shown in Table 1. A number of these factors are regulated by nutrients and metabolites and assist in partitioning nutrients to tissues. As mentioned earlier, hormones such as the sex steroids or pST can alter the priority of lean tissue growth. In the case of pST the metabolic environment is altered in response to increased levels of this hormone which directs nutrients toward muscle accretion and away from adipose tissue accretion. GH accomplishes this by affecting hormones and metabolites which ultimately change the growth priorities of different tissues (White, 1993). At the same time, this alters nutrient requirements to support the increased protein accretion (Figure 4). GH directly decreases fat accretion in adipose tissue. At the same time, GH increases the output of glucose from the liver and causes tissues in the body such as adipose and muscle to become resistant to insulin. Since these body tissue become less sensitive to insulin, they take up less glucose from the blood stream. This causes blood glucose levels to rise which causes insulin to be secreted in larger amounts, raising insulin levels. GH also increases the level of insulin-like growth factor-1 (IGF-1) which has growth-promoting and insulin-like

actions on peripheral tissues. It is interesting that GH (which causes insulin resistance in tissues), directly or indirectly increases the release of insulin and insulin-like hormones (IGF-1) which on the surface appears to go against its actions on tissue insulin resistance. All of this hormonal interplay ultimately translates into decreased lipid accretion and causes adipose tissue to become less sensitive to insulin which directs nutrients away from this tissue. The nutrients which normally would go toward adipose tissue growth are now available and can be directed toward lean growth partly because of the elevated tissue IGFs and circulating insulin which stimulate the growth of lean tissue increasing its growth priority.

There is another interesting conflict in the understanding of GH action on muscle and adipose tissue growth. GH

is known to exert most of its growth promoting actions through the secretion of the IGFs. The IGFs are known to stimulate both muscle as well as adipose tissue growth at the cellular level. Why then doesn't GH increase adipose tissue priority for growth as much as it increases muscle? Part of the answer is the hormone-nutrient interactions which cause less nutrients to be directed towards adipose tissue compared with muscle. However, there is much more involved. A study

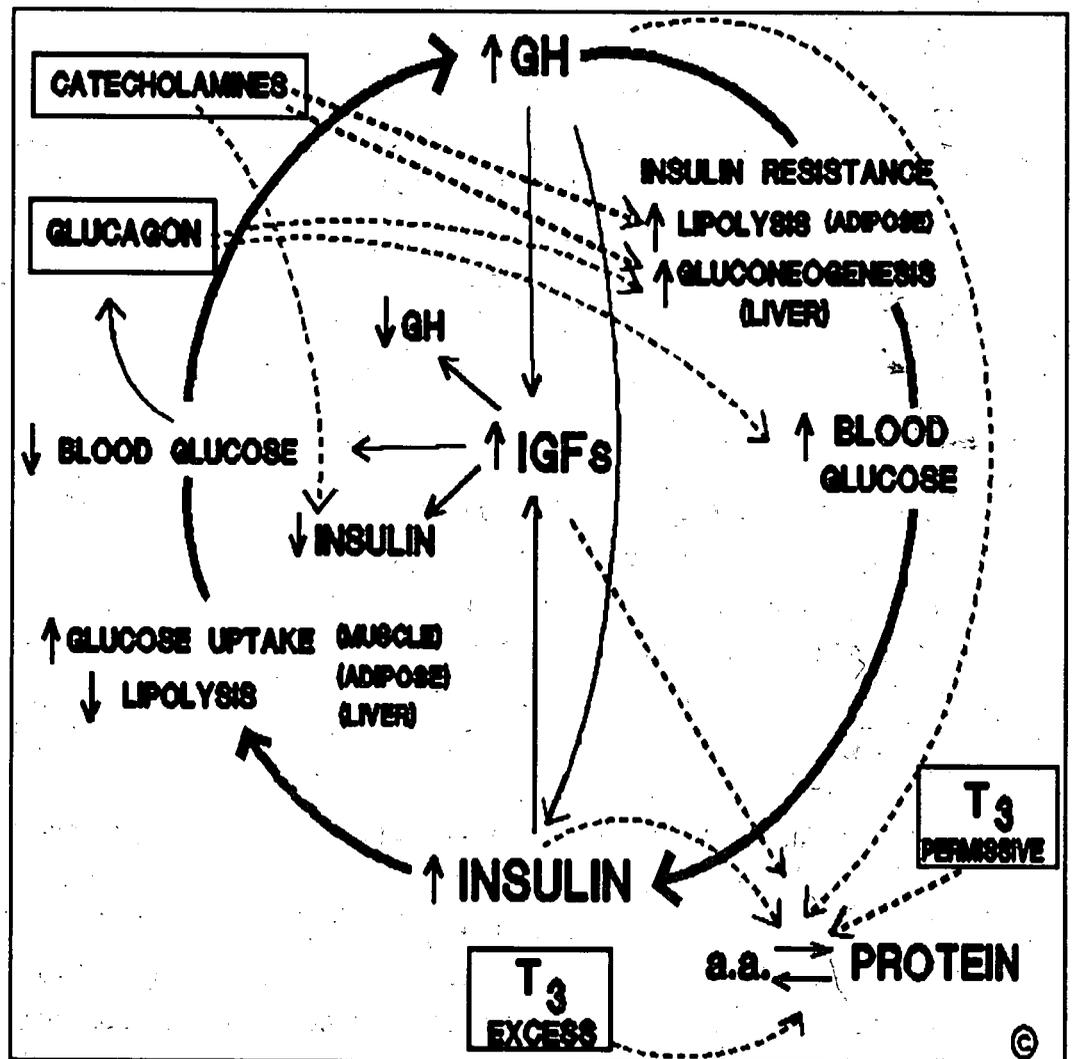


Figure 4: Hormone - Nutrient Interactions involved in growth regulation. (Adapted from White, 1993).

performed in our laboratory by Duffy et al., (1992) demonstrated that pST injection in finishing pigs caused the beneficial responses that have been reported in terms of increasing the efficiency of lean gain. However, we discovered that in addition to the expected increase in IGF-I with pST injection, there was an increase in specific IGF-Binding Proteins (IGFBPs). These IGFBPs have been shown in certain cases to inhibit the growth-promoting actions of the IGFs. We found that adipose tissue showed a large increase in the expression of one of these inhibitory IGFBPs in response to GH while muscle tissue did not. This could be a hormonal mechanism which would increase the priority for muscle growth (increased IGF with no increase in inhibitory IGFBPs) while at the same time decreasing adipose growth priority (increased inhibitory IGFBPs in the tissue).

Although there are many other complex interactions involved, this begins to explain some of the biological mechanisms behind the nutritional regulation of growth. These positive responses to pST are more pronounced during the later stages of growth when more adipose tissue is being deposited. This is likely because in older pigs where pST is not supplemented, the metabolic environment favors the flow of nutrients toward adipose tissue. Although very different mechanisms are involved, the effects of keeping males intact has similar effects on tissue growth priorities. Since simply increasing or decreasing a hormone, whether it is GH or testosterone, causes such dramatic changes in lean gain, these process must be extremely complex. Hormone-nutrient interactions are very delicate and poorly understood at this time.

Even though we may not think about nutrition and growth in basic hormonal and cellular terms on an every day basis, we need to be interested in these kinds of biological processes. These are the processes that allow our animals to survive and grow. They govern lean gain potential and whether or not we are feeding our animals properly. This ultimately boils down to the fact that the basic mechanisms that control growth also control the profitability of our swine operations.

It is important to realize that the progress that has been made to date toward understanding the nutritional regulation of growth has required in many cases, the use of extremely drastic disturbances of the metabolism and physiology of the animal. Such models for studying the role of nutrients, hormones and tissues in the regulation of growth are protein and energy malnutrition, fasting, diabetes, gene insertion, castration and hormone supplementation. These drastic treatments are frequently necessary since the control of growth under everyday conditions is often subtle to the point of being nondetectable with current research technologies. Further investigation and the use of new and emerging technologies should help to improve our understanding of the complex mechanisms involved in the nutritional control of growth.

Conclusions

The nutritional control of growth is complex and poorly understood. Insights into its regulation have generally come from investigations which use very drastic changes in nutritional status such as protein and energy malnutrition, fasting, diseases and hormonal treatments. This has been necessary since the changes in the nutrient-hormonal-physiological environment which direct the priority for tissue growth are often subtle and under normal circumstances beyond the detection limits of research techniques today. Understanding the underlying biology of animal growth and the tissue priority for nutrients is key to improving our understanding and manipulation of the nutritional regulation of growth. As priorities for tissue growth are altered through improved genetics, hormone supplementation or improved environment and management practices, we must always be cognizant that these changes will also affect nutrient requirements. Constant vigilance is needed in order to provide modern animals with the nutrients they require for maximum lean growth and we must constantly redefine nutrient requirements in light of modern genetics, growth promotants and management practices.

TABLE 1. Summary of the General Effects of Various Hormones on Whole Body and Tissue Growth

HORMONES	BODY	MUSCLE	BONE	ADIPOSE
GH ^a	+++	+++	+++	---
IGFs	+++	+++	+++	+++
PROLACTIN ^b	*	*	*	*(-)
INSULIN ^c	++	++	+	+++
THYROID ₃ ^d	+/-	+	+	--
PARATHYROID	*	*	+/-	*
CALCITONIN	*	*	+	*
CATECHOLAMINES	-	-	*	--
PROSTAGLANDINS ^e	+/-	+/-	+/-	+/-
SEX STEROIDS	+++	+++	+	-
CORTISOL	-	-	-	--

^a GH has many indirect effects through the IGFs.

^b Prolactin causes lipolysis in poultry adipose tissue.

^c Insulin has primarily metabolic effects on tissue and body growth.

^d T₃ has mainly permissive effects on growth and allows the tissues to respond to the other hormones. Very low or very high levels of this hormone have very negative effects on growth.

^e Different prostaglandins have various and often opposing effects on tissue growth. PGs can elicit their effects within the cell that produces them or they may have paracrine or endocrine actions as well.

Table 1 summarizes the general effects of the hormones growth factors on the growth and development of the whole body and the major tissues. The (+) indicate a general positive effect on growth while the (-) indicates a general negative effect and the (*) indicates no or little known effect on growth. These general effects indicated here may be either direct, indirect or a combination of both depending upon the hormone or tissue involved.

(Adapted from White, 1993).

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FEEDING FOR LEAN GROWTH IN SWINE

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INTRODUCTION

Research has demonstrated that the growing pig's requirement for dietary lysine and its response to change in energy intake is determined largely by its capacity for muscle growth (Campbell and Taverner 1988a). In the majority of situations the most appropriate and generally the most profitable diet and feeding strategy is that which most closely matches the animal's potential for muscle growth. Because the latter changes with live weight and is affected by sex and genotype all these factors need to be considered in the design of diets and feeding strategies for growing pigs.

I. EFFECT OF LIVE WEIGHT

To a limited extent the decline in the growing pig's capacity for muscle growth with increase in live weight is accounted for by a concomitant reduction in the dietary lysine: DE value of diets for heavier pigs and in the difference in energy content of diets given pigs during the early and later stages of development.

However, rate of muscle growth relative to energy intake declines continuously with increase in live weight from birth to maturity. Maximal rate of muscle growth also declines with increase in live weight subsequent to 50 to 80 kg depending on genotype and sex, and reaches zero at maturity. Consequently, the efficiency and profitability of production may be improved if dietary lysine and energy concentrations were altered more regularly to match the concomitant changes in the pig's potential for muscle growth. Such a system however, would involve the use of a larger number of diets than the traditional weaner grower and finisher diets and consequently may have serious practical limitations, particularly for established enterprises. On the other hand, the use of a single diet for pigs between 20 and 90 kg is difficult to justify on either biological or economic grounds particularly if the lysine concentration of these diets is based on the estimated requirement for the younger animals.

II. EFFECT OF SEX

A. Pigs between 20 and 50 kg live weight

Females and castrated males have a lower capacity for muscle growth than entire males. Whilst this difference is reflected to some extent in the different degrees of energy restriction imposed on male and female finisher pigs, its practical implications have not been fully explored or exploited.

During the earlier stages of development (to 50 kg), rate of protein deposition increases linearly with increase in energy intake up to the limit of the animal's appetite (Campbell et al 1985a). Because of the constant relationship between protein growth and change in energy intake the younger pigs requirement for protein for muscle growth can only be satisfied by diets with a constant lysine:DE value. The most appropriate feeding strategy in the period 20 to 50 kg is that which promotes near maximum energy intake and thus most fully exploits this potential. The implementation of such a strategy allows very rapid growth, but because rate of protein deposition is linearly related to energy intake, does not result in excessive fat deposition or deterioration in feed:gain.

Ensuring maximum energy intake however, is not merely a matter of offering pigs a 'grower' diet ad libitum. Between 20 and 50 kg, pigs eat to the limit of their ingestive capacity which lies between 1.8 and 2.0 kg/d. On the other hand, over the same live weight range the pig's demand for energy, which is a reflection of its potential for protein and fat growth, lies between 30 and 32 MJ DE/d. Consequently, unless offered diets with energy concentrations between 14 and 15 MJ/kg the animal is unable to satisfy its demand for energy or fully express its potential for growth. The effect of dietary energy content on growth performance is shown in Table 1, which gives the results of an experiment in which entire male pigs were given five diets ranging in DE concentration from 11.8 to 15.1 MJ/kg between 22 and 50 kg live weight.

B. Effects of sex and level of energy intake on protein deposition in pigs between 50 and 90 kg

Subsequent to 50 kg the genetic potential for protein deposition of entire male, females and castrated male pigs tends to lie within the limits of appetite. Table 2 gives the results of an experiment in which entire male and female pigs growing between 48 and 90 kg were given five levels of intake of a protein-adequate diet. The results showed that for both sexes, rate of protein deposition increased linearly with increase in DE intake up to 32 MJ/d but remained constant at 130g/d for males and 102g/d for females thereafter.

The results (Table 2) show the adverse effects on carcass fatness and feed:gain of raising DE intake above the level at which the pig's potential for protein growth is achieved. Nevertheless, providing the relationship between energy intake and rate of protein deposition is known, these effects are predictable and can be taken into account when designing feeding strategies for heavier pigs. Because maximal rate of protein deposition was achieved at a DE intake of approximately 32 MJ/d, the level of dietary lysine required to support maximal muscle growth would decline with each increase in DE intake above 32 MJ/d. Thus the possibility of using cheaper diets for pig given high levels of energy intake would also have to be considered when deciding the most profitable nutritional strategy for heavier pigs.

However, in the majority of cases the most profitable feeding level would be that which provided an average DE intake of between 32 and 34 MJ/d, and thus allowed the pig to express its potential for muscle growth but prevent the adverse effects of higher energy intakes on feed:gain and carcass fatness. The latter strategy may involve either the use of a relatively low energy diet (eg. 12-12.5 MJ DE/d) offered ad libitum on the use of a restricted feeding program.

The results in Table 2 also show that both maximal rate of protein deposition and the slope of the linear portion of the relationship between energy intake and rate of protein deposition was lower for females than for entire males. Thus unless there was a marked difference in obligatory protein losses between the sexes the level of dietary lysine required to support muscle growth in females would be expected to be lower than that for entire males.

The latter contention has been confirmed experimentally (Campbell et al, 1988) and is illustrated in Table 3. These results show that between 20 and 50 kg live weight the level of dietary lysine required to support maximum growth performance is similar for both sexes.

However, between 50 and 90 kg the level of dietary lysine required to support maximum growth performance in females was 15% below that required for entire males. Experimental results have also shown that between 50 and 90 kg female pigs are less tolerant of high protein intake than males, and that levels of dietary lysine only marginally in excess of requirement tend to depress growth performance. This effect however, is influenced by genotype.

In the short term there is considerable scope for improving the efficiency of pig production by using lower lysine diets for female finisher pigs.

The separate feeding of the sexes during the later stages of production would also enable high energy diets to be used for males and relatively low energy diets used for females which would further reduce the cost of production and prevent excess carcass fatness often observed in female pigs during the final stages of production.

In the longer term the profitability of production would be most readily achieved by increasing the female's capacity for muscle growth. The latter might be achieved by genetic selection or by hormone manipulation, both of which are discussed below.

III. EFFECT OF GENOTYPE OR STRAIN

Differences in growth performance and body composition have been reported between different strains and breeds of pigs. However, until recently there has been little information on the effect of genotype on energy and protein metabolism or on the extent of variation which might exist between commercial strains. The results of a study conducted at the ARI, Werribee provides an insight into the effects of genetic selection on muscle growth and the consequent effects on growth performance and energy utilization.

In the experiment conducted at Werribee, protein deposition was measured in two strains of entire male pig (Large White x Landrace), given seven levels of intake of a protein-adequate diet between 45 and 90 kg live weight.

One strain (Strain A) was introduced to the experimental piggery by caesarian section from sows obtained from a large commercial piggery (6000 sows) where all breeding stock have been selected on the basis of growth performance under adlibitum feeding for some 12 years. The other strain (Strain B) was from the experimental herd of some 50-60 sows and were representative of slower growing commercial genotypes.

The results for protein deposition (Table 4) showed that at all levels of feed intake Strain A pigs deposited protein faster than Strain B. The form of the relationship between energy intake and rate of protein deposition also differed between the strains. For Strain B pigs, rate of protein deposition increased linearly with increase in DE intake up to a maximum rate of 129g/d at approximately 33 MJ DE/d (80% adlibitum)

For Strain A pigs there was no evidence of any genetic ceiling for rate of protein accretion and the latter increased linearly with increase in energy intake up to 187 g/d on the adlibitum feeding treatment (40 MJ DE/d). It appears that selection under adlibitum feeding had raised the capacity for muscle growth of these pigs (Strain A) beyond the upper limit of appetite.

The slope of the relationship between DE intake and rate of protein deposition for Strain A was also higher than that of the linear portion of the relationship for Strain B. Given the marked difference in capacity for protein accretion between the strains, the levels of dietary lysine and other essential amino acids required to support muscle growth would also be expected to differ as would the responses of the two strains to change in level of feeding. The latter is obvious from Table 4 which shows the effects of energy intake on growth rate, feed:gain and P2 fat thickness of the two strains. For Strain A pigs the most appropriate feeding strategy would be that which promoted maximum energy intake, and thus fully exploited the pigs high potential for muscle growth. This would probably involve the adlibitum feeding of diets with energy and lysine concentrations generally considered more appropriate for younger pigs. For Strain B pigs however, the most appropriate and most profitable feeding strategy may involve a degree of energy restriction.

Field trials conducted in conjunction with the work at the ARI indicate the potential for muscle growth in commercial strains within Australia range from somewhat below that of the Strain B pigs used in the experiment at Werribee up to 85-90% of that of Strain A. Because of this wide variation there is a need, in the short term, for producers to measure the capacity for muscle growth of their stock and to use this information to design appropriate diets and feeding strategies. In the longer term, the profitability of individual enterprises and of pig production in general will be most readily improved by the identification and spread of genuinely superior stock.

The results of the experiment conducted at Werribee show however, that unless the improvement in the pig's genetic capacity for muscle growth is matched by a concomitant improvement in its nutritional management, and in particular the level of dietary essential amino acids, much of the potential benefit offered by such animals will not be realised.

The results of the experiment presented in Table 4 suggest that in terms of growth performance, genetic improvement is associated with increase in both the maximum muscle growth and in the slope of the linear component of the relationship between energy intake and muscle growth. The relative rate of improvement in either of these characters can probably be influenced by the selection procedure employed, and in the future it may be more profitable to concentrate on increasing the slope of the relationship between energy intake and rate of protein deposition.

This would enable more rapid and efficient growth to be obtained at the levels of energy intake achieved by pigs offered feed ad libitum under commercial conditions, which is often substantially lower than that achieved by pigs kept under experimental conditions or in performance testing situations.

IV. EXOGENOUS PORCINE SOMATOTROPIN (PST) ADMINISTRATION

The relationship between protein deposition capacity and dietary amino acid requirements is best illustrated by the interrelationship between exogenous PST administration and dietary lysine content on pig performance and protein accretion.

Exogenous PST administration stimulates protein deposition and inhibits lipogenesis resulting in marked improvements in growth performance and reduction in carcass fat content. (Campbell et al 1989, Etherton et al 1987; Evock et al 1987). However, initiation and support of the higher rates of protein deposition able to be induced by PST technology requires a concomitant increase in dietary lysine content. This is demonstrated in Table 5 which presents the results of an experiment in which the responses of control and PST treated boars were compared over six levels of dietary lysine between 60 and 90 kg live weight.

Exogenous PST administration increased maximal protein deposition (measured in the head off empty body) from 118 to 215 g/d (81%). However, the magnitude of the improvement induced by PST was directly related to dietary lysine content and on the two lowest lysine diets PST administration had no positive effect on protein deposition or growth performance.

The level of dietary lysine required to support maximal protein accretion in control and PST treated pigs was approximately 0.75 and 1.2% respectively. The corresponding dietary lysine:DE values were 0.5 and 0.8 g/MJ respectively.

Apart from demonstrating the potential of PST technology to alter the efficiency of pig meat production, the results show that future improvements in the efficiency of growth will be dependent on identifying and removing the intrinsic factors constraining protein deposition capacity. This can be achieved by genetics and/or employment of new technologies such as exogenous PST administration. However, it is evident from the information discussed here that the advantages offered by enhancing the growing pigs capacity for protein deposition (muscle growth) will only be fully realised if dietary nutrient levels and feeding strategies are enhanced accordingly.

CONCLUSIONS

The growing pigs capacity for protein accretion is the major factor determining growth performance and dietary amino acid requirements. In the short term, considerable improvement in the efficiency of production could be achieved by matching more closely the pigs' nutritional management to its capacity for protein growth.

Future improvements in the efficiency and profitability of pig meat production will be dependent on identifying and removing intrinsic constraints to lean tissue growth capacity, particularly in heavier pigs.

This can be achieved by conventional (eg. genetics) or biotechnological (eg. exogenous PST administration) techniques. However, in either case the potential advantages offered by pigs with increased lean tissue growth capacity will only be fully realized if dietary amino acid levels and energy intakes are adjusted accordingly.

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Table 1. Effect of dietary DE concentration on the voluntary feed intake and performance of entire male pigs growing from 22 to 50 kg (Campbell and Taverner, 1986).

	Dietary energy content (MJ/kg)				
	11.8	12.7	13.6	14.5	15.1
Voluntary feed intake (kg/d)	2.19	2.21	2.19	2.17	2.05
Voluntary energy intake (MJ DE/d)	25.7	27.7	29.7	31.3	30.9
Daily gain (g)	695	776	847	898	913
Feed:gain	3.16	2.89	2.61	2.39	2.25
Carcass P2 (mm)	14.4	15.3	15.6	16.0	16.4

Table 2. Effects of energy intake between 48 and 90 kg on rate of protein deposition and the performance of entire male (M) and female (F) pigs (Campbell et al, 1985b).

		Energy intake (MJ DE/d)				
		22.6	26.4	31.7	36.0	Ad lib+
Protein deposition (g/d)	M	69.4	94.8	129.5	130.0	132.0
	F	63.4	84.5	103.0	102.0	99.0
Daily gain (g)	M	418	576	793	842	884
	F	358	552	654	742	795
Feed:gain	M	3.9	3.4	2.9	3.1	3.5
	F	4.6	3.6	3.4	3.5	3.6
Body fat (g/kg)	M	203	249	257	315	332
	F	293	332	353	368	397

+ 39.8 MJ ME/d for M and 37.9 MJ ME/d for F (P < 0.05).

Table 3. Effect of dietary lysine content on the feed:gain of entire male (M) and female (F) pigs growing from 20 to 50 and 50 to 90 kg live weight (Campbell et al, 1988).

		Dietary lysine (g/MJ DE)							
		0.4	0.5	0.6	0.67	0.76	0.83	0.94	1.02
20-50 kg	M	3.3	2.9	2.6	2.4	2.2	2.2	2.3	2.3
	F	3.3	2.9	2.6	2.4	2.25	2.3	2.4	2.4
50-90 kg	M	3.5	2.9	2.7	2.9	3.1	3.0	2.9	2.9
	F	3.5	2.9	2.9	3.2	3.2	3.3	3.5	3.3

Table 4. Effects of energy intake between 45 and 90 kg live weight on protein deposition and growth performance in faster (A) and slower (B) growing strains of entire male pigs (Campbell and Taverner, 1988).

Energy Intake (MJ DE/d)	Strain	Protein Deposition (g)	Daily gain (g)	Feed gain	Carcass Fat (%)
22.2	A	92	567	2.60	18.8
	B	81	470	3.12	24.4
25.1	A	105	622	2.66	19.4
	B	87	595	2.80	26.6
27.6	A	119	764	2.39	21.0
	B	105	680	2.69	29.0
30.6	A	135	826	2.40	23.6
	B	115	734	2.77	28.9
33.5	A	148	944	2.36	25.4
	B	128	820	2.70	30.3
36.8	A	166	1110	2.23	25.8
	B	129	870	2.85	32.2
Adlibitum ^a	A	189	1202	2.26	26.0
	B	125	915	3.05	36.6

^a Adlibitum energy intake was 40.6 and 40.7 MJ DE/d for strain A and B pigs respectively.

Table 5. Effects of exogenous porcine growth hormone administration and dietary lysine content between 60 and 90 kg on the growth performance and carcass P2 fat thickness of entire male pigs (Campbell et al 1989).

pGH (mg/kg/d)	Dietary Lysine (%)	Protein Deposition (g/d)	Daily Gain (g)	Feed:gain	P2 (mm)
0	.45	67	628	3.71	20.5
	.66	107	803	2.86	19.8
	.88	118	862	2.65	18.6
	1.09	115	823	2.78	20.2
	1.31	119	887	2.63	17.2
	1.53	117	860	2.71	18.4
0.09	.45	74	588	3.87	17.0
	.66	104	760	3.02	15.0
	.88	146	961	2.35	12.4
	1.09	175	1108	2.07	14.2
	1.31	216	1204	1.80	14.0
	1.53	213	1338	1.69	13.1

PATTERNS OF LACTATIONAL FEED INTAKE AND THEIR INFLUENCE ON REPRODUCTIVE PERFORMANCE

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Introduction

Nutrient intake during lactation affects the overall productivity of the breeding herd by influencing milk production and the post-weaning reproductive performance of the sow. Manifestations of suboptimal nutrient intake include prolonged weaning-to-service intervals (King, 1987), reduced subsequent litter size (Kirkwood et al., 1988) and smaller litter weights at weaning (Tokach et al., 1992a). While numerous studies have observed that the average nutrient or feed intake throughout lactation is related to reproductive performance, the results of a recent study in our laboratory suggest that nutrient-induced endocrine aberrations occur early in lactation, perhaps as early as two weeks post-farrowing in primiparous sows. These aberrations may manifest in, among other ways, prolonged weaning-to-service intervals (Tokach et al., 1992b). The overall objective of these studies is to determine whether differences in patterns of feed intake during lactation influence the lactational and post weaning reproductive performance of the primiparous sow.

Study 1: Field survey of feed intake and intake patterns during lactation on commercial farms

Materials and Methods. Swine herds located in southern Minnesota and using the PigCHAMP® swine production information system participated in this study during the calendar year 1991.

Feed intake of lactating sows was recorded twice daily on standardized feed consumption cards.

In addition, several other data items were recorded on each farm to establish their importance as risk factors for reduced feed intake. These include: (1) daily recordings of high and low temperatures in a representative farrowing room, (2) quarterly recordings of water-flow rates (ml/min) from 20 farrowing crate waterers randomly selected from the farrowing rooms of each farm, and (3) P2 backfat of representative sows one week prior to farrowing during the summer (June and July) and winter (September to January). In addition, farm-level information recorded at the first and last of four quarterly visits included: genetics, herd size, average weaning age, farrowing schedule, farrowing crate design, floor type, waterer type, feeder design, type of waste management system, use of creep, use of evaporated (drip) cooling systems, type of ventilation system and controls, and lighting programs. A sample of lactation feed was taken from each batch feed at mixing, placed in a plastic container, and was stored refrigerated or frozen until dispatched to the University, where it was stored at -20°C.

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Each farm was visited four times at quarterly intervals to determine the accuracy of amounts being fed to sows as recorded by producers, and to determine whether management practices, facilities, health status or diet had changed during the intervening period.

Definitions of Feed Intake Patterns.

After collection, the pattern of feed intake recorded on each feed card was categorized into one of six patterns (Figure 1.)

- I: No dip.
- II: Major dip. A major dip was ≥ 1.6 kg/day decrease from the previous feeding, with intake remaining low for ≥ 2 days.
- III: Minor dip. A minor dip was a decrease of < 1.6 kg/day from the previous feeding.
- IV: Feed intake was low throughout the feeding period, never exceeding 4.5 kg/d.
- V: Feed intake increased slowly during lactation. Intake during the first week did not exceed 2.7 kg/d.
- VI: Feed intake gradually increased. This pattern describes a change in which there is a subsequent ≥ 1.8 kg increase in feed intake from the average intake of days 8 and 9.

Other Characteristics.

Peak day: The day on which the highest daily feed intake during lactation first occurs.

Peak intake: The average of the highest weights of feed/day for two consecutive days.

Statistical Analyses.

Summary statistics, multiple pairwise comparisons of means (Tukey), the Wilk-Shapiro test, and ANOVA were used to analyze and compare average feed intake, the lowest feed intake days, and day of peak intake among various patterns and seasons of the year.

Results

Of 34 herds initially enrolled in this project, four dropped out immediately at the initial stage, due to either problems with disease or a shortage of labor. Data were collected from the thirty remaining herds for the entire one-year period of the study. Daily feed intake data was collected for approximately 12,000 lactating sows. While the analysis of data from all farms is not completed at the time of writing, data summaries from 10 farms are available.

Across all farms, Patterns II and III were most common, comprising approximately 62% of total observations. Patterns IV and V occurred in less than 3% of total lactations (Figure 2.) However, the proportions of patterns varied widely among farms. Lowest daily feed intake for individual sows occurred at all days of lactation, with 90% of those observations occurring between days 7 to 19 (Figure 3.) Average day of peak intake among herds was 12.6 (sem ± 0.92); the median occurred on day 16. Of the ten herds analyzed, the earliest average day of peak intake was 7.5, and the latest 16.1 days of lactation.

There was considerable variation among farms in days of peak feed intake: Two farms had their peaks on day 7; 5 farms had their peak intakes on days 11 to 13; and 2 farms had their peaks on days 16 or 17. There was no significant differences in the average feed intake among patterns I, II, III and VI. Patterns IV and V had significantly reduced average feed intake relative to the other patterns (Figure 4.) The distribution of feed intake patterns for 2 farms having differing days of peak feed intake is shown in Figure 5. Noticeable differences in the proportion of sows having patterns I and VI were observed. Although 8 farms had significant differences in feed intake across month of the year, there was no effect of month when farms were combined (Figure 6).

Study 2: Influence of feed intake during different stages of lactation on the post weaning reproductive performance of primiparous sows.

Materials and Methods. Thirty-six primiparous sows were assigned to each of five treatments designed to mimic common patterns of feed intake observed in the field (Table 1). Metabolizable energy intake was either 16.5 (H) or 6.5 (L) Mcal/day. These diets were isonutrient for lysine, providing 45 gm lysine/day. Sows and their litters were weighed and sow backfat measurements taken immediately after farrowing, and at days 7 and 14 of lactation, and at weaning.

Table 1. Study Design

Treatment	1st week	2nd week	3rd week
Positive control	Ration H	H	H
Negative control	L	L	L
Reduced Energy Week 1	L	H	H
Reduced Energy Week 2	H	L	H
Reduced Energy Week 3	H	H	L

Statistical Analyses.

Kruskal-Wallis ANOVA and multiple comparison were used to analyze the influence of treatments on weaning-to-estrus interval. General linear model using contrast for repeated measures (SAS) was used to analyze the changes in sow body weights and P2 backfat, and litter weight gain during the 21-day lactation.

Results.

Comparing sows which consumed $\geq 70\%$ of their dietary allowances, there was no significant difference in weaning-to-estrus interval among treatments (Figure 7). Sows fed the LLL and

HHL patterns lost more body weight and backfat ($P<.01$) than sows fed HHH, LHH and HLH (Figure 8). There was no significant difference in litter weight gain among treatments. However, in the third week, litters in HHH gained more than litters in LLL ($P<.05$). Analyses of blood samples for reproductive and metabolic hormones and for metabolites have not yet been completed.

Discussion

Six distinct daily feed intake patterns have been identified in the lactating sows in the 10 commercial herds examined so far. While the frequency of patterns varied among farms, patterns I, II and III were most commonly observed on all farms. Patterns IV and V were observed infrequently on all farms. While there is an abundance of published information relating average intake throughout lactation to reproductive and lactational performance, there is a paucity of information on how voluntary feed intake of lactating sows changes during lactation. In agreement with our observations, Dourmad (1991) described transient reductions in feed intake during mid lactation. Our data show that while there is no predictable time of reduced feed intake during lactation, reduction in feed intake typically occurs during mid lactation

The results of our second trial indicate that sows fed a high-energy diet throughout lactation returned to estrus more promptly than those fed low-energy diet. There was no clear difference in weaning-to-estrus interval among groups having a 1-week reduction in feed intake at different stages of lactation, and these groups were not different from those fed high or low energy throughout lactation. These results are in mild contradiction to earlier observations in our laboratory suggesting that stage during lactation in which feed intake is reduced would have an effect on reproductive performance. Sows fed low energy throughout lactation and those fed low energy during the last week lost more weight and backfat than other sows. This suggests that metabolic differences occurred among treatments that might mediate subtle differences in reproductive events, such as luteinizing hormone release. The completion of endocrine and metabolite assays is needed to further elucidate the effects of feed intake pattern on reproductive processes.

While our intent is to use the farms' PigCHAMP® records to determine the influence of feed intake pattern on reproductive and lactational performance, these analyses have not yet been completed. Similarly, the effects of various risk factors (e.g. ambient temperature, equipment design) on feed intake, pattern of feed intake, and sow performance have yet to be completed.

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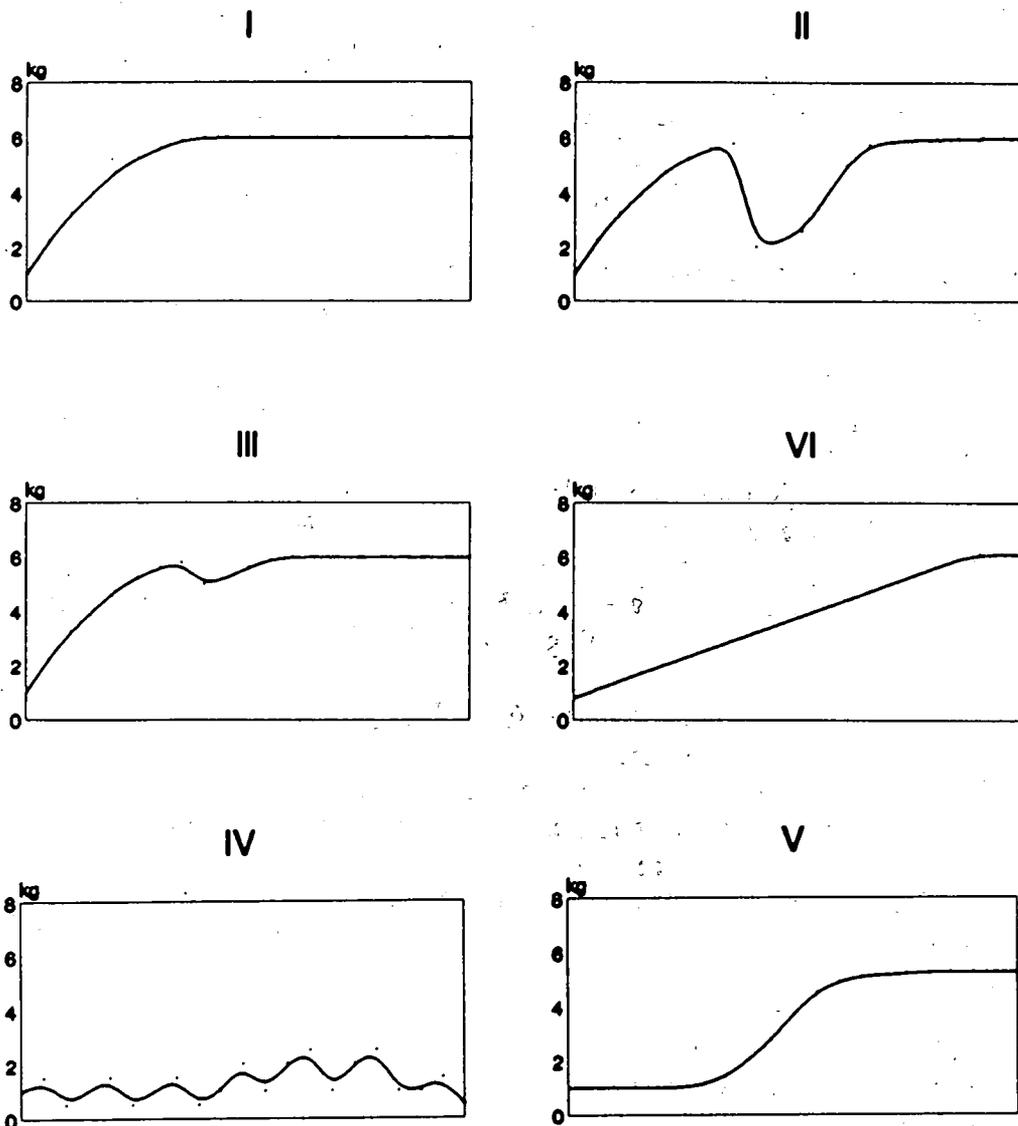


Figure 1. 6 patterns. Common patterns (I, II, III and VI), and few patterns (IV and V).

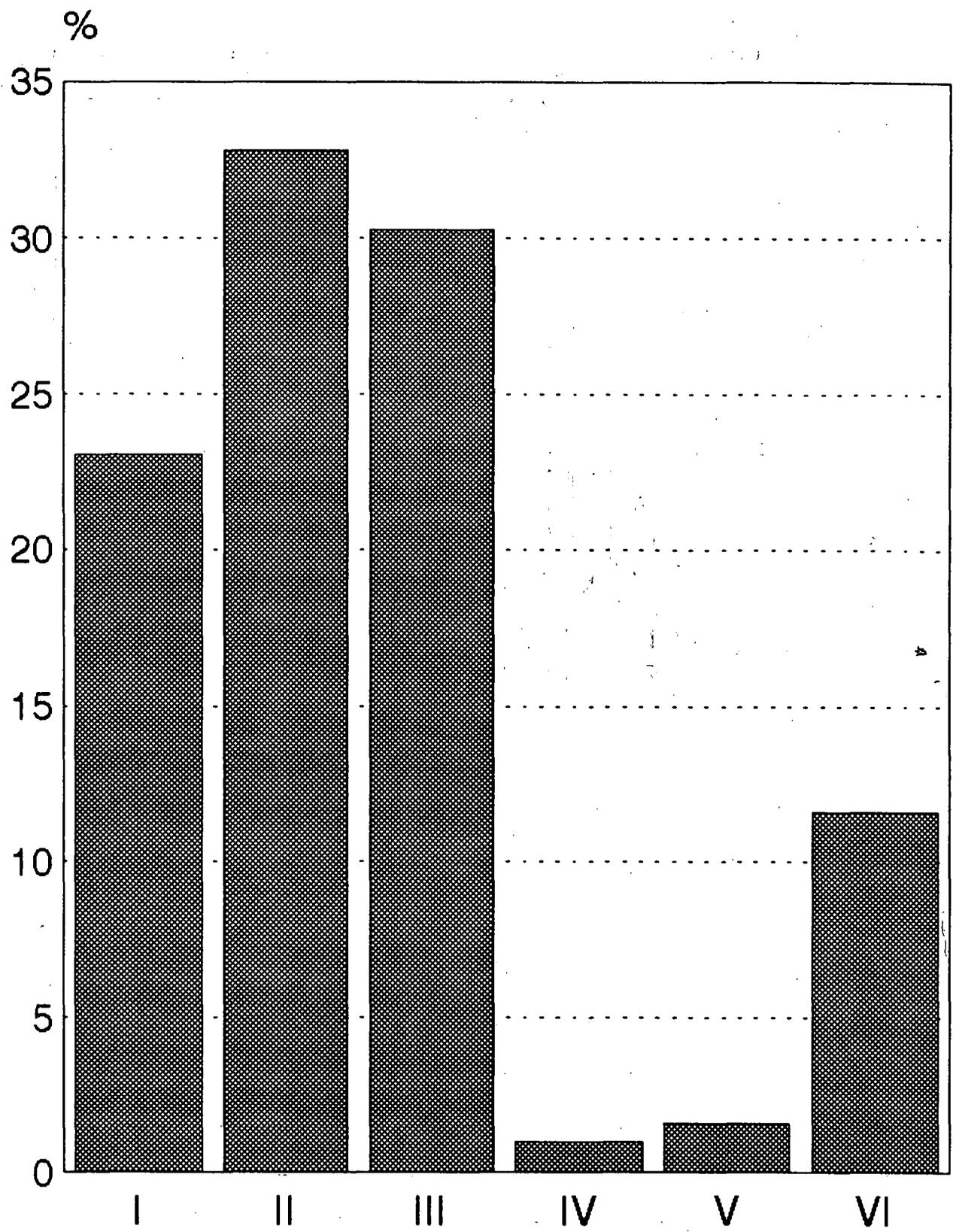


Figure 2. Distribution of feed intake patterns across 10 farms.

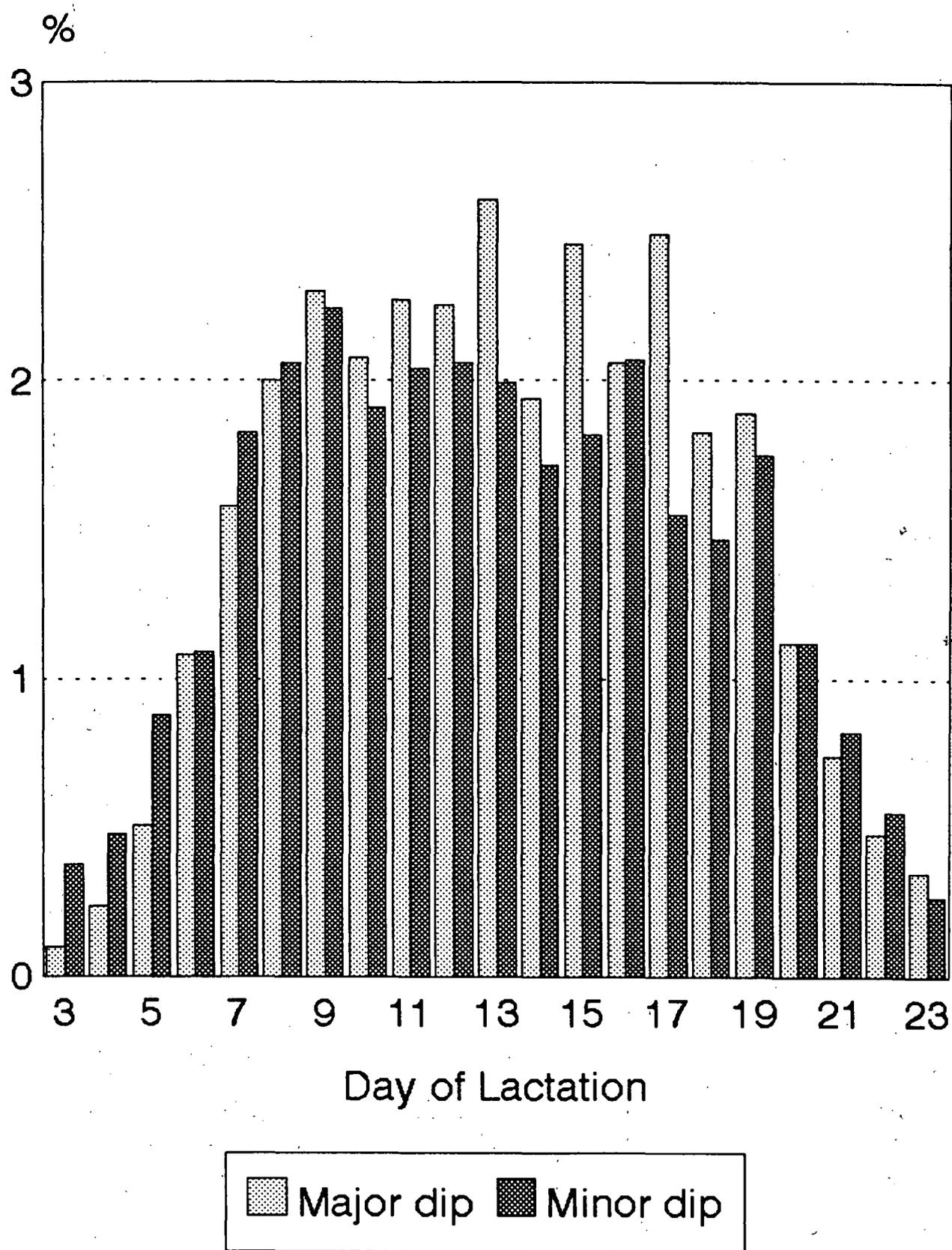


Figure
observed

Figure 3. Distribution of major and minor dips in feed intake during lactation.

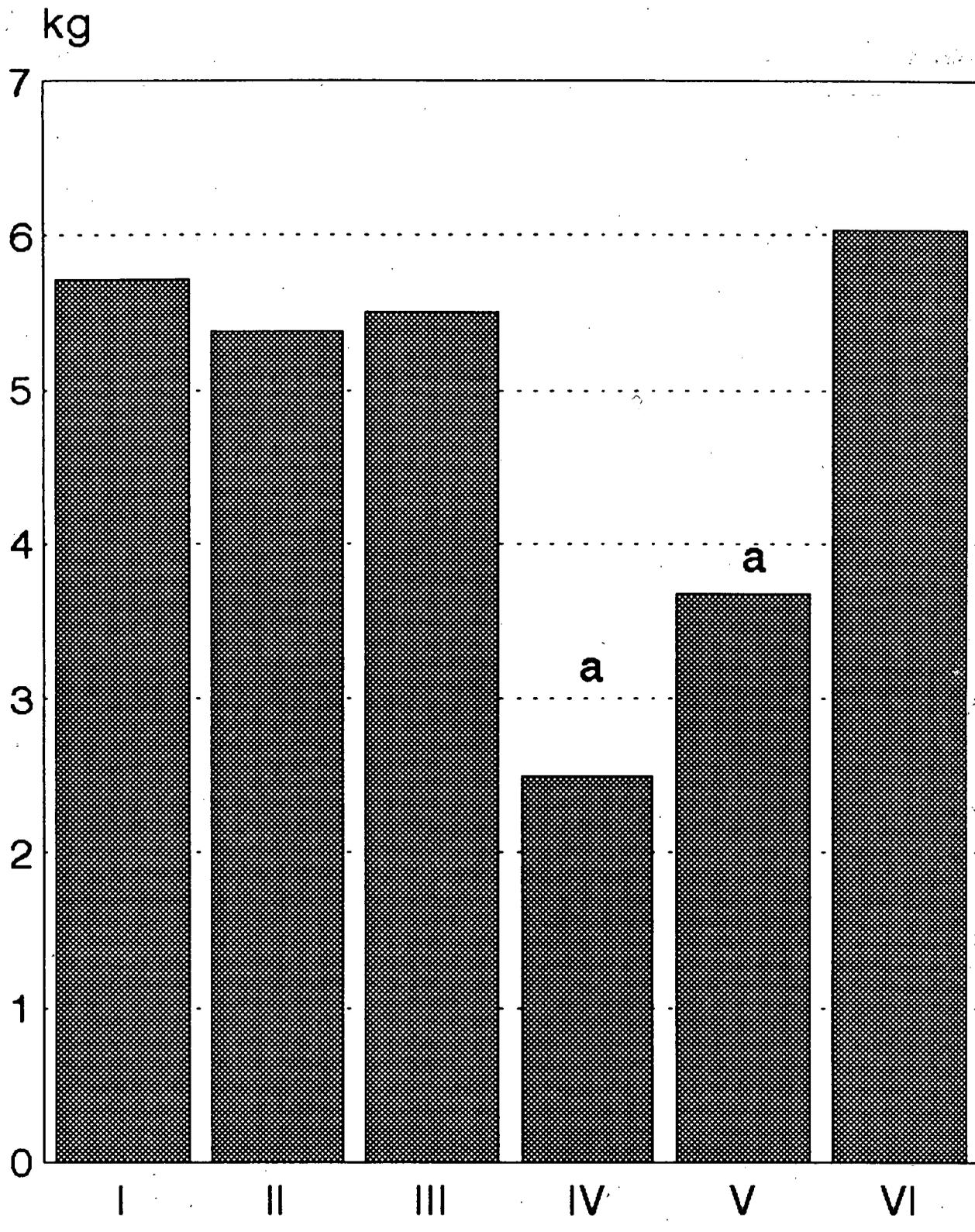
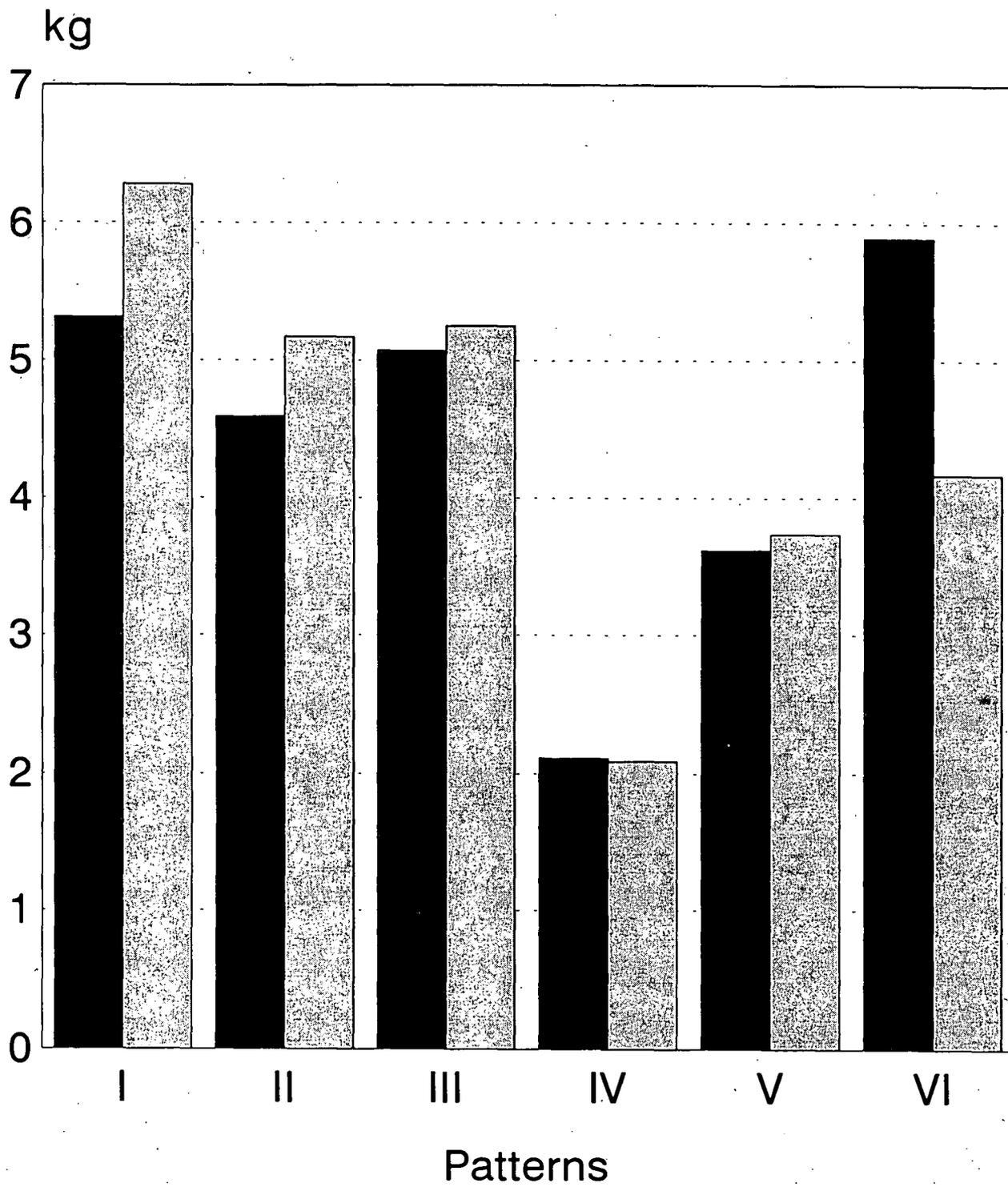


Figure 4. Mean feed intake across lactation for the 6 patterns observed on two farms.



■ A farm has peak d7 ▨ B farm has peak d13

Figure 5. Mean feed intake throughout lactation for the 6 patterns observed on two farms.

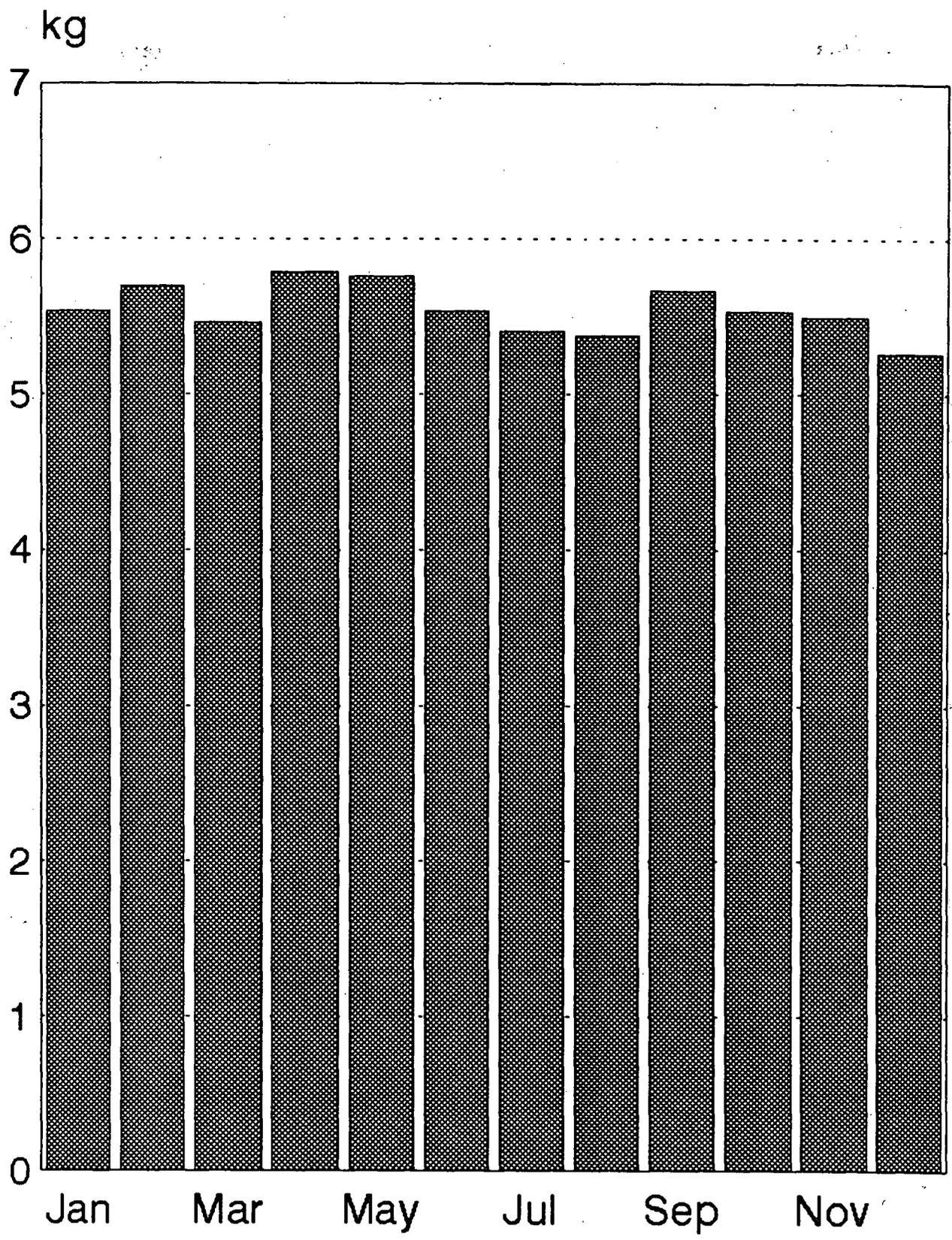


Figure 6. Mean lactational feed intake (SEM=.21).

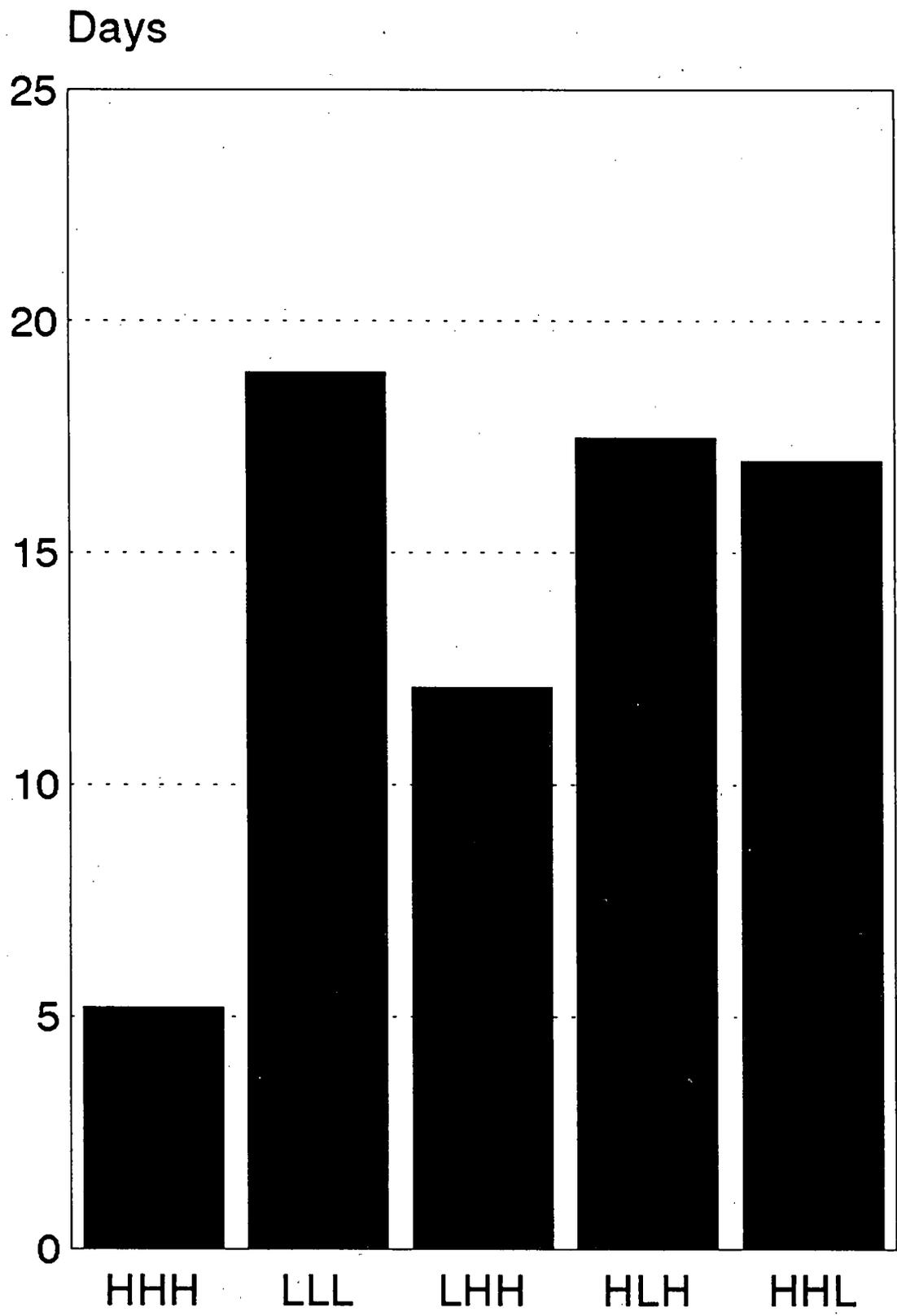


Figure 7. Weaning-to-estrus interval for sows fed according to one of the five different patterns.

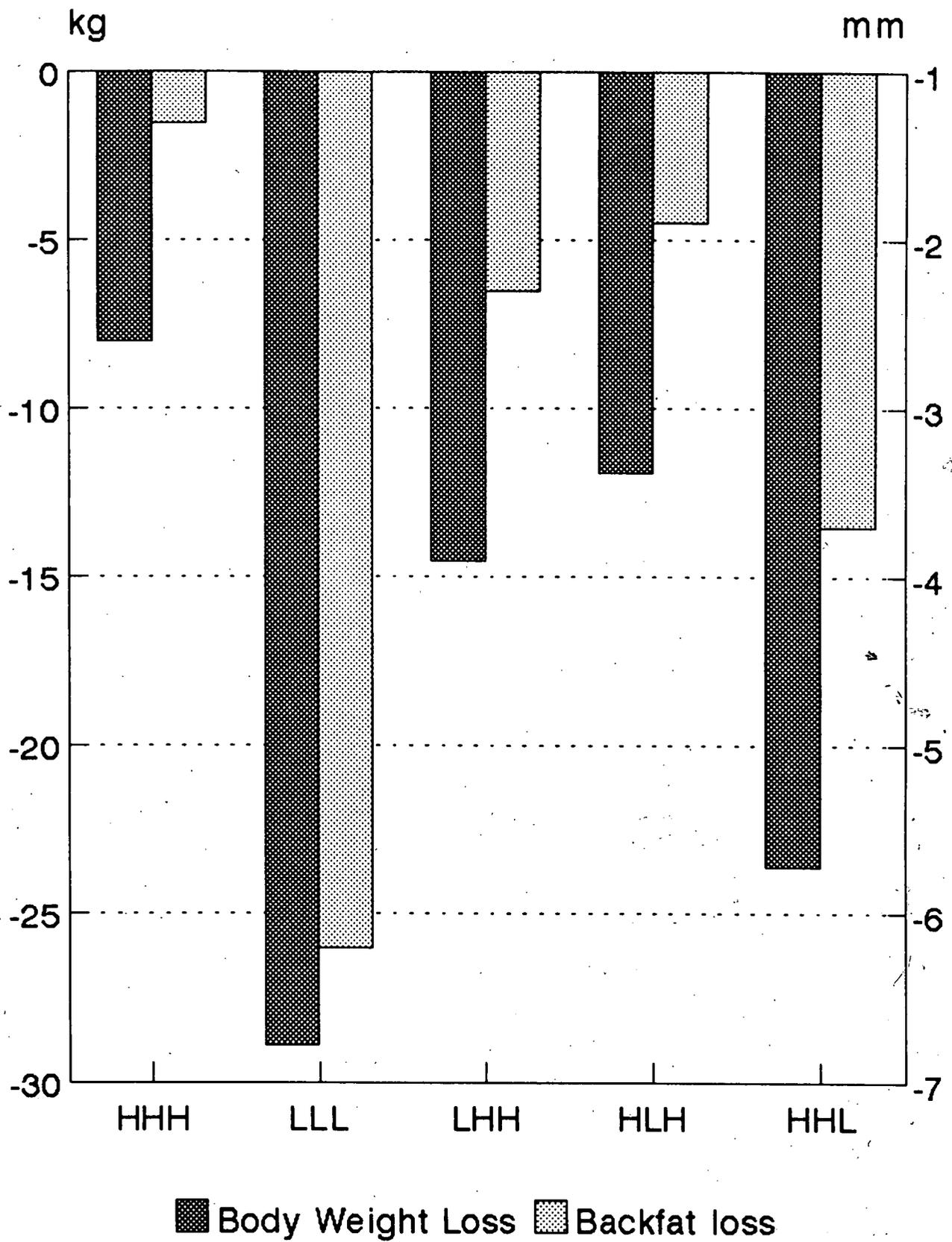


Figure 8. Changes in body weight and backfat during lactation in sows fed according to one of five different patterns.

A PRACTICAL EVALUATION OF STARTER DIETS IN MULTI-PHASE SWINE FEEDING PROGRAMS

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INTRODUCTION

The primary goal of a feeding program for starter pigs is to economically ease the transition from a liquid milk diet of the nursing period to a dry diet provided in the nursery phase of production. Throughout this transition, growth rate of the pig should be maintained near maximal levels. This is a formidable challenge for many swine producers when one considers that the nursing pig consumes a liquid milk diet containing about 35% fat, 32% lactose and 29% protein on a dry matter basis (Klobasa et al., 1987) and can grow at a rate in excess of 200 g/day (Schoenherr et al., 1989; Johnston et al., 1991). At weaning, the pig is switched abruptly to a dry diet that contains ingredients of lower digestibility compared with the diet provided by the sow. The nutritional, social, and environmental changes experienced by the young pig at weaning impose a variety of stresses that can reduce pig performance.

The swine industry is changing rapidly and adopting production practices that create new challenges for the nutrition and management of pigs in the nursery phase of production. The continually increasing intensity of production has dictated increased output from the breeding herd. Shortening the lactation period through early weaning is one way to increase pig production from the sow herd. Decreasing age at weaning from 56 days in the 1960's to 21 days or less in the 1990's requires radical changes in the formulation of diets for starter pigs. The central concern is that the digestive system of pigs weaned at very young ages (< 21 days) is not developed sufficiently to effectively utilize diets based on cereal grains and vegetable proteins. Therefore, the physiological capabilities of pigs weaned at young ages dictate a diet that is formulated much differently than diets for pigs weaned at older ages.

Medicated early weaning (MEW) is a new technology that appears to greatly reduce disease stressed encountered by pigs throughout the nursery phase and improve growth performance of pigs. With disease stresses markedly reduced, new peaks of pig performance may be achievable. Hodge (1974) reported growth rates over 500 g/d for pigs weaned at 3-4 days of age from a minimal disease herd. This report suggests young pigs have a potential for growth that is not realized in commercial production. Attempting to realize this growth potential creates new challenges for nutritionists who are asked to formulate diets for MEW pigs weaned at 5 to 15 days of age. Controlled studies of the nutritional needs of pigs managed in an MEW program are just beginning in major research universities in this country.

Current trends in the swine industry suggest that producers have adopted the practice of weaning pigs at a young age and have accepted the challenge of feeding and managing these young pigs throughout the nursery phase. In response to this challenge producers have constructed expensive nursery facilities that enable the strict environmental control necessary to satisfy temperature requirements of young pigs. Economic realities dictate that producers maximize pig flow through these facilities and reduce death loss so that fixed costs per pig can be minimized. Obviously, a properly designed and implemented nutritional program is necessary to maximize pig performance and reduce production costs.

Feeding programs have been radically changed to accommodate the nutritional needs of the young pig. Complex diets containing a high proportion of milk products, specially processed soybean products, and animal by-products have allowed nutritionists to more accurately tailor diet to the digestive capacity of

newly-weaned pigs. Researchers continue to search for new ingredients that may satisfy the biological needs of the pig and the economic constraints of the producer.

The adoption of phase feeding programs recognizes that the pig's digestive system continues to develop during the nursery period and that diets can be formulated to match the pig's digestive capabilities. Phase feeding programs provide an expensive diet containing a high proportion of high quality ingredients in the immediate postweaning period. High quality, expensive ingredients are gradually replaced with less expensive, lower quality ingredients that the pig can utilize as it matures. This approach seems to be a reasonable compromise between the pig's nutritional needs and the economic constraints swine producers face.

While phase feeding programs for nursery pigs make sense biologically, questions surface regarding economic considerations of feeding programs for starter pigs. For instance, how much can one afford to pay for diets that support maximal performance of starter pigs? Alternatively, is there a lower optimal level of performance that will return more profit to the producer? Should all farms be using similar feeding programs in the nursery phase of production to maximize profits?

In most scientific endeavors, there are more questions than there are answers. In this paper, we will try to address some of the questions raised above. Our primary goal is to provide an overview of recent developments in feeding programs for nursery pigs and to suggest how these developments may be implemented in practical swine feeding programs.

NUTRIENT REQUIREMENT CONCEPTS

EXPRESSION

Which is the correct way to express requirements of starting pigs for amino acids, minerals and vitamins - as amount per day or as concentration in the diet? The answer in this case (as in most others) is neither! However, perhaps surprisingly, in this case it is more nearly correct to express these requirements as concentration in the diet, as shown in a later paragraph.

This becomes a significant issue in starting pig nutrition, because there is massive variation in voluntary feed intake of starting pigs with variation in factors such as environment, facilities, weaning age and diet quality.

Roger Campbell (Campbell and Dunkin, 1983b) found that feed (energy) intake normally limits protein accretion in young pigs, (Table 1). The increment in protein accretion resulting from an increment of DE intake shows no sign of diminishing as intake reaches ad libitum, so it may be suspected that this relationship would extend to even higher intakes if they could be achieved. If feed intake is increased the potential protein accretion rate increases, and logically the amount of amino acids needed does also. Quantitative daily amino acid needs are directly related to energy intake. In fact, because the ratio of lysine needed per unit of growth to that needed for maintenance is higher than the corresponding ratio for energy, the appropriate lysine:energy ratio would appear to increase slightly as energy intake increases, and indirect empirical support for this logic is shown in Figure 1 (right side). In this case (Lepine et al., 1991) starting pigs fed a diet containing dried whey, versus one without, consumed more feed and also responded to higher dietary lysine concentrations. Overall, expression of lysine needs as a proportion of energy (or feed) is much more accurate over a wide range of feed intakes than is expression as a given number of grams per day. Certainly, when feed intake is low there is no reason to increase the lysine concentration in the diet to ensure intake of a target amount of lysine, because the limitation of energy will prevent the pig from using that lysine for protein accretion.

CHANGES WITH GROWTH (AGE)

Requirements for amino acids and other nutrients, expressed as concentration in the diet, usually decline with age (body weight) of the pig. There are at least two reasons for this decline: (1) The composition of the gain changes in the direction of more fat and less lean tissue; and (2) the growth rate as a proportion of metabolic body weight declines, causing the proportion of nutrients required for maintenance (high energy requirement) to increase. It is instructive to examine the relevance of these factors to starting pigs.

Table 1. Effect of Energy Intake on Rate of Protein Deposition in Pigs from 15 to 42 lb. Live Weight^a

Daily DE intake, MCal/kg ^{.75}	Protein deposition, g/day
0.24	37.5
0.32	50.9
0.39	62.2
0.48 ^b	78.6

^aFrom Campbell and Dunkin, 1983b.

^bAd libitum.

The more important factor in most cases is the change in composition of gain with increasing age/body weight. There are only limited data available on the change in composition of gain during the starting period, but these limited data suggest there is little change in composition during this growth phase. Calculations from the data from two studies of weekly changes in N retention of young pigs are shown in Table 2, expressed as g N retained/kg body weight gain, a measure of lean content of the gain. Fuller (1965) studied the effects of ambient temperature, but the data in Table 2 are restricted to those from 8 individual pigs in the best environments (68 or 77° F). Data were considered for 4 weeks during which the pigs grew from about 15 to about 45 lb. body weight. Cera et al. (1988) weaned pigs at 21 days of age and measured growth and nitrogen retention for four weeks. Diets contained 6% corn oil or no supplemental fat. The method of N balance is subject to error and in both studies there was variation from week to week, but there was no marked shift in composition of gain toward fatness (lower numbers) with time during this period. There is some indication that supplemental corn oil increased the fat content of the gain, but other data (Schenck et al., 1989) do not support this suggestion. Data from two Australian studies (Campbell and Dunkin, 1983a,b) are summarized in Table 3. They do not show a higher fat:protein ratio in the gain of pigs from 15 to 42 lb. than of younger pigs from 4 to 14 lb.

These comparisons suggest little if any shift in the composition of gain during the starting period. That suggests, in turn, little reduction in the amino acid requirement expressed per unit energy or as % of the diet.

Table 2. Nitrogen Retention (G) Per Kg Body Weight Gain

Treatments	68 or 77° F	0% Corn oil	6% Corn oil
Week 1	24.5	28.3	20.4
Week 2	27.3	38.4	27.6
Week 3	25.1	21.7	20.7
Week 4	23.8	45.6	34.6

Source: Fuller, 1965; Cera et al., 1988.

Table 3. Ratio of Fat To Protein In Gain of Young Pigs at Two Stages of Growth

Daily DE Intake, MCal/kg ^{.75}	Stage of growth	
	4 to 14 lb. ^a	15 to 42 lb. ^b
0.17 ^c	0.28	--
0.24	--	0.43
0.27 ^c	0.66	--
0.32	--	0.69
0.34 ^c	0.88	--
0.39	--	0.90
0.43 ^c	1.09	--
0.48	--	1.02

^aFrom Campbell and Dunkin, 1983a.

^bFrom Campbell and Dunkin, 1983b.

^cEstimated.

The second factor, the change in proportion of each nutrient going to maintenance, may not apply to the starting pig. Some data (e.g. Lepine et al., 1991) would suggest that the growth rate relative to metabolic body weight does not decline during this period. It would seem unlikely for this factor to justify the magnitude of reduction in dietary lysine percentage often recommended.

These logical arguments are supported by recent data from Lepine et al. (1991), shown in Figure 1, demonstrating that pigs may actually respond to higher dietary lysine concentrations when older and growing faster than when younger and growing more slowly.

There are two other practical factors that individual feed manufacturers or pork producers may want to consider relative to lysine concentrations. First, a slight change in lysine concentration in an expensive complex diet fed immediately after weaning would have a nearly insignificant proportional effect on the diet cost, so it may be prudent to use a high level in order to ensure maximum feed efficiency. Second, and conversely, a moderate amino acid restriction during the starting period is partially counteracted by compensatory growth during subsequent growth (Pettigrew and Stairs, 1991).

PHASE FEEDING

CONCEPTS

The pig is physiologically immature when weaned. Limiting physiological functions include digestion (including digestive enzyme secretion) and immune response, as shown in Figure 2. This immaturity of the weanling pig limits its ability to perform well on a simple corn-soy diet. That fact has led to the use of other ingredients, including milk and blood products, in starter diets. The pig matures rapidly during the 4- to 6-week starting period (Figure 2), so that with time an increasing proportion of the diet can be corn and soybean meal without compromising growth performance. Because of this rapid maturation, the starting period should be separated into phases with appropriate diets used for each phase. We recommend the use of a 3-phase program, roughly as introduced by Nelssen (1986). This program divides the starting period into Phase I, from weaning at about 21 days to 15 lb. body weight; Phase II, from 15 to 25 lb.; and Phase III, from 25 lb. to removal from the nursery at about 50 lb.

Increasing interest in medicated early weaning (MEW) to improve pig health has created a need for appropriate diets for pigs weaned as early as 10 days of age. Such diets would be fed before the Phase I diet, and would be even more complex.

DIETARY RECOMMENDATIONS BY PHASE

Our recommendations are described in general terms below, and in more detail in Table 4.

MEW diet

This diet should be fed to weaned pigs until they weigh 10 lb. It should contain only limited amounts of corn (raw starch) and soybean meal. It should contain large amounts of other ingredients, such as dry skim milk, dried whey and spray-dried porcine plasma. Fat should be added only to facilitate pelleting, up to 5% depending upon the ingredients. We suggest higher amino acid levels than are probably needed, because the small cost of raising these levels is unimportant in this very expensive diet, and these high levels will ensure feed efficiency and growth rate are not limited by amino acid supply. Recommendations concerning this diet are based almost entirely on our perceptions of the pig's physiological capabilities, because there is a dearth of supporting data.

Phase I diet

The Phase I diet can contain only slightly more corn and soybean meal than the MEW diet, and again we suggest high amino acid levels as insurance. It should be fed until pigs are 15 lb. If weaning occurs at 4 weeks of age, a Phase I diet is not needed.

Phase II diet

The Phase II diet should be fed until pigs reach 25 lb. It should contain ingredients such as dried whey, or spray-dried porcine blood meal, but need not contain the most expensive ingredients. If dried whey is used, about 3% fat should be added to prevent amino acid damage during pelleting. The cost of raising amino acid concentrations in this diet is significant, so we suggest target levels near the estimated requirements (see below).

Phase III diet

This diet, to be fed from 25 to about 50 lb., can be a simple one based on only corn and soybean meal. The appropriate lysine concentration depends on several factors including fat level (Lin and Jensen, 1985a,b; Schenck et al., 1988a,b; Tanner and Hitchcock, 1988; Brendemuhl and Harrison, 1990; Libal et al., 1990), ingredient selection (Libal et al., 1990; Lepine et al., 1991), and environmental temperature (Schenck et al., 1988a,b) but we suggest a lysine concentration of about 1.25% for general use, which appears to be a reasonable central value from variable recent results (Rogerson and Campbell, 1982; Aherne and Nielsen, 1983; Pollman et al., 1983a,b; Pollman et al., 1984; Lin and Jensen, 1985a,b; Thaler et al., 1986; Easter et al., 1988; Goodband et al., 1988; Martinez and Knabe, 1988; Schenck et al., 1988a,b; Danielsen et al., 1989; Brendemuhl and Harrison, 1990; Libal et al., 1990; Lepine et al., 1991). Other suggested amino acid concentrations are based on the ideal protein pattern of Wang and Fuller (1989). The ideal protein pattern should vary with variation in growth rate, but this approach will suffice until more detailed information is available.

NUTRITIONAL VALUE AND APPLICATION OF FEED INGREDIENTS

The objective for this section of the paper is to provide an overview of the research and evaluation of several feed ingredients (mainly protein/carbohydrate sources) used in feeding programs for early weaned pigs.

Table 4. Suggested Diet Composition For a 3-Phase Starter Program^a

Phase	MEW	Phase I	Phase II	Phase III
Weight range	To 11 lb.	11 to 15 lb.	15 to 25 lb.	25 to 50 lb.
Nutrients	% of diet			
Lysine	1.50	1.50	1.25	1.25
Methionine + cystine	.95	.95	.79	.79
Tryptophan	.27	.27	.23	.23
Threonine	1.08	1.08	.90	.90
Ingredients	% of diet			
Spray-dried porcine plasma	5-15	5-10	--	--
Spray-dried blood meal	--	--	5-10	--
Dry skim milk	20-30	10-20	--	--
Dried whey	15-30	10-20	10-20	0-10
Fish meal	--	--	0-5	--
Special soy products ^b	--	--	0-20	--

^aFor use in intensive pork production systems.

^bSoy protein concentrate, extruded soy protein concentrate, or isolated soy protein.

MILK PRODUCTS: DRIED WHEY AND DRIED SKIM MILK

Dried whey (DW) and dried skim milk (DSM) are by-products of the cheese and milk industry. Both products contain high lactose (milk sugar) levels and milk protein components (lactalbumin and lactoglobulin). DW contains about 70% lactose, whereas DSM contains 50%. DSM contains over twice as much crude protein as DW (33% vs. 13%) and is considerably more expensive. When researchers at different locations have evaluated DW in starter trials, variation in growth response exists (Mahan, 1984; Bertram and Schoenherr, 1990). DW sources do differ in quality (and possible feeding value), stemming mainly from the variation in manufacturing techniques used. Only high quality DW sources (Edible grade or top feed grade) are recommended for early weaned pigs.

Research has consistently shown that the addition of milk products to corn-soybean meal starter diets will improve performance of pigs between 3-5 weeks of age, or until they weigh about 25 pounds. Providing milk products after this point is generally not warranted. Improvements in performance of early-weaned pigs fed diets containing milk products apparently are due to the ability of the young pig to utilize the carbohydrate and protein fractions from milk more effectively than those components from plant feed ingredients. Tokach et al. (1989a) reported that improved performance noted in 3-week-old pigs fed a diet

containing DW probably is the result of both the carbohydrate (lactose) and protein (lactalbumin) fractions. However, when both fractions were present in the diet, no additive effects were noted. Giesting et al. (1985) showed that lactose promoted a greater daily gain and feed intake response than did other carbohydrate sources, whereas casein improved feed utilization over soy proteins sources. Other researchers (Mahan 1991, 1992; Coffey et al., 1990) have demonstrated that the lactose component is the primary cause of improved gain and feed intake responses when milk products are added to starter diets compared to plant proteins and carbohydrates. Turlington et al. (1989) also reported that lactose and casein will improve nutrient digestibility and slow digesta flow rate as compared to dextrose and soybean meal in diets for 21 to 35 day old pigs.

The literature clearly states that the addition of milk products to corn-soybean meal starter diets will improve performance of early weaned pigs. The suggested mode of action is probably an improvement in feed acceptance (intake) and/or an increase in nutrient digestibility, possibly due to slower digesta flow. Even so, the high cost of milk products prohibits their use in starter diets for pigs beyond 5-6 weeks of age and has stimulated researchers to seek satisfactory replacements, especially for DSM during Phase I, that will provide similar or better performance.

FISH MEAL

Fish meal appears to be well suited for the weanling pig. It is generally readily accepted and has proven to be a highly digestible protein source. The quality of meal (as influenced by freshness of raw material and method of heat processing) may affect its nutritional value, and thus growth response (Stoner et al., 1989).

An earlier report (Bayley and Holmer, 1972) showed that solvent extracted fish meal plus DW could replace DSM in the diet for 10-day-old pigs without affecting performance. Other, more recent, studies indicate that fish meal (Menhaden) or fish protein hydrolysate, fed alone or in combination with DW in a corn-soybean meal diet, will support excellent growth performance in weanling pigs (Stoner et al., 1985; Stoner et al., 1986; Gore et al., 1989).

The potential for replacing DSM with select Menhaden fish meal (SMFM) in a complex, high nutrient density diet was evaluated by Stoner et al. (1988). They reported that SMFM can be used in combination with DW to completely replace DSM, or SMFM can be used to replace 50% of the DSM without affecting growth performance of pigs weaned at 21 d of age. They also noted that a minimum lactose level in the diet was necessary to sustain growth comparable to that of the high nutrient density diet. When lactose level was 14%, growth performance was significantly less than when lactose level was 19-24%.

If fish meal is to be used to replace milk products (namely DSM) in starter diets, consideration should be given to quality of the meal and lactose content of the diet.

SOY PROTEIN SOURCES

Delayed Transient Hypersensitivity Response

Researchers have shown that certain feed ingredients contribute to a lag in postweaning performance and possibly diarrhea. Several studies indicate that early weaned pigs fed diets containing traditional soybean products have a transient hypersensitivity response (allergy) to soybean proteins (Newby et al., 1984; Giesting et al., 1986; Li et al., 1990; Li et al., 1991; Friesen et al., 1991). Baby pigs, while still nursing the sow, can be exposed (sensitized) to soybean proteins if they consume sow feed or creep feed containing soybean meal. Once the pig has been sensitized to soybean proteins, antibodies specific to

these proteins are produced by the pig to protect against future invasions of soy protein in the small intestine. This response appears to be caused by soy protein antigens (glycinin and beta-conglycinin) found in soybeans. Consequently, when pigs are weaned and placed on a starter diet that contains various amounts of soybean meal, the antibodies specific to soy antigens mount an immune response at the intestinal level of the pig. Damage to the microvilli lining, reducing the absorptive capacity of intestinal tissues, is generally the result of this immune response.

Li et al. (1990) reported that challenging 21-day-old weaned pigs with soybean meal, following oral infusion of soybean meal during a period from 7 to 14 days of age, resulted in villous atrophy and decidedly lowered growth rate (.19 vs. .45 lb/d) by 28 days of age. However, growth performance was only temporarily decreased because by 56 days of age no difference in overall growth rate existed. In another study, Li et al. (1991) orally infused pigs with 6 g/d of either DSM or various soy protein sources from 7-11 days of age and then fed a diet containing the corresponding protein source from weaning (d 21) to 35 days of age. Sows were fed a corn-corn gluten meal diet from d 109 of pregnancy throughout lactation to avoid exposure of pigs to soybean proteins. All pigs were fed a corn-soybean meal diet containing 10% DW, 1.25% lysine and 3% soy oil for the remaining 21 days of the experiment. Results for the period from d 0-14 postweaning indicate that pigs fed diets containing soybean meal had lower daily gains, daily feed intake and poorer feed/gain than pigs fed the diet containing milk products (Table 5). They also had lower villus height, higher serum anti-soy IgG titers and increased skin-fold thickness compared to pigs on the DSM treatment. Pigs fed other soy proteins also had lower growth rates (0-14 d postweaning) compared to those fed milk proteins. However, pigs fed the moist-extruded soy protein concentrate tended to have higher gains and improved feed utilization compared to those fed soybean meal or other soybean products, indicating that further processing of soybean products may lower their antigenic properties. Consistent with their earlier study, these researchers found no significant differences in growth performance and feed utilization among treatments from d 14 to 35 days postweaning.

At some point, a pig must develop a tolerance to soy proteins. A recent study by Friesen et al. (1991) points out that pigs cannot be fed diets devoid of soy protein during Phase I without experiencing decreased growth performance during Phase II. Whether pigs in this study were first exposed to soy protein early in Phase I or in Phase II, the magnitude of the delayed transient hypersensitivity response (ie. reduced growth performance) was similar for pigs in both phases. In fact, the overall growth performance (d 0 to 35 postweaning) was slightly poorer in pigs fed a milk diet during the Phase I period.

It seems apparent that pigs have the ability to develop a tolerance to soy protein within 2 wk postweaning and should be exposed to soy protein as early as possible. European researchers have indicated that approximately 600 g of creep feed is required to develop a tolerance to soy protein prior to weaning (English et al., 1980). However, the amount of soybean meal (or other soy products) needed to develop soy tolerance in the early weaned pig that has not received creep feed prior to weaning has not been determined and warrants further research.

Specially Processed Soy Products

Processing method may be a major factor influencing soybean utilization by the early weaned pig (Li et al., 1989). Three specially processed soy products with potential for replacing milk products in starter diets have been investigated. They are soy protein isolate (SPI), soy protein concentrate (SPC), and modified soy flour (MSF). Soy protein isolate is produced by using precipitation techniques to separate the large storage proteins of defatted soy flakes from the soluble and insoluble carbohydrates, lipids and smaller proteins (including trypsin inhibitors). This provides a high quality soy product that is approximately 90% crude protein. Soy protein concentrate is produced by extracting the soluble carbohydrates from the defatted soy flakes, resulting in a product containing about 70% crude protein

(Table 6). Modified soy flour (contains about 55% CP) is produced by fine grinding dehulled soybean meal and then further processing it by toasting or extrusion.

Table 5. Effect of Different Soybean Products on Starter Pig Performance^a

Criteria	Treatment				
	Milk protein	Soybean meal	Soy protein concn.	Extruded soy prot. concn.	Exper. soy prot. concn.
ADG, lb					
d 0 - 14	.72 ^b	.40 ^c	.46 ^c	.50 ^c	.46 ^c
d 14 - 35	.98	1.18	1.15	1.12	1.16
d 0 - 35	.87	.86	.87	.89	.87
ADFI, lb					
d 0 - 14	.66 ^b	.55 ^c	.51 ^c	.53 ^c	.55 ^c
d 14 - 35	1.72	1.91	1.86	1.74	1.84
d 0 - 35	1.29	1.33	1.50	1.31	1.29
F/G					
d 0 - 14	.99 ^b	1.38 ^c	1.14 ^c	1.07 ^b	1.18 ^c
d 14 - 35	1.77	1.65	1.63	1.58	1.65
d 0 - 35	1.50	1.57	1.72	1.47	1.52
Anti-Soy IgG titers (Log ₂ , ELISA)					
D 7 pre-weaning	3.05	3.10	2.91	2.96	2.99
D 6 post-weaning	3.12 ^c	5.16 ^b	2.94 ^c	3.14 ^c	3.26 ^c
Villus height, um ^c	364 ^b	234 ^d	309 ^c	319 ^c	280 ^c
Crypt depth, um ^c	198 ^c	222 ^b	215 ^c	196 ^c	190 ^c

^aFive pigs per pen, five replications per treatment, avg initial age of 21 d.

^bMeans same row with different superscript differ (P<.05);
^{bcd}(P<.01)

^c6 days postweaning

Table 6. Amino Acid Profile of Protein Sources Used in Pig Starter Diets (Expressed as Percent of Protein)

Item	Soybean meal ^a	Spray-dried porcine plasma ^b	Skim milk ^a	Soy protein concn. ^b	Soy protein isolate ^a
Crude protein	48.00	70.00	33.30	66.00	86.00
Lysine	6.43	8.71	7.63	6.38	6.20
Methionine	1.46	.76	2.70	1.40	1.50
Cystine	1.44	3.20	1.35	1.40	1.50
Tryptophan	1.42	1.90	1.29	1.40	1.00
Threonine	3.92	5.90	4.71	4.20	4.00
Isoleucine	4.39	2.80	6.55	4.65	4.90
Valine	5.09	5.89	6.88	5.00	5.30
Leucine	7.48	7.94	9.91	7.90	8.30
Phenylalanine	4.87	5.29	4.71	5.10	5.00
Tyrosine	3.53	5.00	3.42	3.90	3.60
Arginine	7.57	6.84	3.48	7.68	7.70
Histidine	2.47	3.57	2.58	2.75	2.50

^aAmino acid values are from National Research Council. *Nutrient Requirements of Swine (1988)*.

^bTypical analysis as suggested by manufacturer.

During the early postweaning period, specially processed soy products are better utilized by pigs than soybean meal (Jones et al., 1989, 1990a, 1990b; Sohn et al., 1990) and result in lower antisozytiter (Jones et al., 1990a). Of the soy products, SPI and SPC appear to have greater nutritional value in simple diets, whereas in more complex diets feeding value is comparable (Stahly et al., 1983; Jones et al., 1990a). In a few cases, SPI and SPC have effectively replaced milk products from d 0-14 post weaning (Jones et al., 1989; Sohn et al., 1990). However, when SPI, SPC, and MSF were all evaluated in the same studies to replace protein from DSM during a 7 d or 14 d period postweaning, the nutritional value of the processed soy product was found to be lower than that of DSM (Jones et al., 1990a, 1990b). Even so, the pigs fed soy products vs. milk products from d 0-14 performed as well, or better, from d 14-35. Recently, Friesen et al. (1991) reported that protein utilization in starter diets was improved with moist extrusion. Though only a small response to extrusion was noted in higher processed soy products, a 20% improvement in growth performance resulted when soy flakes were processed by moist extrusion. This probably indicates greater deactivation of growth inhibitors or favorable structural changes to soybean proteins.

The nutritional value of soy products is usually improved as the processing technique becomes more elaborate (SPI>SPC>MSF), but cost will increase as well. Moist extrusion may further improve their feeding value. Also, processed soy products will out perform soybean meal but not milk products when fed for a 2 wk period following early weaning.

SPRAY-DRIED BLOOD PRODUCTS

Probably no other feed ingredients have created more excitement in the area of early-weaned pig nutrition than the by-products of blood obtained from pork slaughter plants, namely, spray-dried porcine plasma (SDPP, also referred to as plasma protein) and spray-dried blood meal (SDBM). The blood is collected into refrigerated tanks and prevented from coagulating by addition of sodium citrate. Centrifugation is then used to separate the plasma fraction from the blood cells. The plasma fraction is then stored at 25° F until it is ready for the spray drying process. This process consists of 1) preheating for 25 min. at 90° F, 2) spray drying for 1 to 2 min. at 405° F, and 3) evaporation of moisture for 1 to 2 min. at 200° F. This results in a fine-grained, light tan-colored powder that contains about 70% crude protein. This protein consists of the albumin, globin, and globulin fractions of blood. SDPP is presently used in the food industry as a supplement for cereal protein in bakery products, and as an emulsifying agent for meat products and pet foods.

SDBM is produced similarly to SDPP, but differs in that it contains the plasma along with the red blood cell fractions of the blood. Keep in mind that SDBM differs greatly from the more traditional vat- or flash-dried blood meals in that spray drying does not expose the product to the high temperatures that can denature proteins. A recent Kansas State study (Nelssen, 1992) showed a clear advantage in growth rate and feed/gain for 21 d old pigs fed spray-dried blood meal products versus flash-dried blood meal.

Blood Products vs. Other Protein Sources

Recently the influence of blood products in starter diets has received considerable attention. Since immunoglobulins are a component of blood plasma, Zimmerman (1987) initially evaluated SDPP for its potential to provide functional antibodies to the early weaned pig, but concluded little, or no, protection was given. In a follow-up study, Gatnau and Zimmerman (1990a) reported that SDPP improved growth performance of pigs when compared to soybean protein fed d 0-14 postweaning, and resulted in equal, or greater, performance compared to milk protein. Several other studies have also shown SDPP to improve feed intake and growth performance (d 0-14) compared to DSM or other protein sources (Gatnau and Zimmerman, 1990b; Hansen et al., 1990; Hansen et al., 1991; Kats et al., 1992; Sohn et al., 1991).

The consistency of finding an increase in feed intake suggests that SDPP is more palatable to the pig than other protein sources studied, and seems to act through stimulation of intake early in the feeding period. When Nebraska researchers (Ermer et al., 1992) allowed pigs to choose between a SDPP and DSM diet over a 21 d preference study, a clear choice for the SDPP diet was seen. The preference for the SDPP diet also increased with time, corresponding to 60% of the total intake on d 2 and 84% on d 20.

Blood products, other than SDPP, have also been evaluated in starter diets. Hansen et al. (1991) compared porcine SDBM, spray-dried bovine plasma (SDBP) and extracted meat protein, as well as SDPP, to DSM in starter diets fed d 0-14 postweaning. Their results showed again that SDPP maximized growth performance in Phase I compared to all other protein sources tested. In fact, pigs fed SDPP had 25% and 28% higher daily gain and feed intake, respectively, than those fed DSM. Moreover, there were no growth performance differences observed between pigs fed DSM, SDBM, or SDBP, suggesting that these blood products could also serve as satisfactory milk protein replacements (Table 7). Extracted meat protein, however, was not a suitable substitute. All blood products were substituted on an equal lysine basis (1.4% total dietary lysine) for DSM and diets were equal in lactose level. When pigs were fed a common diet (1.25% lysine, C-SBM-10%DW-4% fish meal) during Phase II (d 14-35), there was a propensity for pigs consuming SDBM during Phase I to have higher daily feed intake and growth rate. This suggests a possible protein source interaction between the two phases. However, Kats et al. (1992) reported no interactions between protein sources fed during Phase I and II, thereby concluding that growth responses attributed to each phase are additive.

Gatnau and Zimmerman (1990b) compared SDPP (10% inclusion rate) to a combination of SDPP (5%) and SDBM (3.75%) or to SDBM alone (7.5%) in diets for pigs weighing 15.4 lb. The blood products were substituted for corn and SBM and final diets were nearly equal in protein, lysine and methionine levels. All diets contained 20% DW. Their results showed that pigs fed SDPP or the combination of SDPP-BM grew significantly ($p < .05$) faster and more efficiently over the first 2 wk of the trial than pigs fed the SDBM diet. Feed intake was significantly higher and daily gain tended to be improved for pigs fed SDPP versus the combination treatment.

Considering the cost for SDPP is 3-4 times that for SDBM, feeding a combination of the two blood products in Phase I may be the most economical strategy. More research is needed to determine the minimum amount of SDPP needed in combination with SDBM to provide optimum growth performance.

Table 7. Effect of Protein Source on Pig Performance*

Item	Skim Milk	Porcine Plasma	Bovine Plasma	Porcine Blood	Meat Extract
Week 1					
(0 to 7d)					
ADG, lb	.71 ^{cd}	.79 ^c	.69 ^{cd}	.63 ^d	.49 ^a
ADFI, lb	.68 ^{cd}	.83 ^c	.72 ^{cd}	.65 ^d	.64 ^d
Feed/gain	.96 ^c	1.05 ^c	1.04 ^c	1.02 ^c	1.30 ^d
Phase I					
(0 to 14d)					
ADG, lb	.72 ^c	.83 ^d	.72 ^c	.75 ^{cd}	.58 ^b
ADFI, lb	.86 ^c	1.10 ^d	.93 ^c	.89 ^c	.80 ^c
Feed/gain	1.19 ^c	1.32 ^{cd}	1.29 ^{cd}	1.19 ^c	1.56 ^d
Phase II					
14 to 35d)					
ADG, lb	1.08	1.06	1.14	1.22	1.12
ADFI, lb	1.88 ^c	1.86 ^c	1.98 ^c	2.21 ^d	1.96 ^c
Feed/gain	1.75	1.75	1.74	1.81	1.74
Overall					
(0 to 35d)					
ADG, lb	.94 ^{cd}	.97 ^{cd}	.97 ^{cd}	1.03 ^c	.91 ^d
ADFI, lb	1.47 ^c	1.55 ^{cd}	1.56 ^{cd}	1.68 ^d	1.53 ^{cd}
Feed/gain	1.58	1.60	1.61	1.63	1.70

*Hansen, et al., 1991. Values are means of six replicate pens containing five pigs each (initially 11.7 lb; 35 d trial).

^{cd}Means in the same row with different superscripts are different ($P < .05$)

Optimum SDPP Level for Phase I

Recent studies were conducted at Iowa State (Gatnau and Zimmerman, 1990c; 1992) to determine the minimum level of SDPP needed in starter diets to optimize growth performance. Varying levels (0, 2, 4, 6, 8, 10%) of SDPP were added to a C-SBM-20%DW basal diet to form the experimental treatments. Corn and SBM were adjusted to maintain equal lysine and energy concentrations in the diets. Their results suggest a level of 6-8% SDPP is optimum during the initial 2 wk feeding period following 4 wk weaning. They also noted reduced growth performance when SDPP was added at levels above the optimum. Calculated methionine levels in the diets ranged from .32% (0-SDPP) to .26% (10% SDPP). Slightly higher levels of SDPP may be required, along with synthetic methionine supplementation, to optimize performance of pigs weaned at 14-21 days.

Comparing Protein Sources in Phase II

It appears from several reports that SDPP is superior to other protein sources for maximizing growth performance during Phase I. To date, considerably less attention has been directed toward optimum formulation of Phase II diets. Tokach et al. (1991), in a recent study, compared several protein sources in the Phase II diet (7-28 d postweaning), and also observed their effect on performance during the subsequent grower period (28-56 d). During Phase I (0-7 d; pigs weaned at 21 d), all pigs received a common complex, high nutrient density diet containing 1.5% lysine, 10% SDPP, 10% lactose and 20% DW. All Phase II diets were formulated to contain 1.18% lysine and 10% DW. Six dietary treatments were fed: 1) a positive control, 4% Menhaden fish meal (FISH), 2) a negative control, synthetic amino acids replaced fish meal to form an ideal protein (AA), along with 3) SDPP, 4) SDBM, 5) SPC, and 6) extruded SPC (ESPC); all replacing fish meal on a lysine basis. During the subsequent growth phase all pigs received a 1.1% lysine, milo-SBM diet. They reported similar growth response when SPC and ESPC were substituted for fish meal, indicating both soy protein sources can effectively replace fish meal in the Phase II diet. However, pigs fed the spray-dried blood products (SDPP and SDBM) grew significantly faster ($P < .06$) than those fed the other four diets (Table 8). They also observed that pigs fed the SDBM diet (but not SDPP) in Phase II grew significantly faster ($P < .03$) during the following 28-56 grower phase.

More research on Phase II feeding programs is necessary. The information we have to date does support a method of staging starter diets to maximize performance in both phases and suggests that diets should include SDPP in Phase I followed by SDBM in Phase II.

Feeding Concerns With Blood Products

The amino acid composition of starter diets containing blood products will differ from that of traditional corn-SBM diets. SDPP is lower in methionine and SDBM is lower in both methionine and isoleucine than many other protein sources. Consequently, lysine is often not the first limiting amino acid in diets containing blood products. Instead, methionine and/or isoleucine will usually be first limiting. Depending on age of the pig and degree of blood product inclusion in the diet, it often is necessary to supplement with additional methionine.

Also, starter diets that are fed in meal form may pose a major flowability problem if they contain blood products (especially in combination with dried milk products). Blood products are very fine-grained (like powder) and tend to be sticky or hygroscopic. Therefore, extra attention to feeder management is required to ensure feed is available to pigs.

Table 8. Influence of Phase II Protein Source on Pig Performance^a

Item	Phase II Dietary Treatment ^b					
	AA	FISH	SDPP	SDBM	SPC	ESPC
Days 7-28						
ADG, lb ^c	.87	.87	.94	.92	.87	.89
ADFI, lb	1.39	1.32	1.41	1.40	1.35	1.36
F/G ^d	1.61	1.52	1.51	1.53	1.56	1.53
Days 28-56						
ADG, lb ^e	1.21	1.20	1.23	1.33	1.25	1.22
Pig wt, lb						
Day 28 ^e	36.3	36.4	37.8	37.4	36.3	36.8
Day 56 ^e	70.1	70.3	72.4	74.7	71.3	71.0

^aTokach et al., 1991.

^bPhase II protein source.

^cBlood products vs others (P<.06).

^dAmino Acids (AA) vs other (P<.02).

^eSDBM vs others (P<.03).

SUPPLEMENTAL FAT

A series of Ohio State studies relating to fat utilization by the weanling pig were reported by Mahan and Cera (1991). A summary of their results from several of the trials reported in this reference are as follows:

- Production of lipase by the newly weaned pig is insufficient to effectively digest dietary fat, thus animal or vegetable lipid utilization appears to be limited during the early postweaning period.
- Lipase production does increase with age; consequently digestibility of added fat sources to the diet improves with age postweaning.
- Young pigs utilize vegetable oils better than animal lipids and coconut oil has the highest digestibility of the vegetable fats evaluated. Feeding refined vegetable oils may be an economical alternative to coconut oil.
- Fat digestibility differences between vegetable and animal fat sources narrow with age.
- In the first 2 wk postweaning, no daily gain response or reduction in feed intake occurs with fat additions to the diet. However, there is an improved gain and feed efficiency response to a 6% fat level addition from 2-5 wk postweaning.

Minnesota studies (Tokach et al., 1989b, 1990a,) revealed essentially identical growth responses to fat additions found in the Ohio State experiments, both in early (wk 1-2) and late (from 2-5 wk) in the postweaning period (even with milk products present in the diet).

A high level of supplemental fat in starter diets seems inappropriate. A moderate fat addition (5-6%) to starter diets reduces the amount of dust in the building and, in the case of diets containing milk products, may reduce heat damage to proteins during pelleting. Also, when fat is added, nutrient levels in the diet should be adjusted upward to compensate for lowered daily feed intake that will likely occur after the first week or two following early weaning.

EFFECT OF NURSERY DIET ON SUBSEQUENT PERFORMANCE

For years the swine industry has questioned the cost-effectiveness of improved, complex starter feeding programs. Will Phase I starter diets that include very expensive feed ingredients of high nutritional value result in favorable growth response during the subsequent growing-finishing (G-F) phase?

The majority of studies conducted on the subsequent performance effects of starter pig nutrition and performance have related performance during week 1 postweaning with the number of days required to reach a common market weight. The study providing actual subsequent performance effects and representing the largest number of pigs (1350), is based on pig gains during the first week postweaning (Tokach, 1992; Table 9). A 7.7 lb weight advantage at the end of the nursery phase (28 days postweaning) resulted in a 10 day reduction in days to market. Furthermore, based on these data, it appears that for about every 1 lb advantage in pig weight at the end of the first week after weaning, there results an approximately 2.2 lb advantage at 28 days postweaning (49 days of age), a 2.9 lb advantage by 56 days postweaning (77 days of age), a 5.0 lb advantage by 156 days postweaning (177 days of age), and a reduction of about 2.9 days to market.

Less dramatic results were obtained in a study (Seerley and Mabry, 1989) involving a limited number of pigs (122), where each 1 lb advantage at the end of the first week postweaning resulted in 1.7 fewer days to market (Table 10).

Table 9. Influence of Daily Gain During the First Week Postweaning on Subsequent Growth Performance

ADG Week 1	Weight (lb) on Day Postweaning			Days to Market
	28	56	156	
< 0	32.4	66.3	232.2	183.3
0 - .33	35.3	70.2	238.4	179.2
.33 - .50	37.3	71.6	245.1	175.2
> .50	40.1	76.6	249.8	173.0

Tokach (1992). Based on 1350 pigs averaging 13.6 lbs at weaning and weaned at 21 days of age.

Table 10. Postweaning Performance of Pigs Fed Three Different Starter Feeding Programs.

	Type of Nursery Diet		
	Day 0-7 Day 8-21	Simple Simple	Milk Pellet Simple
Nursery period			
No. of pigs	41	40	42
Initial weight, lb	15.3	15.4	15.4
Weight on day 7, lba	17.3	21.1	21.4
Weight on day 21, lba	27.0	30.5	35.2
Growing-finishing period			
No. of pigs	27	26	30
Final weight, lb	220	228	228
Days to 230, lb	171	166	164

Seerly and Mabry (1989). Based on 122 pigs used in 7 replicates.

Results consistent with the previous studies have been obtained at the University of Minnesota (Tokach et al., 1990b). In this study, pigs fed complex starter diets responded with substantially improved daily gain and feed efficiency in Phase I. Consequently, pigs fed the complex diets were 3.3 lb heavier at 56 days than those fed simple diets. Compensatory gain did not occur during the G-F phase. Pigs fed the complex diet for the initial 2 wk postweaning were 9 lb heavier at 180 days of age, indicating that the weight gain advantage due to feeding the complex diets during the early nursery phase was maintained, or increased, to market weight. In this study a 1 lb weight advantage for pigs leaving the nursery at 35 days postweaning resulted in a range of between 0.7 to 3 fewer days to reach market weight. Other researchers have also compared complex vs. simple starter diets and have reported a nursery phase growth advantage with resulting pig weight differences being maintained during the G-F period (Stairs et al., 1991; Pollmann et al., 1992).

The magnitude of the maintained growth performance differences in the above studies will vary to some degree but, on the average, suggest that for every 1 lb increase in nursery pig weight there will be a 2 to 3-day reduction in days to market weight. Nutrition and management programs in the grower-finisher phase can vary substantially between commercial operations and can have a significant impact on the magnitude of reduction in days to market based on feeding programs used in the nursery. Nevertheless, these studies consistently show that performance and weight advantages obtained during the starter phase are at least maintained, and usually magnified by the time pigs reach market weight.

It is important to differentiate between subsequent growth performance following nutrient restriction and being fed a simple corn-soybean meal starter diet (Pettigrew and Stairs, 1991). It appears that pigs will at least partially compensate for a moderate nutrient restriction during the starter phase by enhanced gain and/or feed efficiency when subsequently given a nutrient-adequate diet (ie. pigs experience compensatory gain). However, weanling pigs that perform slowly during the starter phase because they are fed a simple (but nutrient adequate) corn-soy diet, instead of a more expensive complex diet, do not compensate during the subsequent G-F period. In fact, research suggests that pigs fed a high-quality complex starter diet may grow even faster during the subsequent G-F period. Assuming that similar growth behavior will occur

under farm conditions, the benefits of higher quality diets should be considered when assessing the cost-effectiveness of nursery feeding programs.

DOES BETTER PERFORMANCE = MORE PROFIT ? AN ECONOMIC EVALUATION

Competitive pork producers recognize that every dollar invested in the swine operation must yield more than a dollar in return. New technologies in starter pig nutrition have provided vastly improved performance of early weaned pigs in the nursery compared to the use of conventional corn-soy diets which were the industry standard before early weaning became a common practice. However, many swine nutritionists and producers continue to debate the economic merits of using diets costing \$800 to \$1200/ton during Phase I of a multi-phase starter feeding program under various pork production conditions. Furthermore, Phase II diets can also contribute a significant amount to total feed cost/pig produced if improperly designed or managed.

As for most swine management decisions, the value of increased performance and the tolerance of high feed price/ton depends on the economic and management conditions on any given farm. Studies evaluating the performance benefits of using complex diets have consistently shown significant weight gain advantages for early weaned pigs, but none have evaluated the influence of these diets on reducing mortality and morbidity. If mortality and morbidity are reduced by feeding complex diets, significant economic benefits can be realized as a result of reduced drug and medication costs, as well as an increase in the pounds of pork marketed/year. However, because no data are available to quantify any potential benefits of complex diets on pig health, it is difficult to include this component in an economic analysis.

It is clear that weight gain advantages obtained by feeding complex diets during the early nursery phase are at least maintained, and usually increased to market weight in farrow-to-finish operations. Thus, the ultimate economic question is "Does the economic value of a weight gain advantage offset the cost of obtaining that weight gain advantage?". The answer to this questions is likely to be different between various production systems. The following economic analysis is designed to put the economics of using complex starter diets into perspective for selected types of on-farm conditions.

EVALUATING THE ECONOMICS OF STARTER FEEDING PROGRAMS IN FARROW TO FINISH OPERATIONS

When evaluating the economic value of increased growth rate in farrow to finish operations, the use of measures such as cost/lb of gain does not provide a true accounting of the real value of using high performance complex starter diets. The real issue for assessing starter diet economics in farrow to finish operations depends on the value of increased growth rate relative to production flow through facilities and the method of marketing slaughter hogs. The value of reduced days to market is only meaningful if it can be achieved consistently, and production flow be adjusted to put more pigs through the unit over time. In other words, low to moderate investment, less intensively managed operations are likely to market slaughter hogs at a common weight rather than at a common age because they do not have rigid time demands on production flow through grow-finish facilities. As a result, increasing growth rate may mean only that the facility sits empty longer between groups of pigs. These operations may obtain greater economic benefits by intensifying production flow to reduce facility costs/pig produced, than by changing starter feeding programs. Once this is accomplished, then the growth rate and economic benefits of using complex diets are more likely to be realized.

In contrast to less intensively managed operations, high investment, intensively managed operations are more likely to market hogs at a common age rather than a common weight in order to meet production schedule demands. Because facility costs are relatively high and profitability is determined by the amount of pork produced per unit of time, the advantage of the faster gains provided by complex starter diets in multi-phase feeding programs are likely to be very economically important.

Therefore, the following economic analysis is designed to evaluate the economics of starter feeding programs for 1) low to moderate investment, less intensively managed operations that market pigs at a relatively constant weight, and 2) high investment, high intensity operations that market pigs at a common age.

Economics of Starter Pig Nutrition for Finishing Pigs Marketed at a Constant Weight

Three major production cost factors need to be considered when estimating the reduction in total production cost associated with a reduction in days to market. Typically, total production cost is comprised of feed costs, facility costs and non-feed variable costs. Non-feed variable costs include, labor, veterinary and medication costs, interest on operating capital, bedding, utilities, equipment maintenance, and miscellaneous supplies.

Reducing days to market has no effect on feed costs in a less intensively managed operation that markets hogs at a constant weight. Studies by Tokach et al. (1990b) and Stairs et al. (1991) have shown that feed conversion of grow-finish pigs previously fed either complex or simple diets during the nursery phase is the same. This means that the benefits of feeding complex diets for reducing the number of days to market does not affect the amount of feed usage/pig marketed, but it does affect the number of days it takes to get the pig to a common market weight (growth rate).

When considering facility cost, less intensively managed grower-finisher facilities that market at a constant weight obtain no real facility cost savings by achieving a reduction in days to market because facility costs are fixed costs that still have to be paid regardless of whether the pigs are in the building or not. Consequently, non-feed variable costs are the only remaining production cost category that will be affected by reducing the number of days to market in a low intensity production facility marketing at a constant weight.

What is the Non-Feed Variable Cost/Pig During the Growing Finishing Phase?

For farrow to finish operations, perhaps the first step in evaluating starter program economics is to simply determine and consider the non-feed variable cost savings (Table 11) for reducing days to market, using actual production cost figures from a given farm.

Table 11. Non-Feed Variable Cost Savings at Various Grow-Finish Facility Costs/Pig/Day.

<u>Reduced Days to Market</u>	<u>Non-Feed Variable Cost/Pig/Day</u>			
	<u>0.05</u>	<u>0.10</u>	<u>0.15</u>	<u>0.20</u>
0	0.00	0.00	0.00	0.00
1	0.05	0.10	0.15	0.20
5	0.25	0.50	0.75	1.00
10	0.50	1.00	1.50	2.00
15	0.75	1.50	2.25	3.00
20	1.00	2.00	3.00	4.00

For low investment, low intensity farrow to finish operations a typical facility cost/finishing pig would be \$0.10 to \$0.15/day.

Determining the Number of Reduced Days to Market Necessary to Meet the Extra Cost of Producing Heavier Pigs Out of the Nursery Based on Actual Farm Non-Feed Variable Costs/Pig/Day

The next step in evaluating the economic value of starter feeding programs is to compare the extra performance (Table 12) and cost (Table 13) of using a complex Phase I diet containing spray dried porcine plasma and milk products with cost and performance of pigs fed a common corn-soy-dried whey diet.

Table 12. Effect of Substituting Spray Dried Porcine Plasma and Lactose or Starch for Milk Products in Starter Pig Diets.

Starter Diet

<u>WK 0-1</u>	<u>HNDD</u>	<u>PLW</u>	<u>PSW</u>	<u>PL</u>	<u>PS</u>	<u>DW</u>
ADG, lb	.67	.89	.83	.82	.69	.57
ADFI, lb	.66	.88	.76	.79	.67	.62

Hansen et al. (1990)

HNDD = control

CAS = casein

PLW = spray dried porcine plasma-lactose-whey

PSW = spray dried porcine plasma-starch-whey

PL = spray dried porcine plasma-lactose

PS = spray dried porcine plasma-starch

DW = dried whey

Table 13. Performance and Cost Comparison Between Pigs Fed PLW and DW Diets During Week 1 Postweaning.*

<u>Starter Diet</u>	<u>Feed Intake</u>	<u>Gain</u>	<u>Total Feed Cost, Wk 1</u>
DW	4.34 lbs	3.99 lbs	\$0.65
PLW	6.16 lbs	6.23 lbs	\$3.08

* Assumes that DW diet cost \$0.15/lb and PLW diet cost \$0.50/lb.

Using these performance data and the assumed price/lb of each diet, the extra 2.24 lbs of gain $[(.89 - .57 \text{ lb/day}) \times 7 \text{ days}]$ obtained from pigs fed the PLW diet must be worth \$2.43 in extra feeder pig value or savings in non-feed variable cost/finishing pig marketed to breakeven. This means that if grow-finish non-feed variable cost/pig is \$0.10/day, you would need to obtain more than a 24 day reduction in days to market to justify the use of the PLW diet in Phase I for 7 days. If non-feed variable costs were even as high as \$0.20/day, you would still need to get a reduction of a little more than 12 days to market to compensate for the increased diet cost of using the PLW diet. If this PLW diet was used for more than 7 days, or fed to pigs that can't take advantage of unique nutrition provided by this complex diet, even greater reductions in days to market would need to be obtained to justify the cost.

This approach applies not only to Phase I diets, but also to the cost/benefit relationships of using all diets during the nursery period. Progressive pork producers who are concerned with designing an optimal feeding program for their operations, must conduct well planned and managed on-farm performance comparisons to accurately evaluate commercial diets and feeding programs. Having those performance data, and using the previously described approach, provides an objective way of assessing whether they are obtaining the most economic value for every dollar spent on starter pig nutrition.

What is the Economic Impact of Observed Reduced Days to Market on Relative to Non-Fed Variable Cost Savings?

For purposes of our analysis, we will assume that nursery pigs fed complex diets will have a 2 lb weight advantage leaving the nursery compared to pigs not fed complex diets, as described earlier in this paper. Using this assumption, this 2 lb weight advantage is equivalent to reducing days to market by about 6 days (Tokach, 1992). Therefore, using a value of \$0.10/day for non-feed variable costs, you could afford to spend an extra \$0.60/pig on starter nutrition to obtain a 2 lb increase in weight for each pig leaving the nursery to breakeven. It is obvious that achieving this amount of performance for such a small cost is not possible due to current costs of ingredients used in complex starter diets.

Therefore, a reduction in market age of less than 6 days is rather insignificant economically. Operations with less intensive production schedules, are often driven more by expected market price changes and labor availability than by a strict all-in-all-out production schedule when marketing slaughter hogs.

Economics of Starter Pig Nutrition for Finishing Pigs Marketed at a Constant Age

The previous example assumes that pigs are marketed at a constant weight which applies more to operations with less intensive production flow than high-investment/high-intensity operations that market pigs at a constant age. Because of the economic importance of a strict production flow and marketing schedule, increasing the lb of pork produced/square ft. of grow-finish space/year (reducing facility cost/cwt marketed) is highly dependent on growth rate. Consequently, the economic value of increased pig weight out of the nursery, and the subsequent performance which allows greater weight at a predetermined market age, are dependent on the quality of the starter feeding program to maximize growth performance.

To evaluate starter diet economics for operations marketing slaughter hogs at a constant age, we need to make some assumptions and calculations to compare the value of increased growth rate when marketing at a constant age (Table 14). To be consistent with previous comparisons, we will assume that the difference in subsequent growth rates of pigs previously fed complex vs. simple diets, is 0.06 lb/day during the grower-finisher phase. This is equivalent to a 6 day reduction in days to market resulting from a 2 lb weight advantage of pigs fed a complex diet leaving the nursery.

Using the previous assumptions, we can afford to spend an extra \$2.97/pig on feed costs in the nursery in order to breakeven.

Determining the Cost of the Starter Feeding Program Relative to the Economic Benefits of Reduced Days to Market

In order to obtain a 0.06 lb/day growth rate advantage (1.50 -1.44 lb/day) use of a complex diet in a 3-phase feeding program is assumed. If this pig consumed 3 lbs of a typical complex Phase I diet (\$0.50/lb), 15 lbs of a typical corn-soy-dried whey Phase II diet (\$0.15/lb), and 50 lbs of a simple corn-soy Phase III diet (\$0.08/lb), the cost of feeding this pig for 6 weeks in the nursery is \$7.75/pig.

Table 14. Determining the Value of Reduced Days to Market for Pigs Marketed at a Constant Age

	<u>Type of Starter Program</u>	
	Complex	Simple
Starting weight, lbs*	52	50
Starting age, days	56	56
Average daily gain grow-finish period, lbs/day	1.50	1.44
Days fed in grower-finisher	119	119
Lbs grow-finish gain	178.5	171.4
Weight of pigs @ 175 days of age	230.5	221.4
Grow-finish feed conversion**	3.20	3.20
Grow-finish feed consumed, lbs	571.2	548.5
Grow-finish feed price, \$/cwt	7.00	7.00
Grow-finish feed cost @ 175 days of age, \$	39.98	38.40
Market hog price, \$/cwt	50.00	50.00
Market value, \$/hog	115.25	110.70
Returns over grow-finish feed cost, \$/hog	75.27	72.30
Advantage for obtaining 0.06 lb/day faster gains, \$/pig	+ \$2.97	----

* Assume that use of a complex diet in Phase I results in a 2 lb advantage at the end of the nursery period, which translates into about a 0.06 lb gain/day advantage for feeding a complex diet as per Tokach (1992).

** Assume that feed conversion is the same for pigs achieving reduced days to market. Tokach et al. (1990b) and Stairs et al. (1991).

If we assume that the pig gaining 1.44 lb/day was not fed a Phase I diet, but consumed 15 lbs of the same corn-soy-dried whey Phase II diet and 53 lbs of the simple corn-soy Phase III diet, the total nursery feed cost for this pig for 6 weeks in the nursery would be \$6.49/pig. The difference in nursery feed cost between feeding the complex vs. the simple starter feeding programs is \$1.26/pig in favor of using the complex diet feeding program. Typically, overall nursery feed conversion is better for pigs fed a complex starter diet feeding program compared to pigs fed less complex or simple diets. Without considering the better feed conversion of using the complex diet feeding program, the additional cost of starter feed for pigs fed the complex diet is about 40 % of the added value resulting from faster gains in the grower-finisher phase. Therefore, it is clear that use of expensive complex diets in a 3-phase feeding program for pigs marketed at a constant age is economically feasible.

A further economic evaluation (Table 15) shows that even with low market hog prices (\$40/cwt) and high grow-finish feed costs (\$0.08/lb), the proper use of an expensive complex Phase I diet for pigs weaned at 25 days of age or less and weighing 12 lbs, is still justified by \$0.49/pig marketed (\$1.75/pig to breakeven - \$1.26/pig estimated starter diet cost difference) when pigs are marketed at a common age.

Table 15. Additional Cost of Starter Nutrition (\$/Pig) to Breakeven When Obtaining a Growth Rate Advantage of 7 Days to Market at Various Market Hog and Grow-Finish Feed Prices.

Market Hog Price, \$/cwt	Grow-Finish Feed Price, \$/Lb		
	0.06	0.07	0.08
40	2.19	1.97	1.75
50	3.19	2.97	2.75
60	4.19	3.97	3.75

EVALUATING THE ECONOMICS OF THE STARTER FEEDING PROGRAM IN FEEDER PIG PRODUCTION OPERATIONS

For feeder pig operations, the economic value of using more expensive complex starter diets instead of less complex, less expensive diets is relatively easy to calculate, but like farrow to finish operations is dependent upon the intensity of production flow through facilities. A typical 2 lb increase in weight per day of age at the end of the nursery period can net an extra \$0.74 profit/pig, assuming a feeder pig is worth \$1/lb and it costs \$1.26 extra in starter feed costs (from the previous example) to obtain those extra 2 lbs. In other words, extra profit per feeder pig sold can be obtained, provided that the extra cost of achieving heavier pigs out of the nursery does not exceed the market value of the gain. If, however, production flow is less rigid, and feeder pigs are sold at a common weight, then the economic value of using complex starter diets is harder to justify.

WHAT DOES ALL OF THIS MEAN?

The whole economic decision depends on two key factors: 1) the economic value of extra gains and weight of pigs fed complex diets in the nursery and at market weight or age and 2) the intensity of production flow of pigs through facilities relative to marketing by weight or by age. In high investment,

high intensity farrow to finish operations that market pigs at a constant age to meet pig flow demands, use of higher cost complex starter diets is essential to obtain higher net profit/pig marketed. However, less intensively managed operations with less restrictive pig flow through facilities make it difficult to obtain enough facility cost savings to justify more expensive starter feeding programs. In these types of farrow to finish operations, considerable management attention should be given to improving pig flow which is likely significantly limiting total profit/pig produced.

THE TAKE-HOME LESSON

New, high quality feed ingredients have been developed and made available to the swine industry in the recent past. These ingredients when combined with traditional feed ingredients in a complex diet support growth performance of nursery pigs superior to simple diets based on corn and soybean meal. Unfortunately, these high quality ingredients are relatively expensive so their use increases feed costs over simple diets based on cereal grains. While public and private research generated the knowledge needed to effectively use these new feed ingredients, practical application of this technology will be driven by economic considerations. Consequently, phase feeding programs for the nursery phase of production were developed in an attempt to maximize growth performance of pigs while controlling feed costs. Phase feeding programs allow the judicious use of high quality, expensive ingredients that match the young pig's digestive capabilities. Violation of the guidelines set forth in a phase feeding program decreases the producer's opportunity for profit.

Do all profit-minded swine producers need to adopt a multi-phase feeding program for nursery pigs which relies on complex, high nutrient dense diets that are relatively expensive? The answer in a word is "no". Swine producers must evaluate their individual operation to determine if multi-phase feeding programs are justified economically by answering the following questions:

1. Is the production schedule in my facilities (nursery or nursery and growing-finishing) so rigid that I must market pigs at a given age?
2. Is the production schedule in my facilities (nursery or nursery and growing-finishing) flexible enough to allow marketing of pigs within a window of 7 to 14 days?

If a producer answer "yes" to question 1, then he/she probably will benefit economically by implementing a phase feeding program using complex, high nutrient dense diets. Alternatively, if a second producer answers "no" to question 1 and "yes" to question 2, then the extra cost associated with a phase feeding program in the nursery will probably not be covered by financial returns from improved pig performance. The second producer could make adoption of a phase feeding program profitable by increasing intensity of the system to take advantage of improved pig performance allowing more pigs to be produced in the facilities per unit time.

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DIGESTIBILITY OF STARCH BY POULTRY

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INTRODUCTION

Starch constitutes between 600 and 700 g/kg of the dry matter of cereals, a larger proportion of many roots and tubers (e.g. cassava and potato) and is a major component of many of the so-called grain legumes such as peas and beans. Depending on its source, differences can exist in the nature of starch and it has often been speculated that these may influence the extent to which it is digested by monogastric animals such as pigs and poultry. For example, it is generally accepted that cereal starches are more effectively digested than those from either roots or tubers while the digestibilities of legume starches tend to be intermediate between these two extremes (Nitsan and Bartov, 1972; Fleming and Vose, 1979; Coates and Rolls, 1981). Raw potato starch is resistant to degradation by some amylases, including those from the pancreas of chickens. The surface properties of the raw potato starch granules have been shown to be responsible for this resistance to amylase attachment (Gallant *et al.*, 1972; 1973). The effects of this resistance are evident when raw potato starch is the main source of carbohydrate in the diet of chickens, the growth rate of the birds being substantially depressed. (Nitsan and Bartov, 1972; D'Mello *et al.*, 1973; Whittemore 1977). Although starch is the major carbohydrate constituent of most poultry diets and an important source of metabolisable energy (over half of the energy metabolised by poultry is derived from starch), the extent to which starch from different plant sources is digested by poultry has received relatively little attention from nutritionists. This is surprising because the dietary starch content is, more often than not, included in equations used to predict dietary metabolisable energy values (Carré *et al.*, 1984; Fisher, 1982; Härtel *et al.*, 1977). It is therefore imperative to know how uniform is the digestion of starch across ingredients and whether it can be affected by processing or by the age of the bird.

CEREALS

In early studies Bolton (1954 ; 1955) concluded that adult cockerels digested the starch in wheat, barley, maize and oats completely, despite the fact that the colorimetric assay used at that time suggested that some starch was present in the excreta of birds given these cereals. However, because his qualitative tests (which were not named) proved negative he attributed the colour to reactions with ketones and bacterial sugars rather than to the hydrolysis products of starch. In contrast to this study and the widely held view which it promoted, Mollah *et al.* (1983) and Rogel *et al.* (1987) reported very variable starch digestibilities for Australian grown wheats, with values ranging from 80 to 99%. A survey in our laboratory of wheats grown in the UK (Longstaff and McNab, 1987), however, suggested that although the starch content of wheat was affected by the variety and the environment under which it had been grown, adult cockerels were able to digest the starch almost completely. No differences could be detected among the six varieties examined, a

mean value of 99.7% being observed. Subsequent evaluations with over 100 wheats grown in the UK using the tube-feeding bioassay (McNab, 1991) have substantiated this view, namely that the starch in wheat is completely digested by adult birds and differences in starch digestibility are unlikely to explain variations in its metabolisable energy value. The view persists, however, particularly in Australia (Annison, 1990; 1991) and within the compound animal feed trade in the UK (Holmes 1992), that shortcomings in the nutritive value of wheat can be the cause of poor performance by broilers and result in wet litter. The current position with wheat starch digestion is extremely confused with some experiments appearing to suggest that it is less than completely digested by chickens because of "antinutritive activity" caused by the viscous properties of arabinoxylans (Choct and Annison, 1990) although the mechanism of this reaction is not understood. Water-insoluble arabinoxylans isolated from wheat and added to experimental diets based on sorghum have been shown to reduce apparent starch digestibility (from 99.2 to 97.2%) which in turn depresses dietary AME (Choct and Annison, 1990). However, water-soluble pentosans had no effect either on AME or on starch digestibility. Because the effects recorded were very small they need to be confirmed under more rigorous experimental conditions.

LEGUMES

Over the years there has been surprisingly little information generated on the digestibility of legume starch by poultry. Guillaume (1978) found that, although autoclaving field beans improved the digestibility of the starch when beans were fed to young broilers, starch digestibility remained at least 15% lower than that of maize. At the time the poorer starch digestibility was tentatively attributed to the presence in the beans of lectins, although no hypothesis was offered to explain the mechanism. In our laboratory we have carried out several experiments with pea and bean starch using balance techniques after tube-feeding adult cockerels 50 g of the materials under test or 3-week-old broiler chicks 10 g of the same materials. Although these assays were originally developed to derive the true metabolisable energy of foods they have been extended to the derivation of the true digestibilities of amino acids (Likuski and Dorrell, 1978) and starch (Longstaff and McNab, 1986). As has already been discussed at this meeting (McNab, 1992) in a strictly classical sense the term digestibility when used in this context is not correct, because part of the output used in the balance equations originates from the urine. However, because there are most unlikely to be any polysaccharides present in urine, the rationale for applying the assay to derive digestibility coefficients for polysaccharides such as starch appears reasonably well justified, particularly when the excreta from control birds feature in the calculation. As has been argued when applying the technique to the derivation of amino acid digestibilities, the use of colostomised birds, although probably preferable on scientific grounds, would be unlikely to improve either the precision or the validity of the measurements. The real assets of this type of bioassay are the ability to examine individual feedstuffs directly and the avoidance of contamination of excreta with food. The disadvantages, which could lead to errors, are firstly the risk of residues from the previous diet remaining in the digestive tracts of the birds when the birds are tube-fed and being excreted during the balance period; this would lead to digestibility coefficients being underestimated. And, secondly, incomplete evacuation of undigested components from the test feedstuffs within the time allocated for collection (usually 48 h) would result in the overestimation of true digestibility.

Results from experiments of this type have shown conclusively that the starch in peas is considerably less well digested by adult cockerels than those from cereals (Longstaff and

McNab, 1987). It was also shown that none of the treatments imposed on peas - grinding to a particle size of less than 1 mm, autoclaving, oven-heating, dehulling or supplementing the peas with a crude commercial cellulase enzyme preparation - was able to increase the digestibility of the pea starch from about 91% (Table 1). *In vivo*, it seems likely that several factors will influence the extent to which starch might be digested; the size and nature of the starch granule itself, the accessibility of the starch to the digestive enzymes (this may depend on the thickness and structure of the endosperm cell walls), the time of exposure to the digestive enzymes (i.e. the rate of food passage) and possibly the presence in the foodstuff (or diet) of enzyme inhibitors. Although it may prove difficult for nutritionists or food technologists to change the nature of the starch it should prove possible to alter its accessibility to enzyme degradation and to knock out any amylase inhibitors and, perhaps, slowdown the rate of food passage.

TABLE 1. Digestibility of starch in peas subject to different treatments by adult cockerels

Treatment	Digestibility (%) \pm SD
whole	75.6 \pm 16.2
ground (1 mm)	88.1 \pm 2.0
heated and ground	90.4 \pm 2.5
autoclaved and ground	91.4 \pm 2.9
dehulled and ground	92.8 \pm 3.4

It seems unlikely that the extent to which the starch in peas is digested is being constrained by inhibition of the appropriate digestive enzymes. Amylase inhibitors have never been detected in either peas or beans (Liener, 1980). Furthermore, the addition to peas of a crude enzyme preparation, which had been shown *in vitro* to have considerable amylolytic activity might have been expected to cause an improvement in any starch digestion which had been hindered by insufficient amylase production by the bird. This did not happen. In this context it is probably relevant to mention that the amount of pancreatic amylase, the principal enzyme involved in starch breakdown, secreted into the small intestine is very large (Longland 1991). For example, it has been calculated that under normal conditions the weight of starch that is capable of being hydrolysed might be equal to at least half of the liveweight of the animal. However, although there is some evidence, at least with pigs, that the amount of enzyme produced and secreted by pigs may be affected by the nature of the diet (Partridge *et al.*, 1982) results from other experiments suggest that neither the nature of the starch nor its dietary concentration affected amylase output (Corring and Saucier, 1972; Zebrowska *et al.*, 1983).

It seems likely that starch digestion, at least in some experiments, is being influenced by its accessibility to the digestive enzymes. For example the lower digestibility of starch (76%) when peas were fed whole could really only be attributed to poor contact between amylase and starch, for it was observed that whole or split cotyledons were excreted by birds fed unground peas. In addition, the ability to detect more starch *in vitro* after one aqueous extraction of peas ground through a 0.5 mm sieve (42.6%) than of those ground through a 1.0 mm sieve (40.1%), together with the observations that the hydrolysis of the starch in samples ground to pass through the 0.5 mm screen was faster than in samples ground to pass

through the 1.0 mm sieve, illustrates that maximising the surface area to starch ratio (and presumably the enzyme to substrate contact) may well be an important factor in the effectiveness of starch breakdown *in vivo*.

It also appears as if the removal of fibre acted as a further aid to starch degradation, because an even more rapid rate of starch hydrolysis was observed *in vitro* when the hulls of peas were excluded from the incubation medium and a better and faster rate of starch digestion was recorded *in vivo* when the birds were fed dehulled peas. Better enzyme to substrate contact is an obvious possible explanation of this response. This observation does, however, partly conflict with those from Snow and O'Dea (1981) who reported that ground brown rice starch was hydrolysed by a mixture of α -1:4, α -1:6 - amyloglucosidase at the same rate as that from the less fibrous ground white rice.

Recent results from our laboratory (Yuste *et al.*, 1991) with purified starches prepared from peas and beans strongly suggest that, although particle size and the presence of cell wall carbohydrates may influence starch digestion when legumes form part of the diet, legume starch is intrinsically more slowly and less effectively digested by both adult and young birds than starches from wheat or cassava (Table 2). Indeed bean starch was significantly less well digested than that from pea. This strongly implies that the structure of the starch is influencing its digestibility and may offer an explanation for data which showed that there are marked differences in the digestibilities of starches from different legumes *in vitro* (Gee, 1985).

TABLE 2. True digestibilities of starches in 50:50 mixtures of soyabean meal and starches by adult cockerels and young broilers

Mixture	Starch Digestibility (%) \pm SD	
	Cockerels	broilers
soya : wheat	99.0 \pm 0.6	99.4 \pm 1.0
soya : cassava	99.2 \pm 0.3	99.3 \pm 0.5
soya : pea	98.0 \pm 0.2	94.2 \pm 6.4
soya : bean	94.5 \pm 2.1	78.2 \pm 5.8
soya : potato	70.2 \pm 6.4	39.3 \pm 6.9

Whether there is an interaction between the animal and its ability to digest legume starches is largely unexplored. However, the high digestibilities *in vivo* of starches from a number of legumes by rats (Fleming and Vose, 1979) suggest that the target species may be a factor in determining the extent to which starch is digested. Certainly the digestibility coefficients obtained for the pea starch in this study are much higher with rats (96.9-99.9%) than have ever been seen with poultry in our laboratory. The observation that the starches isolated from peas, field beans and potatoes, respectively, were less well digested by 3-week-old broiler chicks (94, 78 and 39%) than by adult cockerels (98, 94 and 70%) does suggest that amylase production may be a limiting factor in the younger bird (Yuste *et al.*, 1991). Well-digested starches (those from maize and wheat) were found to be digested quickly, next to no starch being detectable in digesta reaching the terminal ileum. Starches which were less well digested at the proximal ileum (cassava, pea and bean) were further digested, but only to a

relatively small extent, during passage through the ileum.

Starches escaping digestion in the small intestine are, at least potentially, available to the microflora of the hindgut as substrates for fermentation. Although the hindgut is conventionally considered as the site of microbial fermentation, there is increasing evidence (at least in pigs) that a significant amount of microbial activity occurs in the lower part of the ileum (Millard and Chesson, 1984 ; Graham *et al.*, 1985). In both poultry and rats the site of greatest microbial activity is the caeca. Despite the fact that caecal enlargement has been observed in rats fed on diets containing legume starch (Fleming and Vose, 1979), the digestibility of starch from beans was unaffected by the absence of caeca in adult cockerels (Longstaff *et al.*, 1991). Although it cannot be ruled out that another part of the gastrointestinal tract has assumed the rôle of the caeca, these data and other results, which involved comparisons between the extents to which starch was digested between the terminal ileum and being excreted, imply that fermentative activity in the hind gut does not result in the disappearance of undigested starch. This view is supported by some studies with germ free and conventional chicks, where it was shown that maize starch digestibility was not affected by the gut microflora (Kussaibati *et al.*, 1982). However, the increase in caecal length observed among chicks receiving cassava, pea, bean and, most noticeably, potato starch would seem to indicate that undigested material was entering the caeca (Yuste *et al.*, 1991). It was, therefore, perhaps surprising to find that no further breakdown of poorly digested starches appeared to occur in the lower gut.

CONCLUSIONS

It does not seem possible at this stage to reach meaningful general conclusions on the extent to which starch is digested by poultry. It appears to be accepted that, with the possible exception of potato starch (Whittemore, 1977), poultry do not require starch to be gelatinised as a prerequisite to its effective digestion (Bolton, 1955 ; Mollah *et al.*, 1983 ; Longstaff and McNab, 1986). Most reports on legume starches tend to support this view and cooking has frequently been shown to result in a reduction in the extent to which starch is digested (Fleming and Vose, 1979 ; Longstaff and McNab, 1987). The most likely explanation for this decrease is the formation, during cooking, of retrograded starch which, because of the formation of intermolecular hydrogen bonds, is generally accepted as being resistant to hydrolysis by amylolytic enzymes (Osman, 1967). Cooking is, therefore, unlikely to offer a practical means whereby the digestibility of starch might be improved, because any possible beneficial effects resulting from pre-gelatinisation will be counterbalanced by the unfavourable effect of retrogradation. It might, however, be important to encourage as rapid a rate of starch hydrolysis as possible in poultry, because of the exceedingly rapid rate (less than 4 h) of food passage (Heuser, 1945 ; Hillerman *et al.*, 1953). Provided conditions could be defined which prevent or perhaps limit starch retrogradation, it is possible that some form of heat processing could benefit the nutritional status of certain starches for poultry.

There seems little doubt that the physical and chemical properties of starch affect the extent to which it is digested by poultry (e.g. potato, field bean). Because certain starches appear to be more extensively digested after they have been isolated from the plant, it seems reasonable to conclude that the endosperm cell walls which envelop the starch in the grain, are acting as a physical barrier to its complete interaction with amylase in the gastrointestinal tract and limiting its digestibility. This hypothesis also allows an explanation for the observation that the addition of oat hulls to diets containing poor quality wheats (low AME)

increases the extent to which their starch is digested (Rogel *et al.*, 1987). The abrasion caused by the actions of the gizzard and the fibre may be sufficient to liberate previously protected starch. Why, however, this should only happen with certain wheats under assays involving continuous feeding is puzzling. The tube-feeding assay in the hands of two different laboratories did not result in the derivation of low TME values (Mollah *et al.*, 1983) and it cannot be completely ruled out that these low AME values and starch digestibility coefficients were artefacts of the classical balance technique. Undetected food spillage could readily explain the low values derived.

Recent thinking in Australia (Annison and Choct, 1991) is focusing on the arabinoxylans of the wheat cell wall as being responsible for poor wheat starch digestibility and low AME values, despite earlier evidence suggesting that these viscous polysaccharides did not result in any impairment of nutrient absorption (Rogel *et al.*, 1987). However, later studies (Choct and Annison, 1990) involving the addition of alkali-soluble arabinoxylans (up to 65.7 g/kg) to a commercial broiler diet depressed apparent starch digestibility from 96 to 82%; furthermore, the moisture content of the excreta was much higher and bird performance markedly reduced. This antinutritive effect has been likened to that induced by the non-starch polysaccharides of barley and rye and it has been shown that the non-starch polysaccharide contents (pentosan plus β -glucan content) of cereals correlates closely with their AME values (Choct and Annison, 1990). Whether this effect is caused by impaired diffusion within the gastrointestinal tract or is mediated by the gut microflora must await the results of future more definitive experimentation. It is interesting that Mead *et al.* (1983) have observed increased numbers of *E. coli* and faecal streptococci in the small intestines of chickens fed on diets based on wheat and excessive proliferation of some bacteria (e.g. *Streptococcus faecium*) has been implicated as a factor depressing growth in chickens (Fuller, 1984). A bacterial interaction could explain why different results are obtained in acute experiments after tube-feeding than are found with classical balance studies involving *ad libitum* feeding over several days.

Finally, starch granules in cereals are frequently associated with the storage proteins, an association which provides the basis for the hardness of the grain (Simmonds *et al.*, 1973; Stenvert and Kingswood, 1977), this relationship does not appear to affect its digestibility. Furthermore, although amylase inhibitors are known to be present at high concentrations in wheat, to be active against chicken pancreatic amylases (Buonocore *et al.*, 1977), and to be resistant to inactivation by heat, they are completely destroyed by the action of pepsin in the gizzard (Macri *et al.*, 1977). The fact that these inhibitors appear to be more resistant to the action of pepsin in "raw" wheat, may explain the beneficial effects of heat treatment that have occasionally been claimed.

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USE OF BARLEY IN GROWING TURKEY DIETS

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Barley is a major crop in Scandinavia, western Canada, and many parts of the U.S.A. Traditionally, it is used for brewing, human foods, and ruminant feeds, although it is also routinely used in some swine feeds. However, barley is perceived by many as an inferior feed grain for poultry feed, regardless of the local supply and price situation. The reluctance of using barley in poultry diets is primarily for two reasons: 1) barley contains less metabolizable energy relative to other cereals; and 2) litter problems in poultry with barley-based feeds. These two problems can be circumvented by the use of microbial enzyme preparations that have recently become available, making barley a much more attractive feedstuff. This is particularly of interest to turkey producers in the upper midwestern region of the U.S., where there is access to competitively-priced barley from local sources or the Pacific Northwestern region of the U.S. The objective of this paper is to demonstrate the potential value of barley for turkeys.

Barley is usually considered a less desirable grain for feeding poultry than corn because it contains less energy and more undigestible components. Barley grain is composed of about 62% starch, 19% cell walls (fiber), and 12% protein on a dry matter basis. Relative to wheat and corn, barley has higher fiber and consequently lower energy value. The fiber content of barley can vary from 16 to 25% of the dry matter (DM), depending on the cultivar and growing conditions (Graham et al., 1987). Typical cell wall of grains consists of fibrillar polysaccharides (mostly cellulose), matrix polysaccharides (pectins, hemicellulose and small amounts of glycoproteins), and lignin (Selvendran and O'Neil, 1987). In barley, the non-starch fiber fraction (cell wall material) consists of cellulose (2.0 to 6.3 % of DM), lignin (1.6 to 3.3 % of DM), beta-glucans (2.4 to 5.2% of DM), and arabinoxylans (5.5 to 11.0% of DM) (Graham et al., 1987; Newman and Walter, 1988). Cellulose, lignin, and arabinoxylans are found mainly in the hull fraction of barley, whereas the beta-glucans comprise of about 75% of the endosperm cell walls.

Beta-glucans are polysaccharides having mixed 1-3 and 1-4 glycosidic linkages and they are deposited in the endosperm cell wall after most of the starch is formed in the barley grain (Amañ et al., 1989). Therefore, the beta-glucan content reaches a maximum level a few days before the grain is ripe for harvest. Moreover, beta-glucan solubility is much higher during grain maturation than at harvest time (Amañ et al., 1989). Barley cultivars grown in hot or dry conditions tend to have higher beta-glucan content than barley grown in more temperate climates (Aastrup, 1979).

About 55% of the mixed-linked beta-glucans in barley are soluble and the rest is insoluble. The soluble mixed-linked beta-glucans give rise to viscous solutions in water. It is these gel-forming soluble beta-glucans that cause problems for poultry (White et al., 1983). Classen (1991) suggested that they reduce nutrient assimilation, growth rate and efficiency of feed utilization, and cause wet litter problems. The soluble beta-glucans increase viscosity of gut lumen contents and acts as a physical barrier to endogenous enzymes and solute diffusion. The rate of diffusion of solutes decreases as viscosity increases in the lumen of the gut. Because enzymes, substrates, and products are all solutes, an increase in viscosity of the gut contents will decrease the rate of digestion significantly. As the rate of digestion decreases, the rate of intestinal throughput decreases, resulting in reduced feed intake and increased microbial activity in the small intestine (Salih et al., 1991). The negative impact of gut microbes is implicated by the improved response of birds fed barley-based diets supplemented with antibiotics (Moran and McGinnis, 1968; Classen et al., 1985).

The cellulolytic or hemicellulolytic enzymes produced by some fungi and bacteria can degrade poorly digestible or viscous polysaccharides. Therefore, the dietary supplementation of suitable enzymes (such as beta-glucanase, xylanase, mannanase, and pectinase) can be a practical way of improving the feeding value of some low energy feedstuffs like barley for poultry. Recent work by Dr. Craig Wyatt at Washington State University illustrated that beta-glucanase supplementation will increase metabolizable energy value of different barley cultivars, depending on the contents of beta-glucan, soluble carbohydrate, or crude protein (Table 1). Supplementation of bacterial or fungal enzymes that contain beta-glucanase have been reported to overcome some of the adverse effects of feeding barley to chickens (Willingham et al., 1959; Rickes et al., 1962; Potter et al., 1965; Hesselman, 1983; Newman et al., 1985; and Edney et al., 1989). However, few studies on the effects of beta-glucanase supplementation in barley-based diets for turkeys are reported in the literature.

Recently, an experiment was conducted at North Carolina State University to evaluate the potential of barley-based diets supplemented with different levels of beta-glucanase to turkeys. Six replicate pens of 28 turkeys were subjected to each of 6 experimental treatments from one day to 18 weeks of age. The following were the six treatments used:

1. Conventional corn-soybean meal diets (Diet A)
2. Barley-soybean meal diets (Diet B)
3. Diet B + 165 beta-glucanase units/kg
4. Diet B + 330 beta-glucanase units/kg
5. Diet B + 660 beta-glucanase units/kg
6. Barley-soybean meal made isocaloric with the corn-soybean meal diet by adding fat (Diet C) + 165 beta-glucanase units/kg

The beta-glucanase enzyme added to the barley diets was the dry form of BAN 1000 S, supplied by Novo Nordisk, Inc., Danbury, Connecticut. The pure form of this enzyme contained 1000 beta-glucanase units (BGU)/g, but as with other commercial enzymes, the enzyme we used also had a number of minor side activities. The treatment diets all had similar nutrient content with the exception for energy, and they were pelleted (Tables 2 and 3). The turkeys consumed the experimental diets free choice and were raised under normal management practices. Treatment effects were evaluated on the basis of body weights, feed conversion, mortality, litter moisture, and carcass parts yield.

Body weights of the turkeys at 3, 9, and 18 weeks of age are shown in Table 4. At 3 weeks of age, the turkeys fed the barley diets without any enzyme weighed only 53% of the turkeys fed the corn diets. However, body weight increased linearly as the level of enzyme increased up to the 330 BGU/kg level; no additional advantage was gained at the 660 BGU/kg level of enzyme. A similar trend was observed at 9 and 18 weeks of age, but the differences among the treatments decreased as the barley-fed turkeys showed some compensatory growth relative to the corn-fed birds during the finishing period. Enzyme supplementation evidently reduced much of the detrimental effects of barley on growth. However, the anti-nutritional factors, such as beta-glucans, could not totally account for the reduced growth rate observed with the barley diets. The favorable growth response to supplemental fat in the enzyme-treated barley diet demonstrated that energy was also a limiting factor.

Body weight and feed conversion of turkeys fed the barley-based diets were inferior to the turkeys fed the corn-based diets (Table 4) reported by Jevne et al. (1988). Feed conversion was apparently hindered by the beta-glucans in the barley because beta-glucanase supplementation improved feed conversion by 14 points. Unlike the trend seen with body weight, however, the level of enzyme supplementation had no significant effect on overall feed conversion. It is noteworthy that feed conversion of the starter feed improved as the level of supplemental enzyme increased. Young birds fed barley-based diets have been shown to be more responsive to supplemental beta-glucanase than older birds (Fry et al., 1958; Fadel et al., 1987; Nasi, 1988). Feed conversion of turkeys fed the enzyme supplemented barley diets after 9 weeks of age was almost as good as those fed the corn diets.

Feed ingredient costs are dependent upon the market conditions. At the time of this experiment, corn cost \$132/ton, soybean meal cost \$300/ton, and barley cost \$70/ton. Consequently, the cost of the barley diets was \$20 to \$40 per ton less than the corn diets. Even though the barley diets resulted in poorer feed conversion than the corn diets, feed ingredient costs were as much as \$0.05 less per pound of body weight gain. Based on these results, barley could have costs as much as 80% the value of corn to be cost effective.

The mortality data clearly demonstrates that too much barley in the diet of turkeys is not good unless enzyme is added to the diet (Table 5). The toms fed the barley diet without enzyme suffered almost 50% more mortality than the toms fed either the corn-based diets or the barley diets containing the enzyme. This high level of mortality corresponded with severely stunted growth, pasty vents, or twisted legs (perosis) similar to those observed with gross nutrient deficiency. This apparent nutrient deficiency observed among the poult fed the barley-based diets without the enzyme could be attributed to the anti-nutritional properties of beta-glucans in barley. The gelling, ion-exchange, and absorbing characteristics of beta-glucans are thought to retard the digestive action of intestinal enzymes and also interfere with the absorption of the liberated nutrients (Nassi, 1988; Classen et al., 1991). Enzyme supplementation (regardless of level) cut mortality normally seen in turkeys fed barley in half, which is evidence that the enzyme supplementation significantly reduced the anti-nutritional effects of beta-glucans.

Much of the mortality observed in this experiment was related to leg problems. Leg problems are related to many factors, but they are often associated with wet and sticky litter conditions. Table 5 illustrates that litter moisture in pens of 6-week-old poult was highest in the barley control group. Litter moisture decreased as the level of enzyme supplementation increased and this trend was observed throughout the experiment.

A sample of toms (approximately 26 lbs live weight) from the treatments that performed the best were killed and cut into commercial parts by a skilled yield technician at a commercial processing plant. The carcass yield data are shown in Table 6. Carcass yields of toms fed barley-based diets compared well to those fed corn-based diets. Yields of the high-value cuts (breast meat, tenderloins, and thigh meat) from the barley-fed toms were as good or better than those of the corn-fed toms, and yield of the low-value cuts (neck, tail, and skin) were lower. Enzyme level had little effect on carcass yield, but the toms fed the 165 BGU/kg level needed 5 more days to attain a 26 lbs market weight than the corn-fed toms. Carcass yield of toms fed the barley-based diet without the enzyme was not determined because they were too much under weight at the time of slaughter.

The results of this experiment confirm previous studies that supplemental beta-glucanase is effective in overcoming barley's detrimental effects on the performance of turkeys. The benefits of enzyme supplementation is much more apparent in young turkeys (0 to 9 weeks of age) than in older turkeys. Corn-based diets will continue to be the standard choice for feeding turkeys in the U.S. However, there will be times when competitively priced barley should be considered as an alternative grain. In such cases, the use of beta-glucanase is recommended at about 330 BGU/kg of complete feed. Sufficient enzyme supplementation will control the mortality, diarrhea, wet litter, and much of the stunted growth problems associated with feeding a barley-based diet. Liberal use of supplemental fat in barley-based diets is also recommended to achieve the best feed conversion.

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Table 1. Proximate analysis of three barley cultivars grown in Washington State

	Steptoe	Harrington	Odessa
Dry Matter, %	91.1	90.7	91.0
Crude Protein, %	12.5	17.06	17.2
Ether Extract, % ²	2.2	2.5	2.4
Soluble Carbohydrate, mg/g ²	95.8	107.1	107.2
β -Glucanase, % ²	3.6	3.9	5.3
Kcal TME _n /kg ³	3,233	3,373	3,149
Kcal TME _n /Kg (+ Enzyme) ⁴	3,322	3,379	3,615

¹Data adopted from C.L. Wyatt, Washington State University, personal communication, 1991).

²Nutrient values based on a dry matter basis.

³TME_n values were determined by feeding rooster no β -glucanase (nitrogen-corrected).

⁴TME_n values were determined by feeding roosters β -glucanase at 6.0825% of the diet (nitrogen-corrected).

Table 2. Percentage Composition of the Basal Diets Fed to Market Toms From Day of Age Until 9 Weeks of Age

Ingredient	Prestarter			Starter			Grower I		
	Diets (0-3 Wks)			Diets (3-6 Wks)			Diets (6-9 Wks)		
	A	B	C	A	B	C	A	B	C
Corn	50.43	-	-	51.55	-	-	-	52.91	--
Barley	-	55.00	48.83	-	56.78	48.68	-	54.64	50.55
Soybean Meal (48%)	38.03	30.94	31.78	38.35	30.93	33.00	35.52	32.74	28.40
Poultry Meal	5.86	8.00	8.00	5.55	8.00	8.00	4.00	4.00	8.00
Fish Meal	2.50	2.50	2.50	-	-	-	-	-	-
Poultry Fat	-	0.69	5.98	0.80	0.80	6.94	3.74	4.86	9.96
Limestone	1.31	1.34	1.31	1.45	1.46	1.43	1.46	1.55	1.40
Dicalcium Phosphate	1.16	0.76	0.80	1.58	1.13	1.17	1.66	1.51	1.05
Salt	0.27	0.19	0.20	0.30	0.30	0.22	0.22	0.17	0.12
D,L-Methionine	0.15	0.22	0.232	0.11	0.16	0.16	0.07	0.11	0.11
L-Lysine-HCl	-	-	-	-	0.065	0.03	-	-	-
Choline Chloride(50%)	0.02	0.09	0.093	0.04	0.11	0.10	0.15	0.15	0.15
Vitamin Premix	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Trace Minerals	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Coban	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065

Calculated Analysis

Protein, % C.P.									
Actual	27.0	27.6	27.4	25.5	27.0	27.4	23.7	24.5	24.2
Calculated	27.5	27.8	27.5	26.0	26.5	26.5	24.1	24.1	24.2
Kcal ME/lb.	1285	1152	1285	1300	1146	1300	1400	1261	1400
Lysine, %	1.65	1.65	1.65	1.58	1.55	1.55	1.34	1.33	1.30
TSAA, %	1.10	1.10	1.10	1.01	0.99	0.99	0.85	0.85	0.85
Crude Fats, %	3.33	3.33	8.52	3.90	3.24	9.25	6.00	7.57	13.00
Calcium, %	1.25	1.25	1.25	1.25	1.25	1.25	1.20	1.20	1.20
Avail. Phosphorus, %	0.58	0.58	0.58	0.58	0.58	0.58	0.55	0.55	0.55
Sodium, %	0.16	0.16	0.16	0.16	0.19	0.16	0.12	0.12	0.12
Cost, \$/100 lbs ³	10.98	8.97	9.53	10.72	8.68	9.39	10.52	8.69	9.01

¹Vitamin premix supplied per kg of diet: 13,200 IU Vitamin A; 4400 ICU Vitamin D₃ 33 IU Vitamin E; 22 mg Vitamin B₁₂; 13 mg Riboflavin; 66 mg Niacin; 22 mg d-Pantothenic Acid; 2.2 mg Menadione; 1.2 mg Folic Acid; 6.6 mg Pyridoxine; 2.2 mg Thiamin; 165 mg d-biotin.

²Mineral Premix supplied per Kg of diet; 150 mg Manganese (MnSO₄·H₂O); 180 mg Zinc (ZnO); 40 mg Iron [Fe₃(SO₄)₂·7H₂O]; 6 mg Copper (CuSO₄);

³Cost based on ingredient prices shown on Table 4.

Table 3. Percentage Composition of Basal Diets Fed to Market Toms From 9 to 18 Weeks of Age.

Ingredient	Grower II Diets (9-12 Wks)			Developer Diets (12-15 Wks)			Finisher Diets (15-18 Wks)		
	A	B	C	A	B	C	A	B	C
Corn	57.42	-	-	66.25	-	-	69.75	-	-
Barley	-	62.58	56.88	-	67.84	62.16	-	73.90	66.49
Soybean Meal	30.21	21.00	22.31	21.31	18.92	14.71	14.93	8.67	7.57
Poultry Meal	4.00	8.00	8.00	4.70	4.00	8.00	7.00	8.00	10.00
Poultry Fat	4.61	5.41	9.80	4.47	5.95	12.45	5.33	6.54	13.29
Limestone	1.34	1.31	1.29	1.09	1.23	1.07	0.91	1.02	0.94
Dicalcium Phosphate	1.70	1.05	1.08	1.41	1.31	0.86	1.33	1.02	0.86
Salt	0.22	0.11	0.12	0.30	0.24	0.20	0.26	0.17	0.15
D, L-Methionine	0.09	0.13	0.13	0.07	0.12	0.12	-	0.10	0.10
L-Lysine-HCl	-	-	-	-	-	0.03	0.09	0.18	0.19
Choline Chloride(50%)	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Vitamin Premix ¹	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Mineral Premix ²	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10

Calculated Analysis

Protein, % C.P.									
Actual	22.0	22.8	22.8	18.5	19.6	19.3	17.8	18.0*	17.8
Calculated	22.0	22.0	22.0	19.0	19.0	19.0	17.5	17.5	17.5
Kcal ME/lb	1440	1290	1400	1475	1301	1475	1500	1326	1500
Lysine, %	1.18	1.12	1.14	0.95	0.95	0.95	0.90	0.90	0.90
TSAA, %	0.80	0.80	0.80	0.70	0.70	0.70	0.65	0.65	0.65
Crude Fat, %	8.40	8.40		8.39	8.40	15.20	9.29	9.29	16.14
Calcium, %	1.15	1.15	1.15	1.00	1.00	1.00	0.95	0.95	0.95
Avail. Phosphorus, %	0.55	0.55	0.55	0.50	0.50	0.50	0.50	0.50	0.50
Sodium, %	0.12	0.12	0.12	0.15	0.15	0.15	0.15	0.15	0.15
Cost, \$/100 lbs ³	10.10	7.77	8.28	9.36	7.13	7.63	9.09	6.65	7.31

¹Vitamin Premix supplied per kg of diet: 13,200 IU Vitamin A; 4400 Vitamin D₃ 33 IU Vitamin E; 22 mg Vitamin B₁₂; 13 mg Riboflavin; 66 mg Niacin; 22 mg d-Pantothenic Acid; 2.2 mg Menadione; 1.2 mg Folic Acid; 6.6 mg Pyridoxine; 2.2 mg Thiamin; 165 mg d-biotin.

²Mineral Premix supplied per Kg of diet; 150 mg Manganese (Mn SO₄ · H₂O); 180 mg Zinc (ZnO); 40 mg Iron [Fe₃ (SO₄)₂ · 7H₂O]; 6 mg Copper (CuSO₄).

³Cost based on ingredient prices shown on Table 4.

Table 4. Effect of barley and enzyme treatment on body weight, feed conversion, and feed cost on market turkey toms¹

Diet	Body Weight, Lbs.			0-18 Weeks of Age	
	3 Weeks	9 Weeks	18 Weeks	Feed/Gain	\$Feed Cost/Lb. Gain
Corn	1.5 ^a	11.5 ^a	25.5 ^a	2.75 ^c	.287 ^a
Barley(B)	0.8 ^d	8.1 ^d	22.2 ^d	3.14 ^a	.244 ^b
B + Ban-66	1.0 ^c	9.7 ^c	23.5 ^c	3.00 ^b	.238 ^b
B + Ban-132	1.2 ^b	10.3 ^b	24.9 ^{ab}	2.98 ^b	.238 ^b
B + Ban-264	1.2 ^b	10.1 ^b	24.3 ^{bc}	2.98 ^b	.239 ^b
B Fat + BAN-66	1.2 ^b	10.2 ^{bc}	24.5 ^{abc}	2.88 ^{bc}	.242 ^b

¹ Means of 6 replicate pens of 28 toms/pen.

^{a,b,c} Means with different letters in a column are significantly different (P < .05).

Table 5. Effect of barley-based diets and enzyme treatment on mortality and litter moisture of market turkey toms

Diet	% Mortality 0-18 Weeks	% Litter Moisture 12 Weeks of Age
Corn	14.0 ^b	21.5 ^b
Barley(B)	23.0 ^a	27.0 ^a
B + Ban-66	11.5 ^b	26.2 ^a
B + BAN-132	11.8 ^b	23.0 ^b
B + BAN-264	12.5 ^b	23.5 ^b
B + FAT + BAN-66	10.6 ^b	21.5 ^b

^{a,b} Means with different letters in a column are significantly different (P < .05).

Table 6. Carcass yield of toms marketed at 26 pounds live weight¹

	Corn	Barley + Ban-66	Barley + Ban-132	Barley-Fat +Ban-66
Days to 26 lbs.	140 ^b	145 ^a	140 ^b	140 ^b
Chilled weight, lbs.	22.13 ^a	21.88 ^c	22.04 ^b	22.01 ^b
Dress, % ²	75.6 ^b	77.3 ^a	76.0 ^a	76.9 ^b
Neck, %	4.2 ^a	3.8 ^b	3.7 ^b	3.8 ^b
Drumettes, %	5.5 ^b	5.8 ^a	6.0 ^a	5.9 ^a
Tail, %	6.4 ^a	6.2 ^b	6.2 ^b	6.3 ^b
Scapular skin, %	1.6 ^a	1.5 ^b	1.6 ^a	1.6 ^a
Scapular meat, %	1.6 ^a	1.5 ^a	1.5 ^a	1.6 ^a
Neck skin, %	3.0 ^a	2.7 ^b	2.8 ^{ab}	3.0 ^a
Breast skin, %	1.9 ^a	1.9 ^a	2.0 ^a	2.0 ^a
Breast meat, %	20.7 ^b	21.3 ^a	20.9 ^{ab}	20.6 ^b
Tenderloins, %	4.9 ^a	5.0 ^a	4.9 ^a	4.9 ^a
Breast bone, %	11.9 ^c	12.2 ^b	12.4 ^a	12.1 ^b
Back bone, %	6.9 ^a	6.7 ^a	6.7 ^a	6.7 ^a
Thigh skin, %	1.4 ^a	1.4 ^a	1.5 ^a	1.5 ^a
Thigh meat, %	13.3 ^b	13.2 ^{bc}	13.1 ^c	13.6 ^c
Thigh bones, %	2.6 ^b	2.5 ^b	2.8 ^a	2.7 ^{ab}
Drumsticks, %	12.6 ^a	12.6 ^a	12.4 ^a	12.5 ^a

¹Data expressed as a percentage of chilled carcass weight. Means of 24 tons/treatment.

²Dressed yield expressed as a percentage of live weight.

a, b, c, Means with different letter superscripts are significantly different (P < .05).

VITAMIN E AND SELENIUM NUTRITION OF POULTRY

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INTRODUCTION

Shortly after the introduction of the revolutionary "vitamin" concept, α -tocopherol was discovered to be the antioxidant present in plant lipids which supported normal gestation in rats and, later, normal vascular function in chicks. These discoveries led to the tocopherols being named, as "vitamin E", among the earliest identified vitamins. In contrast, the first suggestion that selenium (Se) might have a nutritional role was not made until the latter 1950's when it was found to replace vitamin E in the diets of rats and chicks for the prevention of dietary hepatic necrosis and exudative diathesis, respectively. During the decade following this discovery, many investigators reported the activity of Se in preventing or ameliorating vitamin E deficiency disorders in several other species. These included nutritional myopathies, reproductive failures, hepatic degeneration (in some species), vascular disorders and growth retardation. Because vitamin E was regarded to function as a biologically specific lipid antioxidant, the nutritional interactions of Se and vitamin E were interpreted by many researchers as evidence of an antioxidant function of Se. As the mode of action of Se remained unclear, controversy developed concerning its nutritional role. One school of thought held that Se was nothing more than a factor that spared the function of vitamin E; another held that it must be a nutrient in its own right.

This controversy was settled in the early 1970's when a syndrome (nutritional pancreatic atrophy)^{*} was found to result from Se deficiency in the vitamin E-fed chick, and Se was found to be an essential constituent of the antioxidant enzyme glutathione peroxidase (SeGSHpx). Those findings, and the research they engendered, have established Se as an essential nutrient the metabolic function of which is intimately related to that of vitamin E. Therefore, the physiological impact of nutritional Se deficiency is properly considered only in the context of combined Se-vitamin E status.

MODES OF ACTION OF VITAMIN E AND SELENIUM

Vitamin E and Se are understood to function as key elements of a multi-component system of antioxidant protection within cells (see review by Combs, 1986). This system is comprised of both hydrophobic elements residing in membranes (vitamin E, ubiquinones, carotenoids) and hydrophilic elements (SeGSHpx, ascorbic acid, glutathione) present in the aqueous phases of the cell (e.g., cytoplasm, mitochondrial matrix space). These various components function in concert to reduce free radicals generated within the cell, thus, preventing the initiation of oxidative reactions (e.g., the peroxidation of polyunsaturated membrane phospholipids and the oxidation of critical protein sulfhydryl groups) that can impair normal cell function. Present understanding, therefore, is that the key elements of this cellular antioxidant system are vitamin E, as the major membrane-bound lipid antioxidant, and Se, as the essential constituent of SeGSHpx. Vitamin E functions as a reductant of free radicals due to the phenolic character of its chromanol hydroxyl group; its antioxidant activity is determined by the number and positions of methyl groups on the chromanol ring and its biological specificity is determined by the configuration of its side-chain. The soluble enzyme SeGSHpx catalyzes the glutathione-dependent reduction of hydroperoxides; it contains 4 gram-atoms of Se per mole, each in the form of selenocysteine (SeCYS) at the active center of the enzyme.

Selenium has other, less well characterized, physiological functions. Recently, other SeCYS-containing proteins have been discovered: a phospholipid hydroperoxide glutathione peroxidase, a 5'-iodothyronine deiodinase, and a protein (selenoprotein P) proposed to have Se-transport function. Whereas clinical signs of Se deficiency are clearly related to losses of SeGSHpx, the physiological roles of these other SeCYS-proteins are presently unclear.

SELENIUM DEFICIENCY DISEASES OF POULTRY

We have reviewed extensively the vitamin E/Se-related deficiency diseases of laboratory animals and livestock species (Combs, 1986). It is the purpose of this presentation to describe only those observed in poultry; these are summarized in Table 1.

Chickens

Depending upon specific dietary conditions, the growing chick may show any of four vitamin E/Se deficiency diseases: encephalomalacia, nutritional muscular dystrophy, exudative diathesis, nutritional pancreatic atrophy. The first two are primarily related to vitamin E deficiency, being completely prevented by small dietary supplements of vitamin E; whereas, the last is primarily related to Se deficiency, as it is strictly dependent upon dietary Se; only very high dietary concentrations of vitamin E or other antioxidants prevent it in the absence of Se. Only the second disease, exudative diathesis, responds to small amounts of either nutrient.

Encephalomalacia in Chicks. This disorder is characterized by microscopic lesions in the cerebellum accompanied by hemorrhages and edema; it is manifest as a severe ataxia and is produced by the deficiency of vitamin E in chick diets containing no synthetic antioxidants. Selenium deficiency can hasten the onset of encephalomalacia in vitamin E- and antioxidant-deficient chicks (Century and Horwitt, 1964); we believe this effect is due to a role of Se in the utilization of vitamin E by neural tissue, as we have found affected animals to show normal brain concentrations of Se and activities of SeGSHpx (Combs and Hady, 1991).

Exudative Diathesis in Chicks. Exudative diathesis is characterized by severe subcutaneous edema, particularly in the depending regions of the body (e.g., abdomen, feet and ventral aspects of the neck and wings). The edema results from abnormally increased capillary permeability. Affected chicks are also anemic and hypoproteinemic, which also contributes to the edema. Exudative diathesis in the vitamin E-deficient chick was found to be prevented by a factor in brewer's yeast, subsequently identified as Se. The combined deficiency of vitamin E and Se produces exudative diathesis in young chicks within 2-4 weeks when they are reared with deficient diets from hatching. By then, hepatic SeGSHpx activities have usually dropped to less than one-third of control (Se-fed) levels, and significant declines in erythrocyte SeGSHpx are noted. The effect of Se deprivation is seen much earlier in the plasma wherein SeGSHpx drops to less than 15% of control levels within 6 days, at which time the initial signs of exudative diathesis are not yet observed. In young chicks, the activity of SeGSHpx in plasma is inversely correlated with the risk to developing exudative diathesis. The direct involvement of SeGSHpx in the etiology of exudative diathesis was indicated by our findings that the disease can be potentiated by SeGSHpx inhibitors (e.g., aurothioglucose, penicillamine) and prevented by treatment with a synthetic Se-compound (ebselen) with SeGSHpx-like catalytic activity (Mercurio and Combs, 1986).

Table 1. Selenium-deficiency syndromes of poultry

Species	Syndrome	Systems Affected	Preventative Factors	
			Se	vitamin E
Chicken	exudative diathesis	capillaries: edema, hemorrhage	+	+
	muscular dystrophy	skeletal muscles: degeneration	+ ^a	+ ^b
	pancreatic atrophy	acinar pancreas: atrophy, periacinar fibrosis	+ ^c	+ ^d
	encephalomalacia	cerebellum	? ^e	+ ^c
	impaired immunity	bursa of Fabricius: epithelial vacuolization	+	+
	reduced egg production	ovary	+	+
	decreased hatchability	embryo	+	+
	reduced growth		+	
Turkey	muscular dystrophy	gizzard, myocardium, skeletal muscle: degeneration	+	+ ^a
	exudative diathesis	capillaries: edema, hemorrhage	+	+
	reduced growth		+	+ ^b
Duck	muscular dystrophy	gizzard, duodenum, skeletal muscle: degeneration	+	+
	connective tissue lesions	tendon fibroblasts: degeneration	+	+
	exudative diathesis	capillaries: edema, hemorrhage	+	+
	reduced growth		+	+
Japanese quail	reduced growth, survival		+	+
	exudative diathesis	capillaries: edema	+	+
	reduced hatchability	embryo	+	+

^aprovides only partial protection.

^bat least partial protection is provided by cyst(e)ine.

^cdisorder exacerbated by feeding high levels of polyunsaturated fatty acids.

^dprotects at only very high levels of intake.

^erole not well understood.

Both the incidence and rate of appearance of the disease are dependent upon the Se-vitamin E status of the flock. Chicks produced from Se- and vitamin E-depleted hens will show exudative diathesis within 6-12 days when they are reared using a low-Se, vitamin E-free diet; however, chicks from adequately nourished hens will show exudates much later if fed such a deficient diet, and chicks fed marginal levels of Se and/or vitamin E will show exudates with lower incidence. Exudative diathesis is readily diagnosed by the appearance of the subcutaneous edema, which progresses to hemorrhage. Affected chicks show reduced activity and food intake; if not treated with Se or vitamin E, they usually survive only a few days.

Nutritional Muscular Dystrophy in Chicks. Nutritional muscular dystrophy is produced only when diets are moderately deficient in the sulfur-containing amino acid cystine. The disease is characterized by degeneration of the skeletal muscles. Prominent lesions are usually visible through the skin as

longitudinal white striations in the pectoralis and gastrocnemius. Affected chicks show generalized muscular weakness and marked decreases in activity. Microscopic examination reveals Zenker's degeneration of muscle fibers, with perivascular infiltration of eosinophils and macrophages; the condition progresses to fibrosis. Hence, dystrophic muscles show elevated activities of lysosomal enzymes and transaminases. Lesions are not found in other organs.

Myopathy generally is observable within 20-25 days when day-old chicks are reared using a dystrophigenic diet. In general, synthetic antioxidants are without effect in preventing nutritional muscular dystrophy in the chick; however, Machlin and Shalkop (1956) found that diphenyl-p-phenylamine diamine (DPPD) could be effective when added at high levels to low-fat diets¹. Therefore, low levels of synthetic antioxidants are used in vitamin E-deficient dystrophigenic diets to prevent other vitamin E- and antioxidant-related disorders (e.g., encephalomalacia) that would otherwise be produced in the chick.

Dietary supplements of Se are effective in reducing (by 10-15%), but not fully preventing nutritional muscular dystrophy in the chick. Calvert and Scott (1963) showed that, although supplemental Se markedly reduced the amount of vitamin E required to prevent myopathy in chicks, it did not affect the level of cystine needed for similar protection. This finding has been interpreted as indicating that nutritional muscular dystrophy in the chick is primarily a disorder of vitamin E and cysteine metabolism, and that the role of Se in this disorder is only to improve the tissue utilization of vitamin E. Hull and Scott (1972) found that both the activity of SeGSHpx and the concentration of reduced glutathione were significantly greater in muscle from dystrophic vs. that of non-dystrophic chicks when each were fed dystrophigenic diets supplemented with Se. This suggests that the metabolic conditions leading to muscular dystrophy in vitamin E and cyste(i)ne deficiency may relate to oxidative stresses associated with either reduced utilization of or increased needs for the SeGSHpx system. This is supported by the findings of Shih et al (1977) of 2-3 fold increases in the ratio of protein-bound disulfide:sulfhydryl content, and of appearances of low molecular weight proteins (presumed to be derived from proteolysis) in dystrophic chick muscle. The apparent oxidation of muscle proteins during nutritional muscular dystrophy suggests that the need for sulfur-containing amino acids by the vitamin E-deficient chick may relate to an increased need for essential amino acids under these circumstances of rapid turnover of muscle proteins. That cysteine is much more effective in this regard than is methionine was explained by the results of Hathcock (1967) which indicated reductions in both the transsulfuration of methionine to cysteine and the conversion of cysteine to taurine in the vitamin E-deficient chick.

Nutritional Pancreatic Atrophy in Chicks. Thompson and Scott (1969, 1970) tested the need for Se *per se* by feeding chicks a low-Se (0.010 ppm) purified diet supplemented with what was believed to be an excess of vitamin E (100 IU/kg). They found that the chick required supplemental Se for growth and survival; unsupplemented chicks showed decreased pancreatic exocrine function and impaired utilization of dietary lipids. The pathogenesis of this condition was described by Gries and Scott (1972). In the severely Se-deficient chick, pancreatic acinar cells first show vacuolation and hyaline body formation; this is followed by loss of zymogen, cytoplasmic shrinkage and dilation of the acinar lumina. Finally, infiltration with fibroblasts and macrophages occurs; the terminal phase is

¹Indeed, the addition of 4% lard to the dystrophigenic diet negated the protective effect of DPPD.

characterized by severe periacinar fibrosis². These histological changes are associated with progressive decreases in the activities of lipase and proteases. Loss of the former impairs the digestion of dietary triglycerides; the consequent reduction in formation of intestinal mixed micelles formation resulted in a general impairment of the enteric absorption of dietary lipids. Thus, the disorder is characterized by steatorrhea; it will also result in a secondary deficiency of vitamin E. The disorder does not involve only the islets of Langerhans; affected chicks show no effects of altered pancreatic endocrine function and have normal plasma concentrations of glucose.

We described the pathogenesis of nutritional pancreatic atrophy in second generation Se- deficient chicks (Combs and Bunk, 1981). The first signs of abnormal acinar cell appearance are usually seen within 4-6 days after hatching when chicks are reared using a Se-deficient, vitamin E-supplemented diet. By that time, chicks appear normal; however, feed intake starts to decline and a slight depression in rate of gain in body weight is seen. By 6-12 days, as acinar cytoplasm diminishes, feed intake is markedly reduced, chicks may lose body weight, and poor feathering is noted. At 12-15 days, some chicks die with pronounced acinar atrophy and mild periacinar fibrosis; mortality increases to ca. 95% by 28 days. In first-generation Se-deficient chicks, onset of the disorder is 5-7 days later. Pancreatic degeneration is reversible by Se treatment; treated chicks show an almost immediate recovery of appetite, which is followed by histological signs of acinar regeneration within 1-2 days, and a return to normal gross appearance and nearly normal acinar histology within two weeks.

We found that the early phase of nutritional pancreatic atrophy is associated with a decrease in the rates of synthesis of RNA and protein (but not DNA), and that this effect was specific for the chick pancreas (Whitacre and Combs, 1983). Upon treatment of deficient chicks with Se, the pancreatic synthesis of RNA and protein returned to normal rates within 12 hrs. We tested the hypothesis that these lesions may relate to altered function of acinar mitochondria; however, our results showed that respiratory function of mitochondria prepared from chick pancreas was not affected by nutritional Se deficiency (Bunk and Combs, 1981; Whitacre and Combs, 1983). Decreases in RNA and protein synthesis appear to result from the disappearance of endoplasmic reticulum from degenerating acinar cells, as indicated by our electron micrographic observations of the atrophic acinar cell (Root and Combs, 1988).

The growth depression associated with severe uncomplicated Se deficiency in the chick is due in part to a depression in appetite. We found that approximately two-thirds of the growth depression in chicks with nutritional pancreatic atrophy could be overcome by force-feeding to levels of intake comparable to the ad libitum levels of Se-adequate chicks (Bunk and Combs, 1980). We further demonstrated that growth was promoted in Se-deficient chicks by dietary supplements of cystine, whereas supplements of methionine were without such effect (Bunk and Combs, 1981). Subsequent studies by Halpin and Baker (1984) confirmed that finding for at least some strains of chickens. Therefore, it appears that the Se- deficient chick with nutritional pancreatic atrophy has either an increased metabolic demand for cysteine which cannot be met by further transsulfuration from methionine, or an impairment in the transsulfuration pathway itself. Our findings that Se-deficient chicks had decreased concentration of homocysteine, cystathionine and cysteine in the plasma free amino acid pool (Bunk and Combs, 1981), and that Se-deficient chicks had increased rates of methionine- methyl group oxidation (LaVorgna and Combs, 1983) are consistent with an insufficient metabolic conversion of methionine to cysteine. We found that nutritional pancreatic atrophy could be

²On this basis, the disease was originally called "pancreatic fibrosis"; we renamed it "nutritional pancreatic atrophy" in recognition that the effect of Se deficiency is the atrophy of acinar cells, the consequence of which is fibrotic infiltration.

produced using a practical-type (i.e., corn-soy based) diet which contained less than 0.01 ppm Se (Combs et al, 1984)³. In that study, Se deprivation produced only a very slight reduction in growth after 30 days, even though it produced clear pancreatic atrophy; this suggested the presence of a factor in the practical diet, apparently not cystine, which prevents the growth depression associated with severe Se deficiency in studies using purified diets.

Nutritional pancreatic atrophy has been considered to be the only clearly delineated pathological condition that results from the deficiency of Se uncomplicated by deficiencies of vitamin E, cystine, etc. However, we found that the condition could also be prevented by dietary supplements with high levels of vitamin E, BHT, DPPD, ethoxyquin or ascorbic acid (Whitacre et al, 1987). Although normal pancreatic function is maintained when chicks consume diets containing at least 0.05 ppm Se, pancreatic atrophy was also prevented with dietary additions of at least 300 IU vitamin E per kg of diet or of 500 ppm of any of these synthetic antioxidants or ascorbic acid. Each of these treatments was fully effective in supporting normal pancreatic histological appearance as well as normal chick growth in the Se-deficient diet. That antioxidant supplementation did not act to increase the utilization of the trace amount of Se in the diet was indicated by the lack of increase in either the Se content of pancreas or the SeGSHpx activities of plasma, pancreas or liver. Therefore, nutritional pancreatic atrophy, while highly responsive to exceedingly low dietary concentrations of Se, must be considered as a disorder involving in a more general way the total antioxidant status of the chick.

Impaired Development of Immunocompetence in Chicks. We found that Se was required for normal development of immunocompetence in the chick (Marsh et al, 1981). Chicks made deficient with respect to either Se or vitamin E within the first two weeks after hatching showed impaired humoral responses to ovine erythrocytes; however, Se and vitamin E appeared to be mutually replaceable for this function by three weeks of age. Dietary concentrations of Se greater than or equal to 0.20 ppm produced significant immunosuppression, but only in male chicks. Subsequent studies have shown lesions of the epithelial tissue of the bursa of Fabricius in Se- and vitamin E-deficient chicks; these lesions appear to be associated with depletion of lymphoid cells in that organ and may explain the diminished B-cell function observed in chicks with the combined deficiency. These results would suggest that Se and/or vitamin E deficiency may affect disease resistance in young chicks.

Reproductive Failure in Breeding Chickens. Cantor and Scott (1974) observed significant reductions in rates of egg production and embryonic survival among Single Comb White Leghorn hens fed a corn-soy based diet containing less than 0.03 ppm total Se without supplemental vitamin E. Both parameters returned to normal by supplementing the diet with 0.10 ppm Se as Na₂SeO₃. That level of added Se resulted in concentrations of Se in eggs averaging 0.121 ppm after three weeks of feeding and was associated with a protective effect against exudative diathesis among progeny reared using a diet deficient in both Se and vitamin E. The studies of Latshaw et al (1977) support a requirement of ca. 0.05 ppm for sustaining egg production in the laying hen. We found that dietary levels of ca. 0.05 ppm Se are adequate to sustain egg production in laying pullets, but that levels less than 0.10 ppm Se resulted in deficiencies of SeGSHpx in hens and impaired hatchability and post-hatching performance of progeny (Combs and Scott, 1979). Progeny of Se- and vitamin E-deficient hens show late-stage embryonic mortality, with a high incidence of hemorrhages in the subcutaneous tissue. Deprivation of Se can affect reproductive performance; we have found uncomplicated Se-deficiency to impair testicular maturation in cockerels, and testicular degeneration has been reported in chronically vitamin E-deficient roosters.

³That study was conducted in China using as major ingredients in the basal diet low-Se corn and soybean meal grown in areas of severe endemic Se deficiency in that country.

Turkeys

Muscular Dystrophies in Poults. Degeneration of the smooth muscle of the gizzard is the most characteristic sign of Se deficiency in the young turkey poult. This condition, originally reported as a sign of vitamin E deficiency was shown to be prevented by dietary supplements of Se (Walter and Jensen, 1963). It is characterized by a hyaline degeneration of smooth muscle, resulting in a pale gross appearance of the organ. Degenerative lesions may also be observed in the myocardium and skeletal muscle. These myopathies are associated with increased serum transaminase activities, and with decreases in hematocrit, blood hemoglobin and albumin concentrations and SeGSHpx activities in several tissues (Cantor et al, 1982). In marked contrast to the skeletal myopathy of the vitamin E-deficient chick, gizzard myopathy in the Se- and vitamin E-deficient poult is not prevented by dietary sulfur-containing amino acids but is completely prevented by supplements of Se. However, the dietary level of vitamin E affects the amount of Se required for the prevention of the disorder. Walter and Jensen (1964) reported that it was necessary to use a basal diet low in methionine and vitamin E, as well as Se, in order to produce gizzard myopathy experimentally. Scott et al (1967) found that while a dietary level of 0.18 ppm Se was required to prevent gizzard myopathy in vitamin E-fed poults, a level of 0.28 ppm was required when the diet was not supplemented with vitamin E. In the latter studies, additions of methionine and vitamin E to the dystrophigenic diet improved growth but did not affect the incidence of gizzard myopathy. Selenium, vitamin E and methionine are not effective in amelioration of the hereditary degenerative skeletal myopathy in turkeys (Harper et al, 1945).

Exudative Diathesis in Poults. The combined deficiency of Se and vitamin E in poults produces a mild exudative diathesis. This condition is characterized by hemorrhages of the thigh and breast muscles; in contrast to the exudative diathesis of the Se- and vitamin E-deficient chick, it involved only a mild edema. Affected poults also show macrocytic anemia and, occasionally, hydropericardium.

Ducks

Nutritional Muscular Dystrophy in Ducklings. A nutritional muscular dystrophy is produced in vitamin E- and Se-deficient ducklings. The first ultrastructural lesions observed in the deficient duckling are degeneration of the sarcoplasmic reticulum and mitochondria of the smooth muscle of the duodenum and gizzard (Van Vleet and Farrans, 1977a,b). Grossly, pale areas of necrosis are seen in the dystrophic gizzard. These changes are accompanied by mineralization of sarcoplasmic debris in necrotic cells, followed by invasion of macrophages and fibroblasts. Abnormalities of capillaries and nonmyelinated nerve fibers are not observed extensively subsequent to the development of extensive necrosis of the muscle. Involvement of the myocardium and skeletal muscles is also seen. Skeletal muscle appears hyalinized with extensive myofibrillar lysis; electron microscopic examination reveals mitochondrial swelling. We found that nutritional muscular dystrophy in the duckling was prevented by supplementing a corn-soy based practical diet (containing 10 IU vitamin E per kg and 0.04 ppm inherent Se) with 0.10 ppm Se as Na_2SeO_3 (Dean and Combs, 1980); however, higher levels of Se were required to produce maximal activities of SeGSHpx in plasma and liver.

Brown et al (1982) proposed that the metabolism of connective tissue may be impaired in the Se- and vitamin E-deficient duckling. They found that the contents of total and soluble collagen were decreased in tendons from ducklings fed a low-Se and -vitamin E practical type diet vs. ducklings fed the diet supplemented with 0.5 ppm Se (as Na_2SeO_3). Degenerated fibroblasts were observed in tendons from Se-deficient animals. They interpreted their findings as indicating an impairment in collagen maturation, suggesting that the functional failure of tendons resulting from such an

impairment may lead to the myofibrillar degeneration seen in nutritional muscular dystrophy. This hypothesis is supported by the observations of Bartlett et al (1973) who reported structural alterations in collagen in tendons from Se- deficient ducklings, and of Brown et al (1974, 1982) and Moran et al (1975), who reported beneficial effects of supplemental ascorbic acid, a substance known to be involved in collagen metabolism, as a protective factor in Se deficiency. It is likely that these responses were effects of high-level antioxidant treatment rather than being due to correction of impaired ascorbic acid biosynthesis, as our studies in ducklings (Dean and Combs, 1980) and chicks (Combs and Pesti, 1976) provide no support for the latter hypothesis. We have found, however, that the use of high-level ascorbic acid supplements to poultry diets can enhance the utilization of dietary Se (Combs and Pesti, 1976).

Exudative Diathesis in Ducklings. Exudative diathesis has been reported in association with nutritional muscular dystrophy in Se- and vitamin E-deficient ducklings. The condition would appear to be similar to that of the chick, i.e., greenish-colored edema of the subcutaneous tissues seen most frequently on the thigh with associated petechial hemorrhages of the thigh musculature. According to Jager (1977), the appearance of exudative diathesis is infrequent and occurs in association with only the more severe cases of nutritional muscular dystrophy in deficient ducklings.

Japanese Quail (*Coturnix coturnix japonica*)

Severely depressed growth, reduced feed consumption, poor feathering and poor survival were reported by Scott and Thompson (1968) in young Japanese quail reared using a diet deficient only in Se. The combined deficiency of Se and vitamin E produced exudative diathesis in some animals. Jensen (1968) found that while oviposition and fertility were not affected by the combined deficiency of Se and vitamin E, embryonic survival (i.e., egg hatchability) was markedly depressed among females reared to maturity with the deficient diet. Many of the surviving progeny of Se- and vitamin E-deficient females showed extreme generalized muscular weakness and prostration after hatching. Supplementation with either Se or vitamin E returned embryonic survival to normal and reduced quail hen mortality.

RECOMMENDED DIETARY LEVELS OF VITAMIN E AND SELENIUM FOR POULTRY

Practical use levels of vitamin E and Se in poultry diets are given in Table 2. It should be noted that these levels are for the total contents of each nutrient in finished feeds. In the case of vitamin E, the instability of the naturally occurring tocopherols in practical feedstuffs makes it difficult to predict with any certainty the vitamin E of such materials; therefore, this means that the use of supplements of stable, bioavailable forms of the vitamin are required to ensure adequate vitamin E nutriture. In the case of Se, however, most practical feedstuffs, particularly those of high protein content, can be expected to provide substantial amount of the mineral. For most corn-soy based diets, this amount is at least 0.5 mg/kg, i.e., one-quarter to one-third of the desired amount; Se supplements are used to make up that difference. In general, this means 0.1-0.15 mg added Se per kg of finished feed are adequate for ensuring the health and productivity of poultry⁴.

⁴While there have been anecdotal reports of benefits of larger supplements to broiler feeds, these are not well documented and must be considered open to question. Further, the use of excess Se, which is eliminated with poultry manure, is of concern for its potential environmental impact.

Table 2. Recommended dietary levels of vitamin E and Se in practical diets for poultry.

Species	vitamin E level ^a IU/kg	Se level ^b mg/kg
chicken, starting & growing chicks	7.5	0.15
laying hens	10	0.10
breeding hens	20	0.15
turkey, starting & growing poults	5	0.20
laying hens	5	0.15
breeding hens	10	0.20
geese, starting & growing	5	0.20
laying & breeding	10	0.20
duck, starting & growing	5	0.15
laying & breeding	10	0.15
pheasants, bobwhite quail, Japanese quail		
starting & growing	7.5	0.15
laying & breeding	20	0.15

^aThe vitamin E contents of practical feedstuffs are highly variable due to such factors as seasonal variations in the crop, fungal destruction of the vitamin and oxidative losses of the vitamin due to drying and storage of the feedstuff. These levels, therefore, represent those used to supplement practical diets.

^bThe feedstuffs used in most corn-soy based diets can be expected to provide at least 0.05 ppm Se, except in certain cases where the major ingredients of the diet are grown in areas of endemic Se-deficiency.

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DETERMINATION OF AVAILABLE ENERGY AND AMINO ACIDS IN POULTRY DIETS

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INTRODUCTION

Apart from the economic importance of energy in the formulation of least cost diets for poultry the present continuing sustained level of interest in metabolisable energy (ME) determinations stems from two main events. The first was the introduction of rapid bioassays for ME in the mid - 1970s and the second was the adoption of energy declarations, with the associated chemical control equation, into the animal feed trade in Europe. This latter development has focused attention on the accuracy, repeatability and suitability of different methods as a means of measuring ME. Over the past thirty years ME has almost universally come to be accepted as the preferred measure of the energy status of poultry diets. The establishment of a relationship between dietary ME content and the amount of food eaten and relating the concentrations of other dietary nutrients to the ME value has accounted for the marked improvement in the precision with which poultry are fed. The ability to measure ME accurately has, therefore, come to be an important component of most poultry nutritional research programmes.

The topic has been widely reviewed both here and elsewhere. Sibbald (1979a) described the evolution of his method and later produced a further very detailed review (Sibbald, 1982). At various times during the past decade many others have assessed progress (Farrell, 1981; McNab and Fisher 1982; McNab, 1990). Since 1975 an enormous literature has unfolded on the topic; Sibbald (1986) listing 561 references concerned with this research area, only 5 of which predate 1975.

Recent reports have tended to highlight the questions of reproducibility of ME values, across laboratories and across time, and of variations in ME data. The introduction of energy declarations and of a control equation encourages this, because it is presumed that each system is based on a well defined and reproducible biological characteristic, namely, the ME of the feed. Attempts to test or verify equations obviously founder if this cannot be observed consistently. Extension of ME values to feed ingredients also requires the establishment of appropriate prediction equations which relate ME to chemical composition or, perhaps, to some other quality control parameters. Progress in this area is facilitated if data from different laboratories can be combined and this results in variations in technique being brought into focus, especially if they are seen to lead to different biases. It might have been hoped that the introduction of an effective rapid bioassay based on sound scientific principles would have fulfilled the laudable aim of technique standardisation. There appears to be two main reasons why this has not happened. Firstly, rapid assays almost invariably require the use of starved birds and this has proved controversial; secondly, it is clear that the adoption of published techniques caused problems in some laboratories and this has led to the introduction of a number of major and minor variations. Consequently there are now

probably more different methods being applied to the derivation of ME values than at any time in the past and the prospect of establishing a single standard procedure is probably as remote as ever.

DEFINITION OF ME

Although ME is usually considered to be a property of a diet, it is really a characteristic of an animal to which the diet is given. ME measurement relates to the complete diet given and values for feed components or ingredients must, in most cases, be obtained by comparisons of data from two or more appropriate diets (substitution or replacement methods). In such derivations the assumption of additivity of ME values amongst feedstuffs is essential and very little progress can be made if this is not upheld. Energy is, of course, a useful currency for describing mass conversion of food elements in the bird. Similar problems, analogous to those discussed here for ME, are to be found in determining the metabolisability of any nutrient, lipid, protein or carbohydrate. For many purposes, but especially for prediction, it would be preferable if both the ME values and the digestibility coefficients for the main components were measured concurrently, but this appears to be done on only rare occasions.

The terminology used in the topic of ME is relatively free from dispute and a widely used convention will be followed here, mainly in agreement with Sibbald (1982, 1986). The term ME is used in a general sense rather than to mean bioavailable energy (Sibbald, 1982) and the expression endogenous energy loss (EEL) is usually defined, not as a biological entity, but as an empirical quantity, e.g. the energy loss from a starved bird. This is convenient and need not be confusing. The convention of ignoring energy lost as gases produced during fermentation is also followed.

Pesti and Edwards (1983) proposed that the nomenclature used in this field should be quite radically changed to reflect the methods which had been used in the evaluation experiments but I believe that this is unnecessarily complex and unhelpful. A more desirable approach might be to modify the methodology until it measures and reflects well-defined biological entities. However the proposition that more care should be taken in relating experimental observations to supposedly well-defined biological elements (Pesti and Edwards, 1983), cannot be overstressed. In this context it is possibly relevant to comment critically on the standard of reporting studies in this discipline in scientific journals. ME values are not observed or, indeed, measured but are derived from a whole series of measurements and far too little basic information is normally reported. Thus, it is frequently impossible to make critical comparisons between different experiments. If more detailed tabulation of results was required it seems likely that, as the philosophy of the topic develops, greater use could be made of existing data and of results from different studies could be combined.

McNab and Fisher (1981) suggested that the observations required to derive ME values were threefold : (i) a knowledge of the energy balance at (ii) a known food intake and (iii) an appropriate measure of EEL. If the values are to be corrected to zero nitrogen-retention, then nitrogen balance must also be measured. It is useful when discussing methods to bear in mind the relationships shown in Figures 1 and 2 which have been discussed previously (McNab and Fisher, 1981 ; Wolynetz and Sibbald, 1984). The regression of excreted energy and food (gross) energy input is shown in Figure 1.

Fig. 1 Regression of excreta energy on food energy input

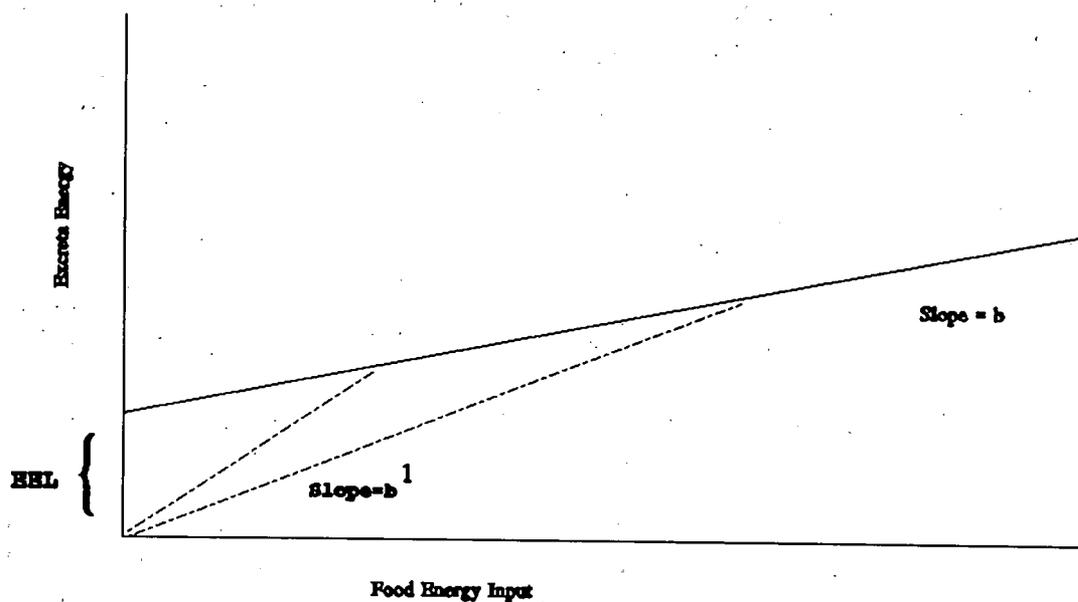
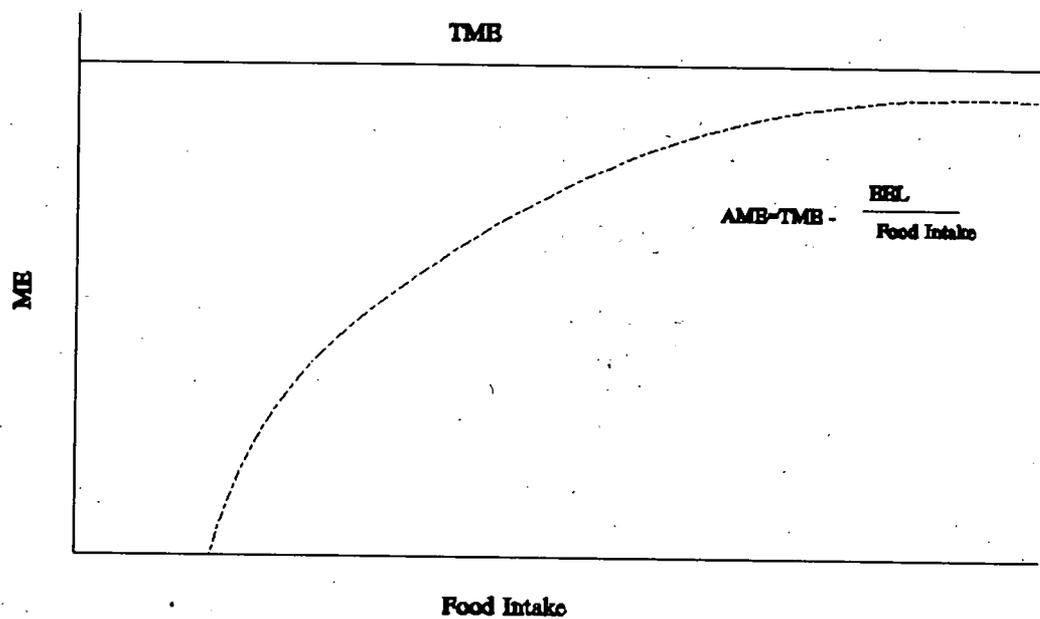


Fig. 2 Relationship between AME, TME and food intake as derived from Fig.1 assuming that EEL does not equal zero.



The intercept on the y axis provides an operational definition of EEL; statistically it is the energy excretion at zero energy input, and the slope of this line yields the true metabolisable energy (TME) of the feed as $TME = GE (1 - b)$ where GE is the gross energy of the feed. Estimates of apparent metabolisable energy (AME) correspond in a similar way to the slopes of lines joining given energy balances with the origin of the graph; thus, for the example in Figure 1, $AME = GE (1 - b')$. The derivation of Figure 2 is obvious if a range of intakes are envisaged. It is also worthy of note that if the intercept is zero then $AME = TME$ and AME is independent of intake. Negative intercepts suggest an artefact of measurement.

METHODS FOR DETERMINING ME

By separating the question of which ME system to use from that of experimental technique, different assays should be judged on how well they provide the three essential pieces of information, energy balance, food intake and EEL. Other factors which may influence the choice will be speed, cost and, perhaps, convenience. Three general types of experiments have been identified as follows (Fisher and McNab, 1987).

1. Traditional assays which involve preliminary feeding periods to establish a "state of equilibrium". Differences in the contents of the digestive tract between the beginning and end of the assay period ("end-effects") are controlled by trying to ensure that they are the same. In most cases complete diets must be fed and substitution methods (described earlier) must be used for ingredients.
2. Rapid assays, using starvation before and after allowing the birds free access to the diet to control the end-effects. Again complete diets and substitution methods for ingredients must be used in most cases.
3. Rapid assays, as above, but using tube-feeding to place the test material directly into the bird's crop. These methods almost invariably avoid the need for substitution, most ingredients being fed as received.

Whilst many variations are found within these three general groups the classification provides a convenient framework within which the many procedural details can be discussed.

ENERGY BALANCE AND FOOD INTAKE

Food presentation and the accurate measurement of energy intake are arguably the most challenging aspects of ME determinations. When birds are given access to food *ad libitum*, a procedure which still seems to be most widely accepted, great care is required to avoid food loss, to prevent separation of the dietary components, to take changes in moisture content into account and to take representative samples. These are difficult to control in a consistent way but specially designed systems have been described and used with apparent success (Terpstra and Janssen, 1975).

Such free-feeding methods are used in type 1 assays which probably form the greater part of the literature on ME determination in poultry. Farrell (1978) proposed that the advantages of a rapid assay, type 2, could be obtained by training birds to consume sufficiently large intakes in 1 h after a 23 h starvation period. In this assay equal quantities of basal diet and test ingredient were combined and pelleting was recommended to maintain intakes across a

range of ingredients. Several laboratories (Muztar and Slinger, 1980b; Jonsson and McNab, 1983; Parsons *et al.*, 1984; Kussaibati and Leclercq, 1985) have reported difficulties in maintaining satisfactory intakes but notwithstanding this, the assay has its adherents. Apart from speed (cost) and amount of material required the technique offers few, if any, advantages over type 1 assays in terms of the accurate measurement of food intake or energy balance (McNab and Fisher, 1981).

It is beyond debate that the presentation of the food by tube in type 3 assays permits the most accurate means of measuring energy intake, food spillage and changes in dry matter content both being avoided. However, because the dose size is reduced, problems may occur in terms of achieving representative samples. The only real disadvantages of the technique are the obvious limits on dose size and, perhaps, attitudes to a procedure frequently referred to as "force-feeding". Experience in our laboratory is that, with practice, the procedure is very rapid (15 to 30 sec/bird to feed 50 g of most feedingstuffs) and that there is little evidence of more stress beyond that involved in handling. Skill is required, however, and experience must be attained, although this is easily achieved by most operators. The use of slurry feeding as a way of reducing stress has been suggested (Wehner and Harrold, 1982) but it is my experience that slurry feeding invariably takes considerably longer. Finely divided, hygroscopic or very bulky ingredients may present problems but, with experience, these can all generally be overcome. In our laboratory glucose monohydrate is fed routinely; this can present problems and granulation is carried out to reduce difficulties.

Excreta collection is another simple task which can be difficult to do well in routine experiments. When trays placed under the cages are used to collect the droppings, by far the most common procedure, the problems include adherence of the excreta to feathers, contamination with scurf, fermentation losses and perhaps loss during removal and transfer. Losses caused by excretion away from the tray are rare but can occur and contamination with regurgitated material can also take place, can be surprisingly difficult to detect and almost impossible to take into account. Sibbald (1986) lists sensible precautions to be taken; frequent collection (12 hourly), as in Dale *et al.*, (1985) are the sorts of devices which might be judged beneficial but are labour-intensive and reduce the benefits of a low cost assay. Alternatives to collection trays have been discussed earlier (Fisher and McNab, 1987) and it has been concluded that trays cannot be avoided in routine experiments.

MINIMISING END EFFECTS

In assessing the reliability of data from type 3 assays it is important to remember that, because inputs are small, any imprecision or uncertainty will have a potentially greater effect on the value derived. In the ideal ME system only excreta derived from the intake recorded should be debited against that energy intake. In type 1 assays where it is customary to carry out the balance over several days and where food intakes are often several hundred grammes, discrepancies or differences in gut-fill at the beginning and end of the experiment were considered to cancel each other out. Although this was accepted it was not entirely satisfactory because changes in intake of rapidly growing birds or in response to unpalatable ingredients may be more likely to cause systematic bias rather than random error. However, with the much smaller intakes used in assays of types 2 and 3 great care must be taken to ensure that the digestive tract is empty of residues at both the beginning and end of the assay. Factors which are likely to influence the amount of material remaining in the gastrointestinal tract are the nature of previous diet, the period for which it is removed, the nature of the test

feedingstuff and the amount given, the length of the collection period, water intake and random variation in caecal evacuation. Sibbald (1976) originally proposed 24 h starvation and 24 h collection periods (24 h + 24 h assay) but now Sibbald (1986) proposes 24 h + 48 h for routine use. In this laboratory 48 h + 48 h is routinely used (McNab and Fisher, 1984; McNab and Blair, 1988). The longer period is clearly more stressful and factors such as bird size and glucose feeding come into consideration.

Sibbald (1982) has shown that 12 h starvation before feeding was insufficient to clear the digestive tract of residues but that extension beyond 24 h had only a small effect on derived TME values. Direct investigation however, shows a measurable difference between residues remaining after 24 h and 48 h starvation (Table 1). These observations and the logic of

TABLE 1. Residues remaining in the gastrointestinal tract of starved cockerels

Starvation Period (h)	Residues (g)	Total Energy (kJ/g)
24	1.59 ± 0.56 (0.83 to 2.58)	20.25
48	0.17 ± 0.08 (0.05 to 0.30)	2.06

equalising the pre- and post-feeding starvation periods encourages the use of the 48 h + 48 h assay and adjustment of other factors to deal with the increased stress. In general, we find clearance rates are variable between feedingstuffs and amounts fed (Sibbald, 1982) and it seems appropriate that a constant maintenance diet of well digested components should be used, although this does not appear to be a very critical issue (Shires *et al.*, 1979). To some extent a correction is made for carry-over of energy from the previous diet in calculating TME in Sibbald's assay because it seems reasonable to expect that a comparable error will occur in both the fed and negative control birds.

The time required to ensure complete clearance of a feedingstuff, especially when single ingredients are fed in type 3 assays, is a complex and largely unresolved issue. The original proposal of 24 h (Sibbald, 1976; Farrell, 1978) is now known to be too short and all data collected under these conditions are unreliable and should be ignored. Farrell (1981) now recommends 32 h and Sibbald (1986) 48 h for routine use. Some TME values comparing data derived from 48 h and 72 h collections when the amounts fed were 50 g are shown in Table 2. These data suggest that for some ingredients (e.g. blood meal) 48 h are insufficient to allow all undigested residues to be voided. The results of Sibbald and Morse (1983), and Sibbald's work elsewhere, suggest that the use of lower intakes alleviates the problem but at the cost of both reduced accuracy and increased influence of endogenous factors. It is our experience that complete clearance is a problem with high protein, and especially finely divided animal products: materials of low density which results in the crop being packed very full can also cause problems, where wetting of the feedstuff in the crop may be a factor.

Palatability may also be involved because, for example, when blood meal-fed birds are given water, distaste seems to be experienced and regurgitation can occur. The sudden introduction of some ingredients may induce gut stasis; attempts to evaluate coffee residues by tube-feeding had to be abandoned because the food did not pass from the crop. At the present time it is only possible to advise caution, particularly with unfamiliar ingredients, and to look out for food residues being excreted after the end of the balance period in doubtful cases. Routinely extending the collection period to 72 h would provide an empirical solution but at the cost of stress on the birds. Longer balance periods also result in higher

endogenous:exogenous energy ratios and the relative importance of the error introduced by correcting for EEL assumes greater significance.

TABLE 2. Comparison of TME_N values derived after 48 and 72 h excreta collection

Ingredient	Samples	TME _N (48 h)	TME _N (72 h)	Rel
Full fat soyameal	4	14.44	14.42	100
Wheat meal	12	12.77	12.75	100
Fish meal	12	13.29	13.06	98
Blood meal	5	13.37	12.09	90
Meat and bone meal	7	10.77	10.46	97
Wheat feed	12	8.59	8.56	100
Carrot	1	9.97	9.80	98
Cabbage	1	9.81	9.44	96
Pea hulls	1	1.79	1.63	91

The assessment of these factors in type 2 assays (Farrell, 1978) is difficult. With high intakes, such as 70-80 g, 32 h collection periods may be too short for certain feedingstuffs; for example, see Sibbald and Morse (1983) for alfalfa and oats. On the other hand, the use of complete diets and allowing a feeding period of 1 h may reduce the problem in comparison to tube-feeding single ingredients. It seems reasonable to suppose that because the crop does not become so tightly packed with dry food under these conditions, water intake and the passage rate of the food residues might be more normal.

The importance of water intake in these assays is yet another area where firm conclusions cannot be reached and which may be a significant source of variation. In our laboratory it has consistently been observed that, despite the ready availability of water tube-fed birds were rarely seen to be drinking (McNab and Blair, 1988). Yeomans (1987) has shown that 90% of water consumption by domestic fowl is associated with voluntary food intake and it may be that lack of access to food reduces the stimulus to drink. Whether low and variable water intakes explain erratic food passage rates and consequently residue clearance is still speculation but Table 3 summarises the findings which led to the routine administration of water (50 ml/bird) during the balance period in our laboratory. This practice also provides an opportunity to palpate the crop and to mix any food residues remaining with water. Only rarely (e.g. blood meal) has it led to losses of food from the crop but it does seem reasonable to argue that it will change the relationship between the amounts fed and clearance rates (Sibbald and Morse, 1983), although this has not been examined.

A direct study into the rôle of water:food ratios on diet digestibility was reported by Van Kampen (1983) but produced ambiguous results. A positive relationship was found among birds with free access to water between AME (y, % G.E.) and the water:food ratio (x).

$$y = 66.38 + 2.97 x \quad (P 0.01, r = 0.49)$$

TABLE 3. Energy voided by cockerels starved of food or fed soyabean meal

Water Administration		Soyabean meal fed (g)	Energy excreted (kJ)	TME (kJ/g)
Before feeding	After feeding			
+	+	0	89.38 ± 20.38	
-	-	25	257.30 ± 41.99	11.00
-	+	25	246.88 ± 33.49	11.42
+	+	25	236.39 ± 5.28	11.83

This is an effect of considerable magnitude but it could not be demonstrated experimentally when water was administered by tube immediately after feeding (a mixture of free- and tube-feeding, feeding time 15 min) in a rapid assay. However, excreta were collected for only 24 h and this may have concealed any treatment effects. More work requires to be carried out on the effect of water consumption on ME values with a range of ingredients and not just with practical diets.

ENDOGENOUS ENERGY LOSS (EEL)

Knowledge of the EEL is a prerequisite for the determination of TME and we strongly recommend its measurement in AME assays. It has to be admitted that there are both difficulties and uncertainties in the determination of this component of the excreta. Any errors which cannot be taken into account will result in errors in the values ascribed to both AME and TME. Three methods have been used to derive EEL : starving birds, giving birds a completely metabolisable energy source (e.g. glucose) or by extrapolating to zero intake a line relating energy excretion to energy intake.

Starvation has been the most widely used means of deriving EEL and is the method currently recommended by Sibbald (1986). However, in a starved state individual birds void quite variable amounts of energy. Values ranging from 33 to 82 kJ/24 h (Farrell, 1978) and from 25 to 69 kJ/24 h (Sibbald and Price, 1978) have been reported for the second 24 h period of 48 h of starvation (24 h + 24 h assay). In our laboratory a somewhat wider range has been found, presumably a consequence of the greater stress associated with the 48 h + 48 h assay. Individual values ranged from 47 to 238 kJ/48 h (24 to 119 kJ/24 h) and the average coefficient of variation within an experiment (6 replicates) was 36.8%.

Neither bird weight nor body weight changes appear to explain a significant proportion of the variation (Muztar and Slinger, 1980a; Sibbald and Price, 1978), although a body weight effect was reported by Shires *et al.*, (1979). Dale and Fuller (1981) have associated differences in EEL with variations in environmental temperature. In winter, when the mean temperature was 5°C, EEL was 133.9 kJ/48 h whereas in summer (30°C), EEL was 75.3 kJ/48 h. It had been shown earlier (Farrell and Swain, 1977) that temperature and the birds' acclimation to it affected the EEL from starved adult cockerels. A curious interaction between temperature, EEL and TME values has been reported by Yamazaki and Zhang (1982). Although starved adult cockerels excreted 126.5 kJ/48 h at cool temperatures (5-

15°C) and 64.6 kJ/48 h at hotter temperatures (25-35°C), the environment did not affect the energy excreted by birds fed 25 g of a proprietary diet. Consequently the TME calculated for the diet at the lower temperature (15.72 kJ/g) differed markedly from that derived in the hotter environment (12.84 kJ/g). We have been unable to confirm any effect caused by temperature with birds fed glucose solutions during the pre-feeding period and tube-fed 50 g glucose. At 5°C EEL was 82.98 kJ/48 h whereas at 35°C it was 84.84 kJ/48 h and TME values of the feedingstuffs tested were consequently unaffected by the temperature.

In our laboratory, with a 48 h + 48 h assay and using birds every 4 weeks, we have found a considerable reduction in EEL and conspicuously less between bird variation when excreta are collected from birds which have been fed glucose (50 g) rather than starved. Sibbald's (1975) results with glucose are at variance with this finding and with that of Dale and Fuller (1981), who have observed that birds given 0, 12.5 and 25 g respectively of a glucose:maize (50:50) mixture voided 57.7, 52.1 and 48.9 kJ/24 h. Reasons for these differences are unclear. Age and strain of the bird but not its sex have been shown to affect EEL from starved birds (Miski and Quazi, 1981). These effects were tentatively attributed to differences in body composition and basal metabolic rate.

More recently data from a series of experiments have indicated that EEL may be an artefact of starvation (Härtel, 1986; 1987) and that when birds are fed continuously (as they are under practical conditions) $TME = AME$. Even when food intakes were reduced to 20 g/day, the derivation of a line relating energy excretion to energy intake and extrapolation to zero intake gave intercept values which did not differ from zero. This finding, of course, supports that of Hill and Anderson (1958) who found no effect of food intake on AME values when food intake was reduced to 0.30 of *ad libitum* and of Potter *et al.*, (1960) who claimed that, under similarly severe restrictions, AME tended to increase slightly; it was speculated that this improvement could be attributed to increased diet digestibility often associated with lower intakes. These results are in direct contrast to those of Guillaume and Summers (1970) and to earlier findings from this laboratory (Jonsson and McNab, 1983). Whether the apparent contradiction can be ascribed to starvation followed by tube-feeding must remain a matter for conjecture at this stage. Recent work (Farrell *et al.*, 1991) does not resolve this issue but does suggest that EEL is positive under *ad libitum* feeding.

What is clear is that both the definition and measurement of EEL from poultry require further investigation. At the present time it can either be argued that the uncertainty is limited and, that for all practical purposes, reasonable estimates of EEL can be obtained from one of the procedures described earlier; or it can be decided that the problem is insoluble and that corrections to account for EEL should be ignored. Broadly speaking these are the respective views of those who either argue for the adoption of a type 3 assay or who maintain that classical assays of type 1 should be retained.

Recent collaborative studies with a type 1 assay in some European laboratories have shown its reliability as a means of deriving the AME_N values of diets (Bourdillon *et al.*, 1990). With 3 diets, a basal mix and this diet replaced with either 300 g/kg of wheat or soya bean meals, the 5 participating groups generated AME_N values for all diets with a high degree of precision (Table 4). However, when these data were used to derive AME_N values for the

TABLE 4. Composition and AME_N values of 3 diets determined in 5 laboratories

Composition (g/kg)	Diet No.		
	1	2	3
Basal mix	1000	700	700
Wheat meal	0	300	0
Soyabean meal	0	0	300
Laboratory	AME _N (kJ/g)		
1	13.90	13.91	12.95
2	14.21	13.97	13.13
3	13.94	14.25	12.96
4	13.66	13.84	12.27
5	14.03	14.20	13.10
Mean ± SD	13.95 ± 0.20	14.03 ± 0.18	12.88 ± 0.35

wheat and soya bean meals the results are conspicuously less definite (Table 5). This illustrates the difficulty, if not the impossibility, of deriving meaningful ME values for raw materials, as opposed to diets, using type 1 assays, even when great care is taken by experienced people.

The simplicity and speed of type 3 assays mean that many more can be carried out with an increase in the amount of information available. For the evaluation of ingredients, which can be assayed directly rather than by dietary substitution, they must be the methods of choice.

TABLE 5. AME_N values of wheat and soyabean meals derived from feeding diets containing 300 g/kg of each by 5 laboratories

Laboratory	Wheat	Soyabean
1	13.93	10.73
2	13.41	10.61
3	14.97	10.67
4	14.26	9.03
5	14.60	10.93
Mean ± SD	14.23 ± 0.60	10.39 ± 0.77

for the future. To fulfil this objective, no effort should be spared to resolve the uncertainty of the size of the EEL. At the moment there seems reasonable grounds for suspecting that many values quoted for EEL are overestimates and that, under the practical conditions of *ad libitum* feeding, EEL_N lies somewhere between 0 and 20 kJ/bird/24 h; with our 48h + 48 h regime, giving 25 g glucose twice during the first 48 h period and feeding 50 g glucose at the start of the balance, we most frequently find an EEL_N value of around 20 kJ/24 h. If this

is assumed to be correct, it can readily be seen that with birds eating 100 g/day, the difference between TME_N and AME_N is only 0.2 kJ/g. In other words, an ingredient with a TME_N value of 15.0 kJ/g would have an AME_N value of 14.8 kJ/g, only 1.3% lower. The effect is, of course, greatest with raw materials of low ME content, although it still can be considered small and much smaller than the 10% differences suggested earlier (Sibbald, 1977). If the conditions adopted for food presentation are confirmed to affect EEL_N , as suggested by Härtel (1986; 1987) and Farrell *et al.*, (1991) then the difference between AME_N and TME_N may be even less and it is doubtful if biological assays capable of detecting such small effects could be designed. With food intakes greater than 100 g/day the differences will be even smaller and this may explain why efforts to detect them have largely been unsuccessful.

AMINO ACID AVAILABILITY

As with dietary energy not all amino acids contained in dietary protein become available to the bird during digestion and metabolism. Although much emphasis has been placed on the amino acid compositions of feedingstuffs and diets, it has been recognised for many years that for almost all foods these values are only useful in predicting the potential worth of the protein. Sibbald (1987) uses the term bioavailable to define that portion of the ingested nutrient which is used for normal metabolic functions. Available amino acids are usually considered to be those actually supplied at the site of protein synthesis. Despite many attempts to devise methods capable of measuring what proportion of the amino acids from the protein ingested reaches these sites, quantitative data which can be used in diet formulation are very limited, often restricted to one amino acid (lysine, say) and are not universally accepted. At the present time about the only acknowledgement that is made to availability in commercial diet formulation is to increase slightly the specification of some of the key nutrients by a small percentage, the precise amount depending on the nature of the ingredient, the marginal cost and the judgement of the nutritionist. In the current climate of high food costs and small profit margins in poultry production in the UK, there is considerable pressure to reduce the extent of overformulation, at least of price-sensitive nutrients.

DIGESTIBILITY

As a first step to describing amino acids in terms of their availability and in order that some progress can be seen to be being made, it seems sensible to establish the extent by which the amino acids contained in the dietary protein are absorbed from the gastrointestinal tract during digestion, the so-called digestibility coefficients. Although it is possible to imagine circumstances whereby an amino acid could be digested but not be available for use by the host animal, it is obvious that undigested amino acids (those appearing in the faeces) have made no contribution to the needs of the animal. Therefore, describing the proteins in feedingstuffs in terms of their digestible amino acids, although perhaps not ideal, is almost certainly closer than total to reflecting the amount that actually becomes available for maintenance and production.

Digestible amino acids are generally calculated from the differences between measures of the amounts in the food and those in the excreta. It is common to express this difference as a proportion of the amount consumed (the digestibility coefficient):

$$\text{Amino acid digestibility} = \frac{\text{Amino acid consumed} - \text{amino acid in faeces}}{\text{Amino acid consumed}}$$

In discussions of this sort, confusion often arises over the terminology used. Strictly speaking the above term should be referred to as apparent digestibility because, of the amino acids in the faeces, only part has arisen from undigested food residues. Part has come from the animal itself and consists of gut secretions, sloughed-off gut tissue, bacteria etc. Sibbald (1987) distinguished between what he calls the metabolic faecal component (secretions, abraded cells, mucus, bile) and the endogenous faecal fraction (bacteria and bacterial debris) but in this paper both are grouped as endogenous faecal material. Its measurement allows true digestibility to be calculated thus:

True amino acid digestibility

$$= \frac{\text{Amino acid consumed} - (\text{amino acid in faeces} - \text{endogenous amino acid in faeces})}{\text{Amino acid consumed}}$$

To derive this term some means of measuring the amount contained in the endogenous component has to be devised.

A further source of debate in measurements of digestibility is the effect of bacteria in the hind gut, an activity that could influence the amounts of both endogenous and exogenous amino acids excreted. Definitions of digestibility can accommodate, at least partly, the effects of the microflora in poultry, either by using caeectomised birds (the caeca are generally acknowledged to be the principal site of microfloral activity) or, arguably better, by basing values on amino acid concentrations in the terminal ileum (i.e. before the bacteria exert any effect). To relate the amino acid concentration at the ileum to that in the food requires the addition of an indigestible marker (such as chromium sesquioxide) to the food and its measurement in both food and ileal contents. Measurement of ileal contents also almost invariably require the birds to be killed. Although cannulation has been used for this type of assay, it requires skilful surgery which is laborious and expensive to carry out on large numbers of birds; maintenance of the flock is also labour-intensive.

A further factor complicating the determination of digestibility with poultry is the fact that birds excrete faeces and urine together and the collection of faeces requires the birds to be colostomised. It has, however, become increasingly common to overlook the effect of urine in assays designed to determine amino acid digestibility, the rationale being that the urinary contribution to the amino acids in poultry excreta is exceedingly small and barely affected by the nature of the input. However, this assumption should be tested and, to be strictly correct, balance experiments where amino acids are measured in excreta determine unmetabolised rather than undigested protein. Also if an amino acid appears in the urine as a metabolite it will result in misleading information.

In addressing the topic of amino acid digestibility in poultry and devising techniques for its measurement, all the factors outlined above have, at one time or another, been considered important enough to have been taken into account. Despite this there is still no clear indication whether data derived from excreta differs from that derived from faeces, whether

the microflora affect digestibility measurements and the significance of any effects or whether values should be expressed as true or apparent coefficients of digestion. In other words, no consensus exists as to a preferred system for expressing the extent to which amino acids in dietary protein are digested by birds.

METHODS FOR DETERMINING AMINO ACID DIGESTIBILITIES

As with ME, digestibility is frequently considered to be a property of a diet or feedingstuff, but it is really a characteristic of an animal to which the food is given. It is, for example, a matter for debate whether the digestibility of a particular food is the same across all monogastric species. Digestibility measurements relate to the complete diet consumed and values for ingredients must, in most cases, be obtained by comparing results from two or more appropriate diets (substitution methods). The assumption that digestibility coefficients are additive amongst feedingstuffs is essential and, as with ME, little progress can be made if this assumption is not upheld.

Using exactly the same logic put forward for the derivation of ME, it can be argued that three observations are required from a bioassay designed to determine digestibility of amino acids. 1. The amount of the amino acids consumed, 2. The amount excreted and 3. A measure of the endogenous amino acid losses. When discussing methods it is useful to remember the relationships proposed for ME and shown in Figures 1 and 2. By regressing excreted amino acid against amino acid intake, the intercept on the y-axis provides a measure of the endogenous amino acid loss (i.e. the amino acid excretion at zero amino acid intake) while the slope of the line gives the true digestibility of the amino acid as follows:

$$\text{true digestibility} = \text{amino acid intake} \times (1-b)$$

Estimates of apparent digestibility correspond in a similar way to the slopes of lines joining given amino acid balances with the origin; thus, in Figure 1, apparent digestibility is equal to the amino acid intake $\times (1-b')$. It should also be remembered that if the intercept is zero then apparent and true digestibilities are the same and apparent digestibility is independent of intake. Negative intercepts imply an artefact in the measurement.

DROPPINGS VS FAECAL COLLECTION

The difficulty involved in separating faeces from urine in poultry has meant that almost all published values are based on the amino acid recovery in droppings rather than the more technically correct faeces. It is generally assumed that the amino acid concentration of urine is low and can be ignored. An experiment by Bragg *et al.*, (1969) compared results from normal and colostomised birds (Table 6). These data suggested that digestibility values derived from normal birds were slightly but significantly different from those derived from colostomised birds, differences which were caused by the colostomised birds excreting greater quantities of endogenous amino acids (Table 7). Because these larger concentrations occasionally led to digestibility values greater than 100%, it was suggested that they were artefacts of the modification and that normal birds gave more realistic digestibility coefficients. Although this experiment suggests that there is little practical difference in using the technically less correct droppings in equations to derive digestibility coefficients, from a scientific standpoint verification of the findings is required.

TABLE 6. True digestibility coefficients (%) of some amino acids in grain sorghum by colostomised and normal birds

	Colostomised	Normal
Ala	93.1	90.9
Arg	92.2	91.0
Asp	98.4	95.8
Glu	93.6	92.8
Gly	87.5	81.3
His	87.8	84.1
<u>iso</u> -Leu	92.3	90.5
Leu	93.5	92.3
Lys	91.7	87.9
Met	93.7	93.2
Phe	93.7	91.7
Pro	88.7	86.4
Ser	91.2	88.6
Thr	88.9	86.1
Tyr	94.0	92.3
Val	90.8	89.6

EFFECT OF FERMENTATION

The effect of fermentation is another largely unresolved issue. It has been argued that undigested amino acids which reach the hind gut can be deaminated by the microflora into products of no nutritional value. Yet, because the deaminated but undigested amino acids do not appear in the faeces, they are judged to have been absorbed. Evidence to support this hypothesis is contradictory. While Johns *et al.* (1986) and Parsons (1985;1988) report important effects caused by the presence of caecal microflora (Table 8), results from our laboratory (Table 9) agree with those of Picard *et al.* (1983) and Green *et al.* (1987) who found only small and non-significant effects. Recent studies in our laboratory (Longstaff *et al.*, 1991) with field beans continue to support the view that activity in the caeca of adult birds has little effect on the extent to which protein is digested. Furthermore, Bielorci and Iosif (1987) have shown that only small differences exist between the digestibilities of the amino acids from soya bean meal in the ileum and excreta (Table 10). The lack of effect was attributed to the very rapid passage rate of digesta and the relatively small volume of the hindgut in poultry.

TABLE 7. Endogenous amino acids excreted (mg/4h) by colostomised or normal 4-week-old chicks (Bragg *et al.*, 1969) or by adult cockerels (McNab, unpublished)

	Colostomised	Normal	Adult
Ala	4.4	5.0	3.0
Arg	2.5	1.8	0.7
Asp	5.8	4.2	4.1
Cys	1.5	1.9	1.7
Glu	6.9	5.4	5.7
Gly	3.5	4.5	N.D.
His	1.1	0.5	4.4
iso-Leu	2.2	1.5	1.6
Leu	3.8	2.4	2.5
Lys	2.1	0.6	1.7
Met	0.8	0.4	0.8
Phe	1.9	1.9	1.2
Pro	3.6	3.0	2.3
Ser	4.0	3.2	3.2
Thr	4.1	3.4	2.8
Tyr	2.2	1.4	1.5
Val	3.7	1.9	2.2
Total	54.1	43.0	39.4(43.9)

Digestibility based on dropping samples from unaltered birds has the decided advantage of simplicity over either the use of caectomised birds or values based on ileal concentrations. It encourages assays to be carried out on larger numbers of birds and this increases the precision of the data. The majority of values published on amino acid digestibilities are derived from measurements made on droppings from intact birds.

TABLE 8. Effect of caeectomy on true amino acid digestibility coefficients (%)

		Normal	Caeectomised
Parsons (1988)			
Feather meal	Lys	73.8	67.9
	Cys	72.3	59.3
	Met	78.4	74.6
Meat meal	Lys	86.9	81.6
	Cys	85.6	79.9
	Met	90.1	87.4
Poultry offal	Lys	86.0	80.0
	Cys	87.4	80.8
	Met	90.5	88.2
Johns <i>et al.</i> , (1986)			
Meat and bone	Thr	78.9	75.4
	Ser	85.1	81.9
	Val	88.6	84.7
	Met	90.2	90.7
	iso-Leu	87.6	87.7
	Leu	88.6	87.2
	Tyr	82.0	66.5
	Phe	85.4	76.4
	His	86.2	81.6
	Lys	88.1	82.0
	Arg	88.9	88.3

TABLE 9. Effect of caecectomy on the digestibility of amino acids (%) in distiller's dried grain

	Normal	Caecectomised
Ala	69.3	71.4
Arg	93.6	93.5
Asp	59.5	54.6
Cys	77.4	74.6
Glu	82.3	83.1
His	63.2	59.1
iso-Leu	87.2	89.4
Leu	85.5	87.6
Lys	77.6	81.1
Met	86.0	87.9
Phe	89.3	91.2
Pro	91.2	90.2
Ser	82.4	82.6
Thr	81.5	80.1
Tyr	86.6	89.7
Val	84.6	86.9
Total	82.8	83.3

TRUE OR APPARENT DIGESTIBILITY COEFFICIENTS

Because the apparent digestibilities of amino acids in a feedingstuff depend on the food intake (Figure 2), care must be taken to ensure that comparisons of values across foodstuffs is made at constant intakes, otherwise a systematic bias may inadvertently be incurred. Probably, for this reason it is preferable to express values in terms of true digestibility coefficients which are independent of food intake (Sibbald, 1979), although, as has already been said, how the endogenous amino acid contributions are determined is still a matter for debate. However, because the endogenous amino acid excretion in birds is a relatively small percentage of the total amino acids excreted after feeding most feedingstuffs, the uncertainty associated with these values has less impact than endogenous energy losses have on true metabolisable energy values. The observation that true amino acid digestibilities established in chickens can be applied to muscovy ducklings, whereas apparent digestibility coefficients differed (Mohamed *et al.*, 1986) between the two species (Table 11) is proof that great care is required to ensure that valid comparisons are being made. More comparisons of this sort are required.

TABLE 10. True digestibility of soya bean meal amino acids (%) at the ileum and in the excreta of chicks (Bielori and Iosif, 1989)

	Ileum	Excreta
Ala	83.5	84.4
Arg	86.3	89.7
Asp	81.1	85.6
Cys	81.6	95.0
Glu	87.9	90.3
His	85.0	88.5
<i>iso</i> -Leu	84.3	86.6
Leu	84.0	86.5
Lys	86.7	88.5
Met	88.9	89.5
Phe	85.2	87.3
Pro	83.7	87.4
Ser	82.8	84.6
Thr	82.2	82.8
Tyr	85.6	88.5
Val	85.2	85.9

TABLE 11. Apparent and true digestibilities (%) of 3 amino acids in a soya bean meal based diet by chicks and muscovy ducklings (Mohamed *et al.*, 1986)

	Apparent		True	
	Chicks	Ducks	Chicks	Ducks
Arg	92.9	87.5	94.5	96.9
Lys	80.7	85.5	96.9	99.0
Thr	76.3	76.6	93.3	91.8

CONCLUSIONS

Although many questions still remain to be resolved on the most valid techniques to measure amino acid digestibility coefficients there are good grounds for optimism. More work is required to determine what factors affect endogenous losses and whether the use of caecectomised birds results in the derivation of significantly different and more meaningful digestibility coefficients. The age of the bird is another factor which may require to be taken into consideration and whether digestibility coefficients derived with adult cockerels can be used with turkeys and ducks.

For poultry nutrition, generally, the prospects are undoubtedly exciting. The introduction and development of the rapid assay based on tube-feeding allows raw materials to be studied directly and values are no longer subject to either the vagaries of food intake or the uncertainties of extrapolation. Their cheapness and speed have allowed many more of them to be carried out with a consequent increase in the accuracy of nutritional information.

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PERFORMANCE OF MALE TURKEYS FED CANOLA, MEAT, POULTRY
BY-PRODUCT, AND FEATHER MEALS REPLACING A LIVE
QUANTITY OF BIOAVAILABLE PROTEIN FROM SOYBEAN MEAL

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INTRODUCTION

The provision of protein and amino acids in feed is a major component in the cost of producing turkeys. Starting diets may contain 45% of protein rich ingredients such as soybean meal, which at that level provides about 21% protein or 75% of the total amino acid requirement. However, because of soybean meal's lower methionine content, even that inclusion rate would not supply enough methionine to elicit maximum growth for most economical performance. Dietary supplementation with methionine is, therefore, essential to achieve the desired performance from turkeys fed diets based on soybean meal.

The dietary concentration of protein is frequently determined by the bird's need for the second most limiting amino acid, usually lysine. It may be cost effective to include methionine and lysine supplements thereby reducing the level of soybean meal. With this approach, savings up to 15% of soybean meal usage may be made.

Benefits may be gained by the use of several alternative protein rich supplements which may at times be cheaper and more readily accessible than soybean meal. These include canola, sunflower, corn gluten, meat and bone, poultry by-product, feather, and blood meals.

Comparisons between proteins of soybean meal and alternative feed sources are usually based on chemical analyses which provide total amino acid concentrations. No attention has been directed at the use of these protein sources considering their available amino acids, especially at reduced protein levels where amino acid supplementation may be utilized.

Some concerns have been expressed that higher levels of soybean meal, i.e. over 40% may in some instances be harmful to the well-being of turkeys. Using lower protein levels and alternative protein sources will ameliorate this situation.

We have for some time been investigating the capacity of supplementary methionine and lysine to reduce the apparent high protein need of growing turkeys. Doing so borders upon the expression of further limiting amino acids. In these lower protein situations where additional limiting amino acids and amino acid balance become important, the amino acid patterns of alternative protein sources may be of interest for potential protein-sparing ability. These protein sources are in their own right of direct feeding interest. Low protein diets as

well as canola meal often have the potential for reducing feed costs as described by Carlson (1991). While undertaking this study on the feeding of alternative protein sources at lower protein levels, diets were formulated based upon available amino acids.

MATERIALS AND METHODS

Supplies of corn, soybean meal, canola meal, meat and bone meal, poultry by-products meal, and feather meal were obtained which would be sufficient for the entire experiment. True metabolizable energies (TME) and true amino acid availabilities (TAAA) were determined on these ingredients using 7 week old hen turkeys. The determined values were utilized in the formulation of the diets.

The experimental design follows: Shown are the number of pens of 11 tons each per treatment.

Diet	<u>Protein Level,</u>	<u>% of NRC (1984)</u>	
	100	85	75
Corn-soy	6	6	6
Canola meal	6	6	6
Meat, and bone meal	6	6	6
Poultry byproducts meal	6	6	6
Canola and meat	6	6	6
Feather	4	4	
<u>Formulation rules:</u>	Only net	Only net	Lys to 85%:
(for amino acid	to 100%	to 100%	net to 100%
supplementation	of NRC M+C	of NRC M+C	of NRC M&C

The diets are shown in Tables 1a through 1c. Except for feather meal at 4%, the other meals were initially used at levels to supply about 5% digestible protein. The levels were dropped with age to keep the ratio of any and test protein constant.

Temperatures in the barn averaged 78, 71, 65, 65, 69 and 73°F in successive 3-week experimental periods.

RESULTS AND DISCUSSION

Data for the composition of the materials to be assayed are given in Table 2. The canola meal was higher in protein than had been encountered previously, i.e., 42.6% vs. 38% as is given by NRC (1984), and commonly shown. That probably meant more of the seed coat had been removed which also led to a somewhat higher energy value.

The amino acid contents in the corn and protein supplements used are presented in Table 3. With the higher protein content in canola meal, one would expect to see higher lysine, yet the analysis showed it to be lower than in NRC (1984). Canola meal also showed much higher

cystine and isoleucine levels than would be expected in proportion to the increased protein content. Feather meal was somewhat lower in protein than that used previously. It showed a lower level of phenylalanine and tyrosine than expected. The system, meat & bone and poultry by-product meals appeared to be typical of that used in industry.

The averaged percentage availability values for the ingredients are shown in Table 4. One would rank corn, soybean meal, meat & bone meal and poultry by-products meal, with averages around 90%, as high in availability of amino acids, with canola meal showing lower availability (85%) and feather meal ranking lowest (81%). Only preliminary analyses used in formulation of the diets are shown in the Table 4.

Turkey body weights at 6, 12, and 18 weeks of age are presented in Table 5. The table is arranged so that one may observe main effects of ingredient and protein levels. Statistical analyses included a factorial 5 x 3 analysis of variance and another where the 17 treatments were analyzed independently.

In observing the average growth responses at 6 weeks, it is surprising how little growth retardation resulted from reducing the protein to 85 and 75 percents of NRC (1984). It is emphasized that methionine was present to 100% of the NRS (1984) sulfur amino acid requirement levels in all treatments. The large body weight responses 9.9 and 13.7%, to meat and bone and poultry by-product meals, respectively, across the three protein levels were surprising; however, one may note in diet tables that the energy levels of these diets were greater than in the corn-soybean and corn-soybean-canola meal diets.

The weights at 12 and 18 weeks of age show that the responses to protein widened with time; at 18 weeks, there was about a pound difference between protein levels. The responses to meat and poultry meals are substantial although lower on a percentage basis. Turkeys fed canola meal, without or with meat meal, weighed somewhat less at 100 and 85% of NRC protein, but not at 75% protein. Inclusion of feather meal, was favorable at either protein level. The combination of canola and meat meals performed satisfactorily.

Feed efficiency values for the entire experiment (18 weeks duration) are shown in Table 5. The large improvement in feed efficiency with the meat and poultry diets is impressive and is in keeping with the higher available energy values in diets containing these ingredients. The presence of canola meal resulted in somewhat reduced feed efficiencies as expected. Protein level did not affect feed efficiency; apparently the influence of lower protein in reducing gains and thereby reducing efficiency was countered by the higher amount of available energy in the lower protein diets.

Feed cost per unit of gain data show that meat and canola meals, separately or in combination were quite attractive economically. Diets of lower protein were also associated with slightly reduced feed cost. (Costs of feed components used in this analysis were, in \$/100 kg. corn, 9.90; soybean meal-dehulled 22.10; sunflower meal, 8.80; canola meal, 15.40; meat and bone meal, 26.50; poultry by-product meal, 29.20; feather meal, 22.10; fermentation residue product, 48.50; dicalcium phosphate, 27.60; calcium carbonate, 3.30; sale, 8.80; DL-methionine (99%), 330.70; L-lysine (78.4%), 198.40; trace mineral mix, 55.10; vitamin mix

MTS-74, 88.20; vitamin mix MTG-74, 66.10; animal fat, 26.50; and mixing charge, 1.70.

SUMMARY

Canola meal, meat and bone meal, poultry by-products meal, and feather meal were substituted into diets of growing turkeys at 100, 85, and 75% of NRC protein requirement levels. In all treatments methionine was added so that methionine and cystine reached 100% or NRC (1984). Lysine was added to the 75% protein treatments to bring lysine to 85% of NRC.

The true availabilities of amino acids (TAAA) in corn, soybean, and these protein supplements were determined so that feeds could be formulated on the basis of available rather than total amino acids. These ingredients were samples of large batches used in the growth study. The TAAA in corn, soybean meal, canola meal, meat and bone meal, poultry by-products meal, and feather meal approximated 91, 90, 85, 91, 89, and 81%, respectively.

Body weights were measured from day old to 18 weeks of age. While they were reduced somewhat with lower diet protein they were still surprisingly good; doubtless because of the methionine and lysine supplementation employed. Body weights were superior with the poultry by-product meal, and meat and bone meal treatments, either because diets containing these supplements were higher in available energy, had improved amino acid balance, or contained unidentified nutritional factors. With the recent ingredient costs used, canola meal, meat and bone meal, or their combination, resulted in reduced feed cost per unit of turkey produced.

ACKNOWLEDGEMENTS

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Table 1a. Composition of 0 to 3 and 3 to 6 week diets for Experiment TG-911.

Ingredient	All lysine from protein sources at 100% NRC plus methionine to supply 100% SAA						All lysine from protein sources at 85% NRC plus methionine to supply 100% SAA						All lysine from protein sources at 75% NRC plus methionine to supply 100% SAA and 10% l-lysine				
	1	2	3	4	5	16	6	7	8	9	10	17	11	12	13	14	15
Weeks 0 to 3																	
Ground corn	38.7	36.0	39.3	38.9	36.6	36.9	46.1	43.3	47.1	46.6	44.3	44.4	51.3	48.4	52.4	51.9	49.4
Soybean meal, dehulled 47%	48.9	37.1	42.0	41.0	30.1	47.1	41.2	29.4	33.9	33.0	22.2	39.3	35.6	23.9	28.2	27.4	16.6
Sunflower meal	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Canola meal	.0	15.0	.0	.0	15.0	.0	.0	15.0	.0	.0	15.0	.0	.0	15.0	.0	.0	15.0
Meat and bone meal	.0	.0	10.0	.0	10.0	.0	.0	.0	10.0	.0	10.0	.0	.0	.0	10.0	.0	10.0
Poultry by-product meal	.0	.0	.0	10.0	.0	.0	.0	.0	.0	10.0	.0	.0	.0	.0	.0	10.0	.0
Feather meal	.0	.0	.0	.0	.0	4.0	.0	.0	.0	.0	.0	4.0	.0	.0	.0	.0	.0
Fermentation residue product ¹	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25
DL-Methionine (99%)	.216	.115	.210	.223	.109	.134	.308	.205	.306	.318	.203	.227	.372	.269	.372	.304	.268
L-Lysine (78.4%)	0	0	0	0	0	0	0	0	0	0	0	0	.193	.189	.199	.196	.192
Animal fat	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Minerals + vitamins	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Nutrients:																	
Protein (%)	27.9	28.4	30.0	29.5	30.5	29.8	25.0	25.5	27.0	26.5	27.6	26.8	23.0	23.6	25.0	24.5	25.6
Metab. energy (kcal/kg)	2782	2744	2894	2864	2857	2801	2848	2810	2964	2934	2925	2868	2890	2851	3006	2978	2967
Available																	
Methionine (%)	.557	.499	.588	.598	.530	.485	.615	.556	.648	.658	.589	.542	.654	.595	.689	.698	.629
Methionine + cystine (%)	.939	.926	.977	.967	.964	.945	.961	.948	1.000	.990	.987	.968	.975	.962	1.015	1.005	1.001
Lysine (%)	1.431	1.411	1.489	1.473	1.469	1.440	1.245	1.228	1.296	1.283	1.279	1.254	1.263	1.246	1.314	1.302	1.297
Threonine (%)	.993	1.019	1.033	1.013	1.059	1.070	.884	.912	.920	.901	.947	.960	.806	.835	.839	.822	.869
Weeks 3 to 6																	
Ground corn	42.6	40.1	43.4	42.9	40.8	41.1	49.8	47.2	50.8	50.3	48.2	48.3	54.6	51.7	55.8	55.2	53.1
Soybean meal, dehulled 47%	45.7	34.8	39.2	38.3	28.3	43.9	38.3	27.5	31.5	30.7	20.7	36.5	33.1	22.6	26.2	25.4	15.4
Sunflower meal	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Canola meal	.0	13.8	.0	.0	13.8	.0	.0	13.8	.0	.0	13.8	.0	.0	13.8	.0	.0	13.8
Meat and bone meal	.0	.0	9.2	.0	9.2	.0	.0	.0	9.2	.0	9.2	.0	.0	.0	9.2	.0	9.2
Poultry by-product meal	.0	.0	.0	9.2	.0	.0	.0	.0	.0	9.2	.0	.0	.0	.0	.0	9.2	.0
Feather meal	.0	.0	.0	.0	.0	3.7	.0	.0	.0	.0	.0	3.7	.0	.0	.0	.0	.0
Fermentation residue product ¹	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25
DL-Methionine (99%)	.136	.044	.128	.141	.035	.084	.222	.128	.217	.228	.123	.147	.280	.183	.277	.288	.183
L-Lysine (78.4%)	0	0	0	0	0	0	0	0	0	0	0	0	.178	.167	.184	.183	.182
Animal fat	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Minerals + vitamins	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Nutrients:																	
Protein (%)	26.6	27.1	28.6	28.1	29.1	28.4	23.9	24.4	25.7	25.2	26.2	25.6	22.0	22.7	23.8	23.4	24.4
Metab. energy (kcal/kg)	2840	2804	2946	2916	2909	2857	2904	2868	3013	2983	2976	2922	2943	2905	3053	3024	3016
Available																	
Methionine (%)	.466	.413	.491	.501	.438	.421	.518	.465	.546	.555	.492	.451	.553	.498	.582	.591	.528
Methionine + cystine (%)	.834	.824	.866	.857	.855	.862	.853	.843	.885	.877	.874	.859	.865	.853	.897	.889	.886
Lysine (%)	1.357	1.340	1.407	1.393	1.390	1.363	1.179	1.165	1.223	1.211	1.208	1.187	1.195	1.179	1.240	1.228	1.225
Threonine (%)	.951	.975	.986	.967	1.010	1.020	.847	.873	.878	.861	.904	.917	.774	.805	.803	.786	.829

¹ Fermento^R. Pet Ag Inc., Elgin, IL.

Table 1b. Composition of 6 to 9 and 9 to 12 week diets for Experiment TG-911.

Ingredient	All lysine from protein sources at 100% NRC plus methionine to supply 100% SAA						All lysine from protein sources at 85% NRC plus methionine to supply 100% SAA						All lysine from protein sources at 75% NRC plus methionine to supply 100% SAA and 10% l-lysine				
	1	2	3	4	5	16	6	7	8	9	10	17	11	12	13	14	15
Weeks 6 to 9																	
Ground corn	49.4	47.1	50.3	49.8	47.9	48.1	56.3	54.0	57.4	56.9	55.0	55.0	61.0	58.6	62.1	61.7	59.7
Soybean meal, dehulled 47%	43.4	33.8	37.5	36.7	27.9	41.8	36.3	26.7	30.1	29.5	20.6	34.7	31.3	21.7	25.1	24.4	15.6
Canola meal	.0	12.2	.0	.0	12.2	.0	.0	12.2	.0	.0	12.2	.0	.0	12.2	.0	.0	12.2
Meat and bone meal	.0	.0	8.2	.0	8.2	.0	.0	.0	8.2	.0	8.2	.0	.0	.0	8.2	.0	8.2
Poultry by-product meal	.0	.0	.0	8.2	.0	.0	.0	.0	.0	8.2	.0	.0	.0	.0	.0	8.2	.0
Feather meal	.0	.0	.0	.0	.0	3.3	.0	.0	.0	.0	.0	3.3	.0	.0	.0	.0	.0
Fermentation residue product ¹	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25	.25
DL-Methionine (99%)	.093	.029	.083	.095	.012	.064	.172	.090	.165	.177	.084	.105	.227	.145	.221	.232	.138
L-Lysine (78.4%)	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.170	.170	.172	.173	.170
Animal fat	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Minerals + vitamins	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Nutrients:																	
Protein (%)	24.5	25.0	26.1	25.7	26.6	26.0	21.8	22.3	23.4	23.0	23.8	23.3	20.0	20.5	21.6	21.2	22.1
Metab. energy (kcal/kg)	3001	2968	3097	3071	3063	3016	3063	3031	3161	3136	3128	3079	3101	3069	3199	3176	3167
Available																	
Methionine (%)	.405	.377	.425	.434	.389	.383	.453	.407	.474	.483	.428	.393	.485	.439	.507	.516	.460
Methionine + cystine (%)	.757	.766	.781	.775	.782	.799	.772	.764	.797	.791	.789	.777	.782	.774	.807	.801	.799
Lysine (%)	1.284	1.270	1.325	1.314	1.310	1.290	1.114	1.102	1.149	1.140	1.137	1.120	1.128	1.116	1.163	1.155	1.151
Threonine (%)	.858	.881	.887	.872	.909	.920	.759	.782	.784	.770	.808	.820	.688	.712	.713	.699	.738
Weeks 9 to 12																	
Ground corn	56.6	54.6	57.5	57.2	55.4	55.5	62.8	60.7	63.9	63.5	61.7	61.7	66.9	64.7	68.1	67.7	65.9
Soybean meal, dehulled 47%	36.7	28.5	31.4	30.9	23.2	35.3	30.4	22.2	24.9	24.4	16.8	29.0	26.0	18.0	20.4	19.9	12.4
Canola meal	.0	10.5	.0	.0	10.5	.0	.0	10.5	.0	.0	10.5	.0	.0	10.5	.0	.0	10.5
Meat and bone meal	.0	.0	7.0	.0	7.0	.0	.0	.0	7.0	.0	7.0	.0	.0	.0	7.0	.0	7.0
Poultry by-product meal	.0	.0	.0	7.0	.0	.0	.0	.0	.0	7.0	.0	.0	.0	.0	.0	7.0	.0
Feather meal	.0	.0	.0	.0	.0	2.8	.0	.0	.0	.0	.0	2.8	.0	.0	.0	.0	.0
Fermentation residue product ¹	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
DL-Methionine (99%)	.059	.020	.050	.060	.005	.050	.128	.058	.132	.000	.050	.084	.174	.103	.169	.179	.098
L-Lysine (78.4%)	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.0	.147	.143	.153	.151	.148
Animal fat	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Minerals + vitamins	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Nutrients:																	
Protein (%)	21.9	22.4	23.2	22.9	23.7	23.2	19.5	20.0	20.8	20.5	21.2	20.8	18.0	18.5	19.2	18.9	19.7
Metab. energy (kcal/kg)	3081	3052	3166	3146	3136	3094	3137	3108	3223	3204	3195	3151	3171	3141	3259	3240	3229
Available																	
Methionine (%)	.343	.334	.358	.367	.343	.339	.383	.344	.411	.409	.361	.345	.411	.371	.426	.437	.388
Methionine + cystine (%)	.665	.689	.684	.679	.702	.717	.677	.671	.708	.692	.690	.694	.685	.678	.704	.699	.697
Lysine (%)	1.126	1.115	1.157	1.149	1.146	1.130	.974	.965	1.001	.995	.992	.978	.985	.975	1.012	1.006	1.003
Threonine (%)	.765	.785	.788	.775	.807	.818	.677	.698	.696	.685	.717	.729	.615	.638	.632	.622	.655

¹ See footnote on table 1a.

Table 1c. Composition of 12 to 15 and 15 to 18 week diets for Experiment TG-911.

Ingredient	All lysine from protein sources at 100% NRC plus methionine to supply 100% SAA						All lysine from protein sources at 85% NRC plus methionine to supply 100% SAA						All lysine from protein sources at 75% NRC plus methionine to supply 90% SAA and 15% l-lysine				
	1	2	3	4	5	16	6	7	8	9	10	17	11	12	13	14	15
Weeks 12 to 15																	
Ground corn	63.9	62.0	64.9	64.5	63.0	62.9	69.1	67.2	70.2	69.9	68.3	68.1	72.4	70.6	73.7	73.4	71.8
Soybean meal, dehulled 47%	28.7	21.6	23.9	23.5	16.8	27.5	23.3	16.3	18.4	18.0	11.3	22.1	19.7	12.7	14.6	14.2	7.6
Canola meal	.0	9.2	.0	.0	9.2	.0	.0	9.2	.0	.0	9.2	.0	.0	9.2	.0	.0	9.2
Meat and bone meal	.0	.0	6.1	.0	6.1	.0	.0	.0	6.1	.0	6.1	.0	.0	.0	6.1	.0	6.1
Poultry by-product meal	.0	.0	.0	6.1	.0	.0	.0	.0	.0	6.1	.0	.0	.0	.0	.0	6.1	.0
Feather meal	.0	.0	.0	.0	.0	2.5	.0	.0	.0	.0	.0	2.5	.0	.0	.0	.0	.0
Fermentation residue product ¹	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
DL-Methionine (99%)	.073	.030	.065	.074	.017	.056	.130	.068	.123	.132	.062	.084	.104	.045	.098	.108	.038
L-Lysine (78.4%)	0	0	0	0	0	0	0	0	0	0	0	0	.179	.180	.186	.186	.185
Animal fat	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Minerals + vitamins	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Nutrients:																	
Protein (%)	18.8	19.2	19.9	19.6	20.3	19.9	16.8	17.2	17.8	17.6	18.2	17.9	15.5	15.9	16.5	16.2	16.9
Metab. energy (kcal/kg)	3213	3188	3290	3274	3264	3225	3261	3235	3338	3324	3313	3274	3289	3264	3368	3354	3342
Available																	
Methionine (%)	.321	.306	.334	.342	.313	.309	.354	.320	.368	.376	.334	.314	.314	.281	.327	.335	.293
Methionine + cystine (%)	.606	.620	.621	.618	.629	.643	.615	.611	.630	.627	.625	.623	.559	.555	.572	.570	.568
Lysine (%)	.933	.925	.955	.951	.947	.936	.805	.798	.824	.820	.818	.808	.859	.853	.880	.876	.873
Threonine (%)	.652	.670	.668	.659	.687	.697	.577	.596	.591	.583	.611	.622	.526	.545	.539	.530	.558
Weeks 15 to 18																	
Ground corn	70.1	68.4	71.1	70.9	69.4	69.3	74.6	72.9	75.7	75.4	74.0	73.8	77.5	75.8	78.8	78.5	77.1
Soybean meal, dehulled 47%	22.8	16.6	18.4	18.1	12.2	21.6	18.1	12.0	13.7	13.4	7.5	17.0	15.1	8.8	10.5	10.1	4.3
Canola meal	.0	8.1	.0	.0	8.1	.0	.0	8.1	.0	.0	8.1	.0	.0	8.1	.0	.0	8.1
Meat and bone meal	.0	.0	5.4	.0	5.4	.0	.0	.0	5.4	.0	5.4	.0	.0	.0	5.4	.0	5.4
Poultry by-product meal	.0	.0	.0	5.4	.0	.0	.0	.0	.0	5.4	.0	.0	.0	.0	.0	5.4	.0
Feather meal	.0	.0	.0	.0	.0	2.2	.0	.0	.0	.0	.0	2.2	.0	.0	.0	.0	.0
Fermentation residue product ¹	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1	.1
DL-Methionine (99%)	.053	.023	.046	.054	.012	.046	.101	.047	.095	.103	.041	.070	.077	.035	.071	.080	.023
L-Lysine (78.4%)	0	0	0	0	0	0	0	0	0	0	0	0	.1519	.1529	.1571	.1595	.1572
Animal fat	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Minerals + vitamins	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
Nutrients:																	
Protein (%)	16.5	16.9	17.4	17.2	17.8	17.5	14.8	15.2	15.7	15.5	16.0	15.8	13.7	14.1	14.5	14.3	14.9
Metab. energy (kcal/kg)	3283	3260	3352	3339	3328	3294	3324	3301	3394	3382	3372	3336	3349	3326	3419	3407	3396
Available																	
Methionine (%)	.276	.271	.287	.294	.276	.274	.304	.275	.315	.322	.285	.277	.267	.249	.278	.286	.254
Methionine + cystine (%)	.536	.556	.547	.545	.563	.575	.543	.539	.554	.552	.550	.558	.492	.499	.502	.501	.504
Lysine (%)	.793	.787	.809	.806	.803	.795	.682	.677	.696	.694	.692	.684	.728	.722	.743	.740	.738
Threonine (%)	.570	.587	.583	.575	.600	.610	.505	.523	.517	.510	.534	.545	.462	.479	.472	.463	.489

¹ See footnote on table 1a.

Table 2. Analyses of ingredients in Experiment TG-911¹

Component	Corn	Canola meal	Soybean meal (47)	Meat & bone meal	Poultry by-product meal	Feather meal
Dry matter, %	87.6	92.2	89.7	94.4	94.6	93.0
Protein, %	8.3	42.6	46.6	53.1	52.8	74.4
Metab. energy, kcal/kg	3430	2300	2440	2600	2700	3100
Calcium, %	.02	.68	.27	10.30	9.00	2.56
Phosphorus, %	.28	1.17	.62	5.10	4.45	1.21

¹ Dry matter, protein, calcium, and phosphorus analyses were performed at Ingman Laboratories, Minneapolis, MN. Dry matter and protein were analyzed at the University of Minnesota. Metabolizable energy values were adapted from the TME results on ingredients and NRC (1984) table values. Dry matter and protein are averages of results of two laboratories.

Table 3. Amino acid composition for ingredients used in Experiment TG-911¹

Amino acid	Corn	Canola meal	Soybean meal (47)	Meat & bone meal	Poultry by-product meal	Feather meal
----- % -----						
Methionine	.15	.83	.63	.77	.81	.63
Cystine	.19	1.04	.74	.60	.51	3.59
Lysine	.30	2.37	2.94	2.66	2.80	2.02
Arginine	.49	2.81	3.49	3.64	3.32	5.14
Tryptophan	.058	.56	.61	.32	.35	.44
Valine	.41	2.18	2.18	2.05	1.94	4.96
Glycine	.33	2.19	1.97	7.01	6.00	6.29
Histidine	.24	1.17	1.28	1.05	1.16	.60
Phenylalanine	.40	1.52	2.51	1.69	1.78	1.62
Tyrosine	.34	1.38	1.87	1.27	1.38	2.67
Threonine	.31	1.87	1.87	1.63	1.64	3.27
Leucine	1.07	3.11	3.67	2.96	2.93	5.79
Isoleucine	.29	1.68	2.10	1.50	1.50	3.34
Serine	.42	1.90	2.43	2.07	1.75	7.60

¹ Analyses were performed by Degussa Corporation, Allendale, NJ.

Table 4. Amino acid availabilities for ingredients in Experiment TG-911¹

Amino acid	Corn	Soybean meal (47)	Canola meal	Meat & bone meal	Poultry by-products meal	Feather meal
Methionine	91.0	89.3	90.4	97.2	96.2	81.9
Cystine	88.6	83.2	81.5	81.0	70.4	65.1
Met + cys	89.6	86.0	83.9	90.1	86.3	67.1
Lysine	90.4	91.0	84.4	92.2	90.9	78.5
Arginine	96.5	95.4	91.8	94.7	91.8	90.7
Valine	88.1	88.4	81.2	91.9	90.8	82.9
Threonine	87.8	88.8	82.2	93.8	91.9	85.7
Leucine	93.8	89.6	85.8	92.9	91.7	85.4
Isoleucine	97.9	89.3	82.8	92.8	91.4	86.3
Ave. essential	91.5	89.0	84.9	91.8	89.0	80.4
Serine	92.1	92.2	84	92.5	88.3	89.0
Proline	92.2	91.9	84.6	87.4	84.5	83.4
Glutamic aci;d	89.8	93.1	91.3	91.8	90.5	83.1
Aspartic acid	88.0	94.1	84.2	93.0	90.3	79.3
Alanine	96.5	87.7	80.3	90.1	88.8	85.1
All amino acids	91.6	90.0	84.9	91.5	88.8	81.7

¹ Values shown were used in formulating diets. They are not final.

Table 5. Effect of diet treatment on body weight, feed efficiency and feed cost per kg gain for male Hybrid turkeys (Experiment TG-911)

Trt	% NRC	Ingredient Substitution	Body weight, at weeks:			Feed efficiency	Feed cost
			6	12	18	0-18 weeks	/ kg gain
			(kg)			(\$)	
1	100%	Corn-soybean	1.866	7.151	13.578	2.721	.463
2	100%	Canola meal (CM)	1.762	7.151	13.309	2.741	.448
3	100%	Meat & bonemeal (MBM)	1.966	7.629	13.814	2.595	.442
4	100%	Poultry-by-product meal	2.085	7.776	13.945	2.624	.463
5	100%	CM + MBM	1.847	7.565	13.636	2.682	.448
		Average	1.905	7.460	13.656	2.673	.453
6	85%	Corn-soybean	1.730	6.934	12.966	2.726	.452
7	85%	Canola meal	1.766	6.821	12.531	2.751	.440
8	85%	Meat & bonemeal	1.938	7.522	13.303	2.581	.428
9	85%	Poultry-by-product meal	2.067	7.605	13.341	2.657	.451
10	85%	CM + MBM	1.910	7.223	13.188	2.657	.423
		Average	1.882	7.221	13.066	2.674	.439
11	75%	Corn-soybean	1.730	6.913	12.613	2.711	.440
12	75%	Canola meal	1.761	6.893	12.614	2.806	.440
13	75%	Meat & bonemeal	1.939	7.306	12.967	2.642	.435
14	75%	Poultry-by-product meal	1.910	6.863	12.617	2.594	.440
15	75%	CM + MBM	1.849	6.974	12.739	2.649	.417
		Average	1.837	6.990	12.710	2.681	.434
16	100%	Feather meal	1.733	7.070	13.742	2.646	.463
17	85%	Feather meal	1.860	7.145	13.085	2.711	.442
		Ingredient Average					
		Corn-soybean	1.775	6.999	13.052	2.719	.452
		Canola meal	1.763	6.955	12.818	2.766	.443
		Meat and bone meal	1.948	7.496	13.361	2.606	.435
		Poultry-by-product meal	2.021	7.414	13.301	2.625	.451
		CM + MBM	1.869	7.254	13.188	2.663	.429

Statistical Analyses:

Factorial (5x3 treatments)

P value

Ingredient (I)	.0001	.0001	.0013	.0001
Protein (P)	.0378	.0001	.0001	.8582
IxP	.1358	.0373	.5082	.1547
Error mean square	.010	.086	.170	.0034
LSD (P<.05)				
I	.067	.195	.274	.039
P	.052	.151	.212	.030

All 17 treatments

P value of treatment	.0001	.0001	.0001	.0001
Error mean square	.011	.092	.180	.0034
LSD (P<.05)	.124	.353	.494	.071