Development and validation of a finishing cattle monitoring system with microcomputer compatibility

by

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TABLE OF CONTENTS

ABSTRACT

Developments in personal computer equipment are providing us with the capability to compile and utilize the vast amounts of numerical data collected over the years and facilitate it's application to everyday life. An example of this can be observed in the latest version of the Iowa State Extension's Feedlot Monitoring Program, whereby many of the documented principals regarding the conversion of feedstuffs to weight in growing cattle have been compiled into PC software and made available to commercial beef feedlots. Along with the primary focus of projecting weight gain, this program also has the capabilities to utilize the developments in live animal evaluation in terms of ultrasonic imaging. This provides a means by which development of the carcass can be assessed on a continual basis along with weight. The primary outputs for analysis involve the live weight, the carcass weight, yield grade, and the quality grade. The commercial aspect of the system then requires monetary aspects to be related to these calculated values of the animal. Determination of animal weight has been defined by standards set by the National Research Council. Development of the ribeye area and backfat depth used for the yield grade calculation along with the intramuscular fat, used to estimate the quality grade, was numerically described to a fair degree of success on observed lots (R^2 = .97, .81, and .79, respectively) using both animal evaluation and feedlot performance. Equations developed from historical feedlot data used to estimate carcass weight and percent kidney-pelvic-heart fat for yield grade estimation, likewise showed fair accuracy (RMSE = 14.27, .29) when applied to independent data. The implications of this system, in terms of commercial feedlots, may result in new paths by which animal value can be estimated prior to slaughter and is a means of sorting cattle into management groups.

GENERAL INTRODUCTION

The threshold of the third millennium is at hand and beef is still considered a valuable commodity. Likewise, cattle are still valued based on weight and some visual characteristics that infer to the productivity of the animal. As time has progressed, though, so have developments appeared in cattle production and marketing, yet the essence of this topic remains the same. What is necessary from a production standpoint is an estimation of animal worth to provide a basis for marketing management, likewise, it may also be necessary for one to change in marketing mentality from the traditional question asked by producers of commodities "What will you give me for it?" to a more appropriate statement " This is what it is worth.". This is somewhat idealistic thinking under current conditions, but with the emergence of beef marketing alliances which try to find a niche in the larger beef industry by their focus on consistency in product, it should not be considered unrealistic.

A great deal of effort is necessary for the alliance to accomplish a goal of consistent products and no longer can a producer dwell on only being a low cost producer or competitive market player since now, if quality is really that important and product consistency is mandatory, some adjustments to previous production practices may have to occur. At this same time, though, a more favorable and consistent return likewise is in order that requires appropriate documentation of production costs during negotiation.

The idea of consistency has in the past revolved around a breed, frame size, or location, but needless to say a large amount of variation can and does exist within each of these entities. Real-time ultrasonic (RTU) evaluation, however, appears to be one means by which problems in variability can be reduced since RTU imaging allows a direct look at the components of interest, the muscle and fat. Therefore, sorting of cattle prior to the final sort in the cooler at the packing house can be accomplished which aids one in maintaining consistency, and for those not involved with an alliance, it can prevent penalty. In either case, the potential for preliminary sorting of cattle exists to aid in feedlot management.

The mission and purpose of this dissertation is to provide a means by which one can account for value and monitor status and performance in the feedlot. Thus to do this what is necessary to know is the amount of beef produced, a factor that is realized by weight. The next step is to analyze the carcass since animal value is based on this either directly or indirectly. When the carcass is considered one can breakdown value in three primary categories: carcass weight, yield grade, and quality grade. Carcass weight can be inferred to by live weight, thus in our estimation of live weight the guidelines presented by the National Research Council's (NRC) 1996 publication on the nutrient requirements of beef cattle can be used. The yield grade of the animal is presented to the public in terms of the yield grade formula. Thus, carcass weight, ribeye area at the 12th rib (REA), 12th rib backfat (BF), and the percentage of kidney-pelvic-heart fat (KPH) must be known for calculation. The quality grade, a verbal assessment based on visual appraisal of intramuscular fat content, can be estimated through RTU imaging as can the REA and BF. The final step is to then provide a framework by which this type of evaluation can be accomplished and maintained. Currently it appears that a microcomputer based system for monitoring feedlot cattle performance as presented by Wilson et al. (1986) may be the most appropriate means since this type of system already has weight projecting and data collecting capabilities. Therefore, what remains is to build in the capabilities for the estimation of carcass characteristics viewed as benchmarks for determination of animal value (i.e. yield and quality grade components) and update features already presented to reflect current program user response, developments in weight gain projections, and microcomputer technology.

Dissertation Organization

The contents of this manuscript involve the development of the ISU Feedlot Monitoring Program Version 1.0 for Windows™ (Dahlke et al., 1996), a PC based system for monitoring finishing cattle in terms of animal performance which can then be coupled to the monetary factors of production. Three papers are provided in this manuscript which involve projecting the factors one may use to assess cattle value. The first paper deals with projecting carcass ribeye area, backfat, and intramuscular fat. The second paper examines group uniformity in terms of projecting a final standard deviation for the group, and the third paper, which is supplemented by the appendices, projects weight with yield and quality grade.

LITERATURE REVIEW

Nutrition and Cattle Growth

The effects of nutrient intake are probably the most documented topic in animal science. Each nutrient in itself is a separate topic that can be discussed at great length in terms of dietary role, deficiency, and excess alone or with other nutrients over the life of the animal. Growth modeling requires one to address this issue, but due to the lengthiness of the subject this paper will rely on the contents of the 1996 Beef NRC publication for the guidelines by which growth will be estimated. The guidelines can be quantified in the form of mathematical equations and the adaptation of these equations to a performance projection system as described in the introduction of this paper is shown in Appendix A. The equations presented focus on the estimation of shrunk body weight, with the contribution of dietary energy and protein being the primary drivers. Naturally other components are required, but in the model presented, these components will be considered as adequate while the protein and energy components are addressed due to the relative amount of variability in intake that does exist with these.

Energy

Energy intake by cattle is expressed in terms of net energy primarily because of the heat increment associated with fermentation of feed in the rumen. It is also recognized in cattle that the energy conversion efficiency for maintenance is higher than that for tissue growth. This system, which can be traced to a publication by Lofgreen and Garret (1968), has been used in practice for a number of years to project weight gain across different cattle fed different diets in different environments. Therefore, it is of little surprise that the system's accuracy may breakdown in practice and that adjustments are necessary to maintain some level of relevance.

A fundamental adjustment to this net energy system is that which is made for differences in the amount of energy required for maintenance. This adjustment, which is now discussed to a greater extent in the 1996 NRC publication on beef nutrition than in previous

NRC reports, can be separated into two components, the first deals with the physical attributes of the animal. The second deals with the environment in which the animal is placed. The animal component is addressed in terms of the size (metabolic body weight), age, gender, body condition, and breed. The environmental factors are confined to current and the previous month's average air temperature, the presence of an ionophore, feed intake, and the insulating qualities of the animal's hide in relation to the current air temperature.

The effect of an ionophore as well as an antibiotic in the feed or melengestrol acetate in heifer rations may also be used in adjusting the daily weight gain after maintenance requirements have been calculated. The effect of these additives may be in actuality reducing maintenance energy requirement as implied by the 1996 NRC publication, but quantifying the effect of an adequate amount of the given additive is generally more convenient to do in terms of weight gain (Stock and Mader, 1991).

Physical activity, disease, and physiological variation between animals likewise can alter the amount of energy one animal requires for maintenance, but due to the restrictions a feedlot puts on an animal in terms of mobility and the difficulty in quantifying the effects of the other two categories, these areas have been left out of the model being used for feedlot cattle. Independent data collected at the Iowa State University Allee Research Center at Newell, Iowa and published by Pusillo (1986) were used to perform a preliminary check on the 1996 NRC's maintenance model. Differences in feed conversion, adjusted for dietary energy, were used to estimate differences in maintenance requirements for a pen of cattle while on feed and compared to the calculated maintenance requirements. The result of this preliminary analysis, looking at monthly averages, indicated a similar relationship between NRC calculated and feed conversion estimated maintenance ratios during cooler weather. Warm weather estimates did not parallel each other as well since differences in feed conversion data did not respond as much as the NRC model estimate said it should have (Table 1).

The energy remaining after the maintenance requirement has been satisfied is considered to be directed towards growth. The extent by which this energy contributes to actual weight gain however is variable due primarily to the animal involved. Allocation of

Table 1. Maintenance differences as indicated by the 1996 Beef NRC guidelines with a comparison to independent data from Iowa

Months on feed	Feed:gain	Added[a] Mcal	-------- Avg. maintenance ratio[b] ----- Calc. NRC	Observed	Adjusted[c]
Nov.-Apr.	6.77	1.03	1.27	1.15	1.17
Jan.-Jun.	6.37	0.67	1.21	1.10	1.11
Mar.-Aug.	5.80	0.15	1.06	1.02	1.03
May-Oct.	5.63	0.00	1.00	1.00	1.00
July-Dec.	5.62	0.00	1.06	1.00	1.03
Sep.-Feb.	6.69	0.95	1.23	1.15	1.16

[a] Average NEm of 0.9 Mcal per pound DM used in calculation.
[b] An animal with a maintenance requirement of 6.5 Mcal of net energy per day was used for comparisons. See Appendix A for maintenance requirement and ratio formulas.
[c] NRC estimate adjusted by 10% upward during months where no increase in maintenance is required.

energy to weight gain has been simplified in a system described by Fox et al. (1992) and is now used by the NRC (1996) where frame size and gender are combined to estimate the weight at which 50% of a group of cattle will grade Choice. This weight then becomes a reference point from which animal maturation and subsequent rates of growth and fattening may be inferred.

Protein

The suggested system of protein nutrition provided in the 1996 Beef NRC is based on principles of the metabolizable protein system developed by Burroughs et al. (1974). The system recognizes the contribution of bacterial crude protein from the rumen separately from the dietary crude protein that is not degraded in the rumen, but is still available to the animal in the lower tract along with the bacterial crude protein. The calculation of the different components, bacterial crude protein (BCP) and undegradable intake protein (UIP), is no longer based on a single, static feedstuff value as was used when crude protein was the sole description of a ration's protein content. Rather, calculation of the diet's protein content is based on the intake of TDN, nitrogen, and effective neutral detergent fiber (eNDF). From this point, one needs to then determine that fraction of UIP, a value generally presented as a constant in terms of the feedstuff fed. The UIP value is presented and used in terms of crude protein, but in some cases may require analysis in terms of the amino acids supplied.

Amino acid supply to the ruminant, although mentioned to some extent in the 1996 Beef NRC, has not received the attention it has in monogastric animals due to the difficulty in analysis and BCP contribution. Owens and Zinn's (1988) discussion on protein nutrition in the ruminant tends to conclude that the amino acid profile of the BCP fraction is quite adequate for maintaining physiological performance. What is necessary, then, is BCP quantity, a factor dependent on the availability of carbohydrates and nitrogen and the rumen environment. It is the eNDF component that is used to address the topic of the rumen environment. The word "effective" is key in this description of fiber since effective implies particle length, and longer particle length stimulates chewing, saliva release, and buffering of the rumen's pH to maintain neutrality rather than the acidotic conditions in the rumen that can exist without the buffering action of saliva. This will decrease BCP output due to the reduction in rumen microflora, and nonprotein nitrogen conversion efficiency will be reduced as well. The remaining point for discussion then deals with how the animal will utilize the nutrient provisions in terms of carcass development.

Animal Evaluation

Evaluation of livestock receives justification on the premis that no two animals are created alike and, therefore, differ in capacity to fulfill a given function. It may be argued that animals of the same genetic makeup are the "same", but when one considers that the creative process continues beyond the allocation of genes at conception and encompasses the future effects of space and time as well, it becomes apparent that differences will exist due to environment since no two organisms will be able to occupy the same space at the same time. A classic example of this in cattle can be observed with coat color patterns in cloned calves. Ozil (1983) showed this in Shorthorn cattle when blastocysts were bisected at day eight and reimplanted into recipients, the result then being calves that looked similar, as would be expected due to a similar genetic makeup, but did not look the same when color patterns were compared.

One can likewise impose variation further through treatment or management. For instance the response of feedlot cattle of similar ancestry by feeding the animal as a calf , yearling, or long yearling as Smith (1994) noted using twin Angus calves, and Harris et al. (1995) accomplished using pairs of cloned cattle. Harris et al. (1995), then noted when repeating the experiment the following year, the conditions allowed for the differences between calf and yearling feeding to occur as well, but to a different magnitude when compared to what was observed in the first year of the trial due to harsh grazing conditions experienced by the yearling cattle prior to being finished. Likewise, Warwick et al. (1970), using what they considered to be monozygotic twins, showed a definite difference in feedlot performance between the intact bull and the castrated full sibling primarily in terms of the composition of weight gain, rate of this gain, and feed conversion. Thus, an implant strategy, which is capable of mimicing the differences in gender to some degree should be included in animal evaluation (Senn and Wagner, 1994; Loy, 1983) as well as age, gender, and body condition. In other words, a practical animal evaluation requires more than an analysis of conformation or ancestral data, but should include previous treatment.

Cattle of variable genetic background would be expected to be affected by those factors or treatments causing cattle of similar ancestry to perform differently, but now we are also dealing with innate genetic differences as well. Fox et al. (1992) describes a method of handling this problem when modeling cattle growth by describing maturity in terms of frame size and mature weight and breed differences in terms of the maintenance requirement.

The evaluation discussed up to this point does not concern itself with rank or comparison, but rather is an observation of gross, external features from which one can recognize a baseline and potential for a given animal to grow and produce meat. Improvement of this evaluation can then be taken a step further by focusing on the carcass components directly since it is the muscle and fat cover which are of concern if meat yield is the reason for our efforts. A visual conformation score provides a better description of an animal's merit in terms of meat yield over breed or age (Martin et al., 1966); however, visual evaluation of the live animal, as Berg and Butterfield (1976) point out, can be deceptive since a plump appearance could be due to fatness or muscling. Ultrasonic evaluation allows a more direct measure of meat yield and quality to be obtained and therefore accuracy in evaluation theoretically can be improved.

Ultrasonic evaluation of live animal carcasses has appeared in animal science literature since the 1950s, but most of the documented developments have occurred in the last ten years. Improvements in the necessary hardware may have been a major contributor to this phenomenon, however, the search for accurate live animal evaluation techniques provides the motives for further utilization of RTU techniques in evaluation.

Duello (1993) evaluated the issue of RTU accuracy both in his own studies as well as in those of others. He concluded that RTU measurements, although not perfect in terms of accuracy, were generally correlated high enough to the actual carcass measure of REA and even more so with BF to justify further use and development of RTU technology. Brethour (1992) likewise considered the accuracy of RTU evaluations to be promising and even considered RTU estimations of BF to be more accurate than the carcass measure once the hide is removed due to the possible influx of air or loss of subcutaneous fat. The idea that hide removal distorts actual BF is supported by Faulkner et al. (1990) where the relationship between BF and RTUBF after hand skinning carcasses showed a higher R^2 value than when compared to carcasses skinned by mechanical hide pullers or air knifes.

Ribeye Area Estimation

The area of the ribeye at the 12th rib provides an indication of the muscle mass of the animal and retail yield of the carcass; thus, it is a component used in evaluation of the carcass as part of the yield grade equation. Serial slaughter and RTU experiments provide evidence that the REA growth has a fairly high correlation with animal live weight gain (Senn and Wagner, 1994; Houghton and Turlington, 1992; Barber et al., 1981). Berg and Butterfield (1976) point out that the muscle mass relative to bone mass is not a constant across all cattle and that as cattle mature, ribeye area growth decreases. These two points explain much of the variation in REA when live weights are adjusted to a common end point as well explaining why ribeye area projection models such as the one provided by Houghton and Turlington (1992) show a negative relationship between REA and BF and the models developed by Hamlin et al. (1995) would be specific for a cattle type (group of breeds).

The role of REA in carcass evaluation promotes it's estimation in the live animal, yet due to the location of the *Longissimus dorsi* and the potential for external fat cover, visual appraisal is difficult. Currently, RTU viewing seems to be the most accessible method to evaluate REA size in the live animal. The directness of the measurement is where the benefit lies in RTU, and although the measure does not correlate perfectly to what the grader would observe on the carcass, the data summarized by Duello (1993) shows a fair amount of potential and a significantly better level of accuracy than what one can visually estimate or infer to by measurements taken of other body members (Berg and Butterfield, 1976).

Backfat Depth Estimation

Subcutaneous fat depth over the *Longissimus dorsi* muscle near the 12th rib is the primary marker used to indicate the degree of finish in cattle. Visual assessment of backfat depth, as mentioned earlier, can be deceptive since the plump appearance that cattle acquire as they finish can be both due to muscle and fat. Dolezal et al. (1993) noted that in an experiment where cattle of three classes of muscle thickness were fed to what was considered to be an equal degree of finish there was a tendency to sell the more muscular cattle with less backfat while thinner muscled cattle were marketed with more back fat. Fatness, however, does appear to smooth the image of the animal, as can be observed when cattle of almost no fat cover, such as Belgian Blue or Piedmontese breeds, are compared to more standard beef cattle (Berg and Butterfield, 1976). The amount of fat, however, when using these clues still can only be approximated.

The use of the noninvasive technique of RTU imaging, as in the estimation of REA, does provide a direct view of the amount of BF and enhance data collection. Duello (1993) even showed that the accuracy obtained when correlating RTUBF to carcass BF is more favorable than that observed with REA. The ability, though, to scan an animal early in the feeding period for projection of later BF thickness is reduced since much of the BF seems to be expressed later in the feeding period. Accretion rates do seem to follow some measurable patterns which can be utilized in modeling. Brethour (1988), for instance, describes rate coefficients that were developed for Continental, English, and Continental x English crossbred cattle due to characteristic accretion rates that also appear to coincide with maturation rate at a given plane of nutrition. Variation in dietary energy density, however, can likewise modify this accretion rate (Stuedemann et al., 1968).

Carcass Weight Estimation

Estimation of carcass weight allows one to identify carcasses that fit into preferred marketing windows as dictated by packers in terms of weight, but also in terms of yield grade. The carcass weight is often represented as some percentage of the live weight and these two weights are highly correlated. Thus, a more accurate live weight estimate allows for a more accurate carcass weight estimate. The variation that then remains can partially be explained by the degree of muscling in terms of the ratio between muscle and bone and the amount of fat allowed to accumulate (Van Koevering et al., 1995; Berg and Butterfield, 1976; Hammes et al., 1964).

Gut fill must also be addressed since this is a factor that can contribute variable amounts of live weight. Brabander et al. (1983) described the effects of fill in calves and showed that the dressing percent in milk fed calves is above 60 percent of live weight while in calves taken from pasture or fed a high roughage diet the dressing percent is generally below 58 percent (Zinn et al., 1970; Hammes et al., 1964; Martz et al., 1996). Naturally the time period between obtaining a live weight and slaughter weight is a factor to consider when calculating or projecting the yield due to digesta passage and respiration losses. An observation of literature values seems to indicate two practices that allow time to impact the relationship between live and carcass weights. The first appears to take animal live weights at the farm prior to transporting the animals to the packing plant where, when slaughtered, a carcass weight is then obtained. The other method appears to obtain the live animal weight and the carcass weight at the packing plant. Thus, the first practice of on farm weight acquisition generally results in a dressing percentage two points lower than when the live weight is taken at the plant since more time is allowed to clear gut contents and realize respiratory losses.

A number of other factors can also contribute to the variation observed here, but quantifying these other minor factors is not easy. Arthur et al. (1995) and Adams et al. (1973) point out that a fair amount of variability in weight exists in those parts such as head, feet, tail, and internal fat removed from the carcass prior to obtaining a carcass weight and both note that cattle of Hereford and Simmental breeding have heavier hides per unit of body weight than the other beef and dairy breeds in their studies. The physiological differences that do exist are then confounded with variations between packing plants in processing methodology, where trimming can reduce carcass weights as can mud on the hide, which can contribute a fair amount of apparent live weight to the animal.

Kidney-Pelvic-Heart Fat

An estimation of yield grade, based on the formula, requires an estimation of BF, REA, carcass weight, and the percent kidney-pelvic-heart fat (KPH) in the carcass. The last component, the KPH value, seems currently to be the most difficult to estimate in the live animal. The estimation of REA and BF has been greatly enhanced through the use of RTU imaging and carcass weight can be implied to by the animal's live weight to some degree. The estimation of KPH, however, is not as simple since a measurement technique such as RTU is not currently in use. Therefore, one must resort to what has been observed and described in literature from slaughter measures. Wellington (1971) provides some insight in terms of differences between breed type and gender with Holsteins and Angus cattle. The results of this trial noted that at a year in age, bulls had less KPH fat than steers and Angus cattle had less KPH fat then Holsteins. A similar observation was mentioned by Kauffman et. al. (1976), but noted that Brown Swiss cattle KPH fat amounts were somewhat between Holstein and Hereford-Angus cross cattle which may infer that dual purpose cattle are intermediate for this characteristic. Naturally differences in processing the carcass in terms of fat trim would impose variability and confound estimations. Carcass perception from one grader to the next could cause similar problems for KPH estimation and it may not be possible to obtain an accurate estimation for all practical situations. Fortunately, the relatively small impact KPH has in the yield grade formula reduces the need for an exact estimate.

Considering that being close to the KPH value will suffice, we can then develop the main observations and formulate a model to approximate current KPH values based on breed type and degree of finish. Fattening patterns in cattle follow a pattern where fat is deposited, first, around viscera and kidneys; second, between muscles; third, subcutaneously; and then within the muscle (Martin, 1972). Therefore, most, but not all, of the fat that is to be deposited as KPH has already been accumulated when the animal is considered finished. The available energy remaining from the diet, which can be measured in terms of backfat, and the metabolic allocation of energy in the body, which has relationship to the breed, seem to provide usable points of reference for KPH estimation.

Quality Grade Estimation

The quality grade is a function of age and the intramuscular fat (IMF) content or marbling in the REA of the animal. However, since most feedlot cattle are processed into beef at a fairly young age, the age of the animal is seldom a factor in quality grade determination. The marbling, or visible IMF, present in cattle carcasses is under genetic control with expression being dependent on both age and diet. Therefore, one tends to observe higher marbling scores in breeds such as Angus cattle when compared to Holsteins (Wellington, 1971), or in high grain (energy dense) versus diets of moderate to low energy density fed for a given time (Martin, 1972), or in limit fed cattle fed to a given weight due to a longer time on feed (Delehant and Hoffman, 1996).

The quality grade is based on marbling score which refers to the IMF content. The IMF and marbling score, however, do not always correlate (Savell et al., 1986) and this may be somewhat related to muscle structure differences between animals. The difference, although subtle, is worth mentioning since IMF has implications with the eating qualities (Parrish et al., 1981) while marbling has implications with carcass value. Therefore, less visible IMF deposits can potentially be graded lower with visual grading or estimation. This then provides some insight to the reason why dairy beef carcasses often receive lower quality grades than the carcasses of beef-type animals when in actuality dairy beef may actually exceed a beef-type animal in IMF percent at a given point of finish (Fisher et al., 1983), or at least be quite similar to the beef animal as Fox and Black (1984) contend.

PROJECTION OF 12TH RIB RIBEYE AREA, 12TH RIB BACKFAT, AND INTRAMUSCULAR FAT DEVELOPMENT IN FINISHING CATTLE BASED ON FEEDLOT PERFORMANCE AND INITIAL ULTRASONIC DATA

A paper to be submitted to the Journal of Animal Science.

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Abstract

Feedlot performance data coupled with real-time ultrasonic (RTU) imaging of carcass components when cattle enter the feedlot can be used as a means by which one can project later ribeye area (REA) development as well as backfat (BF) and intramuscular fat (IMF) accretion to a fairly high degree of accuracy. The standard error of prediction (SEP) observed when using these inputs to project a final REA, BF, or IMF was 0.42 in.^{2}, 0.05 in., and 0.74 percent, respectively. It is interesting to note that these projection equations were more accurate than the final RTU estimates obtained when compared to the actual carcass values since RTUREA, RTUBF, and RTUIMF had a SEP of 1.15 in.^{2}, 0.12 in., and 1.85 percent, respectively, when compared to the actual carcass measurements. The reasons for this are not completely clear, but seem to be due to muscle size and environmental temperature effects on the RTU equipment when the RTU images are taken.

Introduction

Utilization of ultrasound technology for the evaluation of carcass composition in livestock steadily makes strides in both equipment and technique. Benefits from these developments for further live animal research are somewhat obvious in that now nondestructive observations of anatomical qualities can be obtained repeatedly and done so rather easily. One can likewise imagine a number of applications RTU may have in a practical setting such as a commercial feedlot where cattle entering the feedlot could be scanned, sorted into management groups, and mapped in terms of carcass development while being fed to finished market weights.

The availability of RTU for carcass evaluation, whether it be for the equipment or the service, continues to improve. The accuracy, likewise, shows some promise as Duello (1993) revealed in his survey of literature and in his own work. However, the values he published also reveal that the accuracy of RTU carcass data is quite variable. The factors which contribute to the variability are probably a collection of numerous items and conditions of varying proportions that as of this time have not yet been fully documented in terms of effect. Brethour (1990), for instance, remarks how a blemish on the hide can significantly distort an estimation of IMF percent. Taking evaluation further and using the example of IMF percent, one may observe in those animals with a finer, more dispersed pattern of IMF, as may be observed with Holstein steers (Rouse, unpublished data), IMF is generally underestimated; thus, there may even be some tissue adjustments which need to be included in order to improve RTU further.

Utilization of RTU measurements to construct growth models of REA, BF, and IMF development is of merit since with these values yield grade and quality grades may be estimated. Brethour (1989) describes nonlinear models that show BF and IMF accretion, of which, a separate accretion rate constant for cattle of English origin, cattle of Continental, and Continental x English crossbred cattle is identified. Hamlin et al. (1991) likewise developed equations from RTU data for REA and BF development for a number of individual breeds. Hamlin et al. (1991) remarked that when data were standardized over time, an equation, quadratic in form, provided the best representation of REA and BF development while, when data were standardized over weight, a linear equation was the most accurate.

Commercial feedlots, however, do not always have a complete history concerning incoming cattle. This inhibits the function of many current models to some extent. Baker et al. (1991) points out, though, that most relative growth characteristics do not differ greatly from one animal to the next, but what does differ, though, is the animal's overall rate of development. Thus, with the goal being to develop equations which describe development of

REA, BF, and IMF across breed, gender, etc. the required link between an initial RTU measure and the final carcass result appears to be feedlot performance.

Materials and Methods

The cattle involved in this study consisted of a crossbred group of 112 August-October born steers of British and Continental beef breeding. The steers were over-wintered and then maintained on pasture during the following year until mid August at the Western Iowa Research and Demonstration Farm at Castana, Iowa. The cattle, which averaged 750 lb. when taken from the pasture, were ultrasonically scanned to estimate the 12th rib ribeye area, 12th rib backfat depth, and intramuscular fat percentage; implanted with Compudose™; given an Ivomec™ injection; and placed into the feedlot (16 groups of 7 steers) at the Castana Farm. The diet, approximately 85 percent concentrate, consisted of shelled corn, ground hay, molasses, and supplemented with a urea-based 40% crude protein, mineral and vitamin premix containing Rumensin™. Feed DM, NDF and ADF were determined from feed samples taken biweekly (Goering and VanSoest, 1970; VanSoest et al., 1991). Feed allocation treatments were assigned to pens with intake allowances per pen to be ad libitum, 95% of ad libitum, or 90% of ad libitum. Feed delivery was either once a day at 8:00 am or 4:00 pm, or twice with half of the ration being delivered at 8:00 am and the rest being delivered at 4:00 pm. The cattle remained in the feedlot until the pen was estimated, on average, to grade Choice at which time the pen was marketed and processed at the IBP plant in Denison, IA.

Cattle live weights and ultrasonic images of REA, BF, and IMF were collected approximately every 28 days and within 21 hours prior to slaughter on each animal. Feed intake and climatic data were collected daily until slaughter. Dry matter estimations of the feed were taken weekly. Data collection involving ultrasonic images was accomplished using an ALOKA 500V real-time ultrasound machine with an attached 17 cm linear array transducer. Images were processed at Iowa State University. Direct measurements of carcass weight, REA, and BF were taken at the packing plant when the cattle were slaughtered. Cattle were graded by the USDA Meat Grading Service after which a slice of the exposed *Longissimus dorsi* muscle from the USDA graded carcasses was then obtained to analyze intramuscular fat content. The fat content of the meat sample was determined with the Soxhlet procedure which uses n-hexane as the solvent.

The RTU scans, composed of one image used to view REA and BF and one image used to view IMF, were collected and processed by the same certified technician throughout the trial. The RTU scan processing was done at Iowa State University. The RTUIMF content was determined using the Iowa State University USOFT program (Amin et al., 1997). The RTU REA, BF, and IMF data were then plotted to determine the patterns of development of these carcass characteristics in order to apply the most appropriate equations for description. Data analysis was accomplished by using the regression techniques included in the SAS software package to identify those measured parameters that contributed to the observed pattern of development.

Results and Discussion

A plot of the average RTUREA, RTUBF, and RTUIMF observations for pens sold at 156 and 174 days on feed along with the average daily temperatures and the final carcass measurement obtained on the specified day are displayed in Figures 1, 2, and 3, respectively. Analysis of these graphics allows three topics of interest to be developed. The first point deals with the slope of the line or rate of development concerning REA growth and the accretion of BF and IMF during this period of the steers life along with the equations used to map this development. The second and third points of interest, although not an original focus in this study, can be developed in terms of general RTU accuracy as seen in this study and the effect that temperature may have on the results obtained. It should be noted that the line labeled as the carcass value rather than the RTU measure on Figures 1, 2, and 3 is based on the first RTU scan and the final carcass value measured directly on the finished carcass at the packing plant.

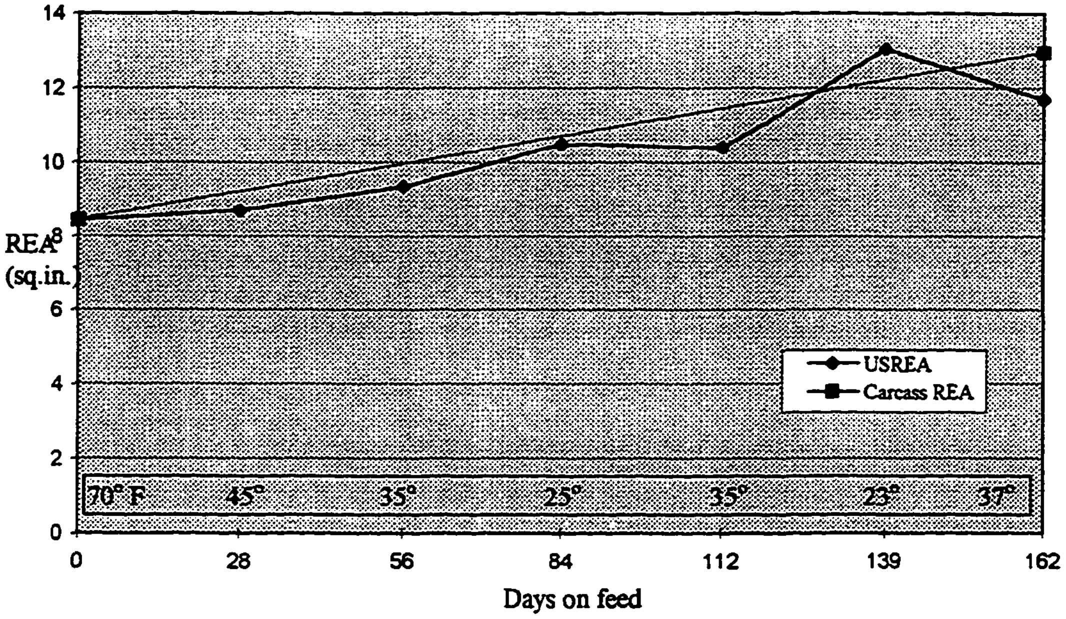

Figure 1. Ribeye area development based on serial ultrasonic scans and final measured carcass data over days in feedlot and average daily temperature in degrees Fahrenheit

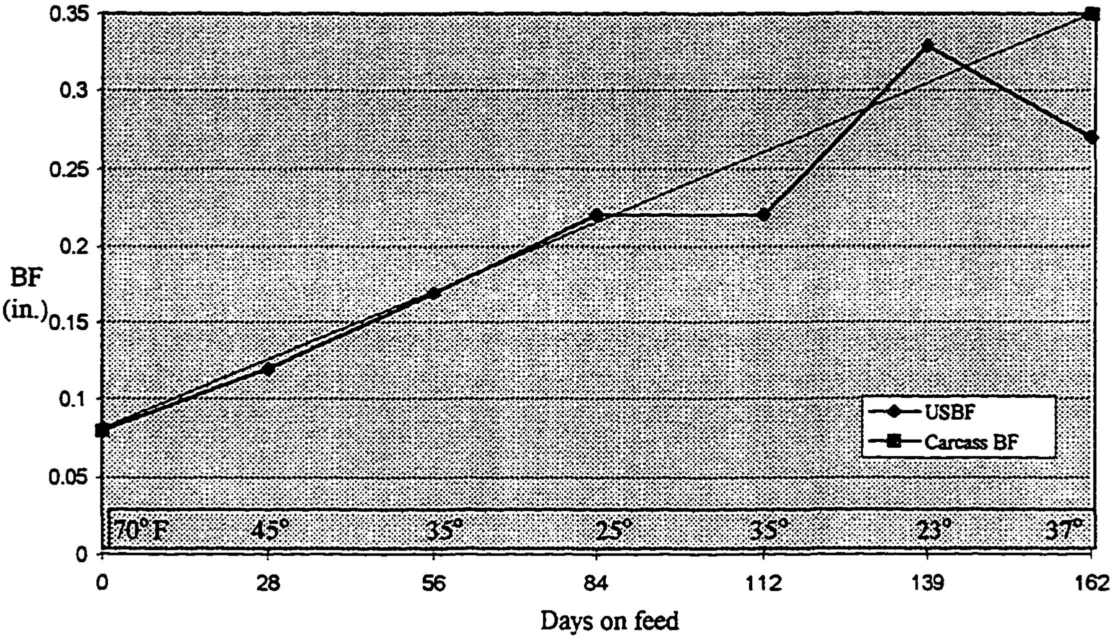

Figure 2. Backfat development based on serial ultrasonic scans and final measured carcass data over days in feedlot and average daily temperature in degrees Fahrenheit

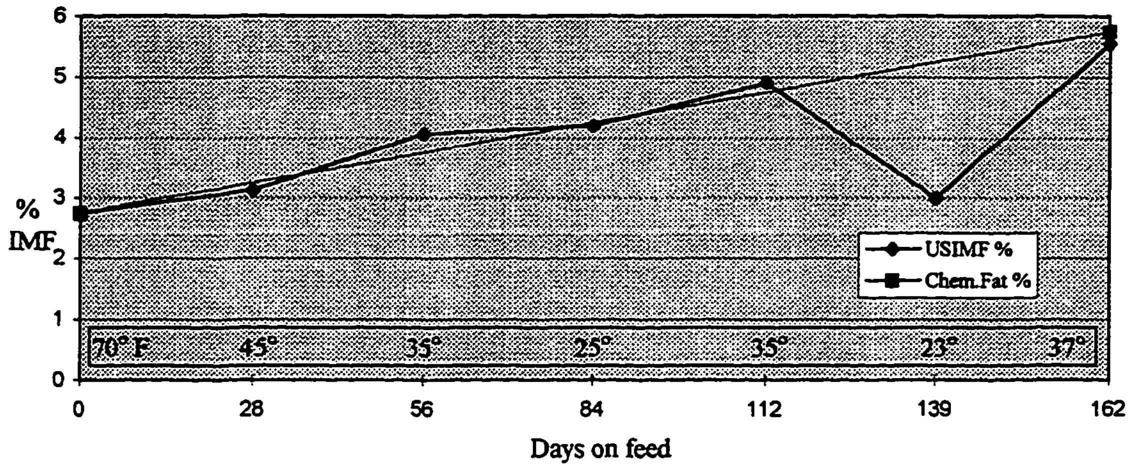

Figure 3. Intramuscular fat development based on serial ultrasonic scans and final measured carcass data over days in feedlot and average daily temperature in degrees Fahrenheit

The plots of average RTUREA, RTUBF, and RTUIMF all show a linear trend during this period steers were on feed; thus, the equations used to describe these processes are linear during this time. Some argument may stem from this stance since REA, BF, and IMF development, over time, could change and probably will as the animal matures or has a change in diet. The data, although representing a small segment of the developmental process does illustrate a time frame that is of interest for commercial beef production since it is through this stage in contemporary beef producing systems that cattle are placed in the feedyard, fed, and marketed. Thus, documentation and modeling of the development of finishing cattle beyond the point considered to be a mature slaughter weight/condition may not be necessary. Likewise, what occurred prior to the time these cattle were placed on feed may not be critical as long as the point at which the cattle are started is documented with an initial RTU measurement of the REA, BF, and IMF.

It should be noted that when observing Figures 1 and 2 the ultrasound estimates of REA and BF underestimate the measured carcass values at slaughter. It also should be noted that this difference appears to become greater over time or as growth occurs. Brethour (1992) states that when dealing with the BF value and comparing what is measured with

RTU on the live animal and what is measured with a ruler on the carcass a difference can be expected due possibly to air introduction into the subcutaneous fat when the hide is removed mechanically at slaughter, a factor that Faulkner et al. (1990) seems to affirm. Turning our attention to Figures 4 and 5, however, may provide some additional evidence as to what is occurring. Note that the graphics have had slaughter day bias removed .

Figure 4, which deals with the bias associated with REA estimation, appears to show a definite bias where animals with a smaller REA are overestimated while those with a larger REA are underestimated. Figure 5, which deals with BF, shows a similar situation, but not as severe. What is occurring to the REA can not be explained by air introduction nor could all the blame be placed on how the halved carcass hangs in the cooler. Thus, the point that appears to require investigation seems to revolve around the physics of ultrasonic properties with their transmission through tissue and equipment calibration. Wilson (1995) comments on this problem as well and states that this problem may be due to both the ultrasound equipment calibration and the technician, but the solution to this problem has yet to be fully resolved. Richardson (1962) describes many basic principles regarding the physics of ultrasound and clearly notes how the physical properties of the medium through which RTU waves pass can change the wave's absorption. Thus, as the muscle of the animal changes in composition, one would expect these types of changes to occur. These wave changes are necessary to allow for the identification of IMF, but problems surface as carcass composition varies due to calibration as Wilson (1995) mentions. The physical mass alone may also be a problem in itself since it appears that the sound waves which are transmitted and then received by the transducer have fairly definite ranges of effectiveness. A large mass then uses relatively dispersed RTU waves from which images are collected. Small muscles may likewise pose a similar problem in an opposite manner due to an overly strong single per unit of mass; thus, the effect being an inflated image. The clarity of the image as well may have some implications on measurement bias. For instance, a large REA may exceed the equipment's capacity to capture the whole image; thus, some guessing may occur when calculating the area. BF analysis, likewise, could be biased due to depth since utilizing a

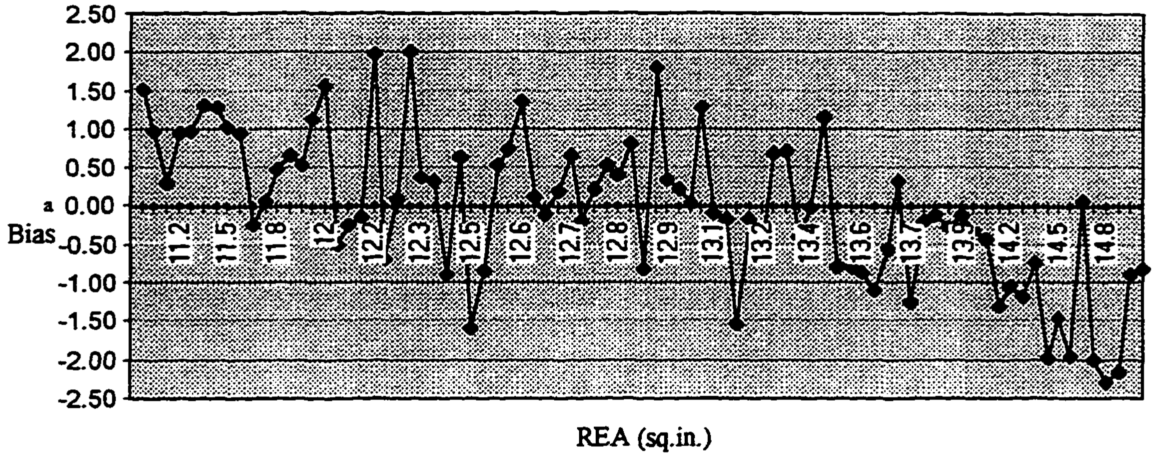

Figure 4. Bias observed in ultrasound ribeye area measurements as ribeye areas increase

[a] Bias = (RTU measure - carcass measure).

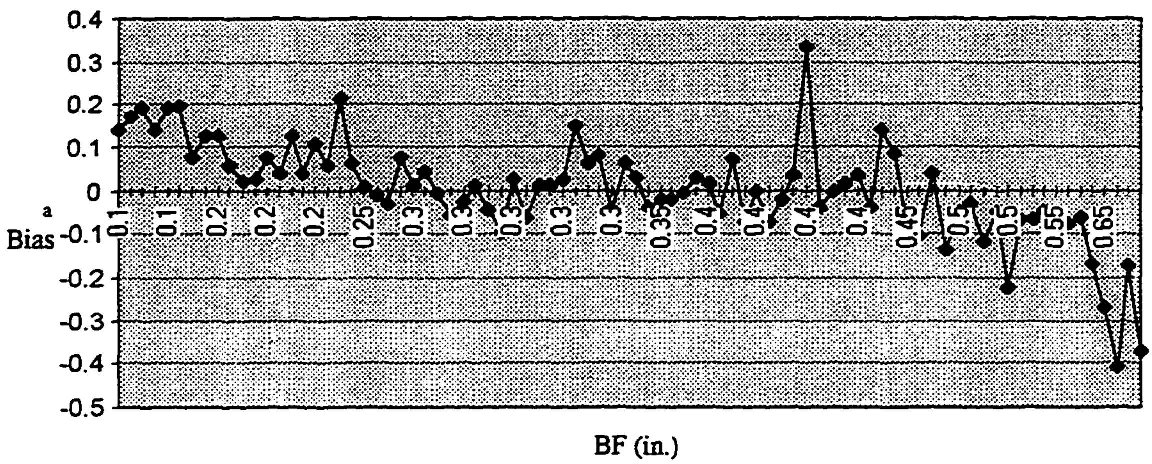

Figure 5. Bias observed in ultrasound backfat measurements as backfat increases

[a] Bias = (RTU measure - carcass measure).

pointer to do the measurement is somewhat crude when measuring incoming cattle, but as the depth increases measurement should become easier and subsequent error, less.

Environmental influences on equipment may also have a fair amount of impact on the image that is viewed as well. The average day time temperatures have been recorded on Figures 1, 2, and 3. The RTU values obtained on day 139 and, to some extent, on day 84 seem to fall out of place relative to the other values obtained. Why this occurred may have some relation to the fact that these two days were also the coldest days of the trial. The ALOKA equipment used here did not have an easy means by which it could be recalibrated on location nor was it possible to minimize temperature variation effects during the day of measurement. The result was elevated REA and BF estimations, while IMF estimations were depressed. The reason for the low IMF estimations was thought to be due to the fact that images obtained during cold weather are generally darker; thus, less speckling appears in the IMF analysis. The reason for the elevated REA and BF estimations is not clear. Could it be that there is less interference for sound wave transmission? It is, however, interesting to note that the bias observed on those cattle sold at day 139 was lower than that observed on the warmer days (Table 2). It does appear that this is a factor one must overcome if RTU is used in the field.

Table 2. Average bias and standard error of prediction for ultrasound measurement to final carcass measurement at slaughter

Days feed	REA		BF		IMF	
at slaughter	Bias[a] (in.^{2})	SEP[b]	Bias (in.)	SEP	Bias (%)	SEP
139	0.02	0.93	0.02	0.10	-2.09	2.08
153	-1.08	0.96	-0.10	0.11	-0.17	1.82
174	-1.49	1.09	-0.08	0.13	-0.38	1.40
Overall	-0.95	1.15	-0.062	0.12	-0.65	1.85

[a] Bias = (RTU measure - carcass measure).
[b] SEP = $[\Sigma(\text{RTU measure} - \text{carcass measure} - \text{bias})^2 / (n-1)]^{0.5}$.

Equations which could be used to predict current REA, BF, and IMF throughout the feeding period were developed based on the initial RTU measurement and the final carcass measurement. These two measures were used primarily due to a higher confidence in their accuracy relative to the others since the final carcass measure was taken directly from the carcass of the slaughtered animal and the first RTU scans were obtained during warm weather and from clean, dry cattle. There was also interest in developing equations that could use a single, early scan measurement to reduce the need to rescan later.

The graphical illustrations of Figures 1 to 3, based on pen averages, appear linear when the influence of what appears to be a climate-equipment interaction is taken out; thus, the equations developed for REA, BF, and IMF are linear and have the form: $y = mx + b$. Using the initial RTU value as the y intercept (b), the estimated carcass measurement as the y value, and doing a regression analysis to determine the appropriate inputs and parameters for the slope (m); three equations capable of estimating REA, BF, and IMF (Equations 1, 2, and 3, respectively) on a given day (x) during a feeding period resulted. The slope (m) of development is the point of interest in all three equations since the unexplained variability observed between animals as they develop from the initial RTU measure to the final carcass measurement is contained within this slope. Note that only the first (day 0) RTU measurements and the final carcass measurements taken directly from the slaughtered animals were used in the development of the equations.

The results of this approach appear favorable when using the equations that were developed on the data set from which they were developed (see tables 3 to 8) and does show a higher degree of accuracy and less variability than the RTU reading taken prior to slaughter. Validation of these equations on independent data sets needs to be done, and the question regarding how these equations will work in conditions outside of a feedlot where higher roughages are fed is yet to be determined.

A preliminary look at the effectiveness of these equations regarding REA development on one independent data set supplied by the Beef Nutrition group at Iowa State University did show promise (Table 9). The cattle included in this independent data set averaged 900 lb. rather than 750 lb. at the time they entered the feedlot. These cattle were maintained in 16

Equation 1. Ribeye area development

REAC = REA + (ADG x 0.0127 + DMF x 0.0061 - WTr x 0.0483) x DOF

where:

REAC = current ribeye area ($in.^2$).
REA = initial ribeye area ($in.^2$).
ADG = cumulative average daily gain (lb.) since initial ribeye measurement was taken.
DMF = (current daily dry matter intake / current body weight (lb.)) x 100 .
Wtr = (current shrunk body weight - initial shrunk body weight) / estimated shrunk weight when 50% of cattle in lot will grade Choice as described by Fox et al., 1992.
DOF = days since initial ribeye area measurement was taken.

Table 3. Parameters of slope describing ribeye area development

Input	Parameter	R^2	SE	P > F
ADG	0.0127	0.9607	0.002	0.0001
DMF	0.0061	0.9655	0.001	0.0001
Wtr	- 0.0483	0.9687	0.014	0.0012

Table 4. Ribeye area equation accuracy on initial data set summarized over lots

	Avg. REA	SD REA	Min. REA	Max. REA	Avg. bias[a]	RMSE[b]	r
Carcass REA	12.97	0.51	12.09	13.88			
Equation REA	12.98	0.30	12.36	13.53	0.02	0.41	0.57

[a] Bias = (RTU measure - carcass measure).
[b] RMSE = root mean square error, $[\Sigma\ (\text{equation estimate - carcass measure})^2 / n]^{0.5}$.

Equation 2. Backfat development

BFC = BF + (ADG x 0.0004 + IMFW x 0.0935 + BWr x 0.0259) x DOF

where:

BFC = current backfat (in.).
BF = initial backfat (in.).
ADG = cumulative average daily gain (lb.) since initial backfat depth measurement was taken.
IMFW = (initial percent intramuscular fat / body weight at time of measurement(lb.)).
BWr = (initial backfat (in.) / body weight at time of measurement (lb.)) x 100.
DOF = days since initial backfat depth measurement was taken.

Table 5. Parameters of slope describing 12th rib backfat development

Input	Parameter	R^2	SE	P > F
ADG	0.0004	0.7997	0.0001	0.0001
IMFW	0.0935	0.8073	0.0568	0.0403
BW	0.0259	0.8106	0.0192	0.1806

Table 6. 12th rib backfat equation accuracy on initial data set summarized over lots [a]

	Avg. BF	SD BF	Min. BF	Max. BF	Avg. bias	RMSE	r
Carcass BF	0.34	0.06	0.21	0.49			
Equation BF	0.36	0.03	0.32	0.42	0.02	0.05	0.58

[a] See footnotes in Table 4.

Equation 3. Intramuscular fat development

$$\mathbf{IMFC = IMF + (W \times 0.0040 - DMF \times 0.0092 + BF \times 0.0779) \times DOF}$$

where:

IMFC= current percentage of intramuscular fat.
IMF = initial percentage of intramuscular fat.
W = centum weight (lb.) when initial marbling measure was taken.
DMF = (current daily dry matter intake / current body weight (lb.)) x 100.
BF = initial backfat measure (in.).
DOF = days since initial intramuscular fat measurement was taken.

Table 7. Parameters of slope describing intramuscular fat development

Input	Parameter	R^2	SE	P > F
W	0.0040	0.7731	0.00001	0.0001
BF	0.0779	0.7826	0.03700	0.0372
DMF	-0.0092	0.7915	0.00500	0.0048

Table 8. Intramuscular fat equation accuracy on initial data set summarized over lots [a]

	Avg. IMF	SD IMF	Min. IMF	Max. IMF	Avg. bias	RMSE	r
Chemical IMF	5.73	0.85	4.51	7.48			
Equation IMF	5.70	0.53	4.92	6.50	- 0.03	0.73	0.50

[a] See footnotes in Table 4.

pens of six head and were fed a slightly higher concentrate level than the cattle used in developing the equations (90 % vs. 85% concentrate). By taking the equations that were developed and applying them to this set of cattle, REA are underestimated. If one considers the idea presented in Figure 4 where as the muscle mass increases the RTU estimation bias becomes larger in terms of under prediction and we then make this linear adjustment, the prediction equations then become fairly close in predicting REA once again. The linear adjustment was calculated from the observations in the data set used to develop the REA equation. The adjustment is as follows: REAadj = [(RTUREA - 8.5) x 0.396] + RTUREA

Although the adjustment presented here uses the 8.5 square inch ribeye as a base since this was the average starting RTUREA for the cattle the equations were determined from. The true base for the ALOKA equipment used here may actually be somewhat higher, perhaps closer to 10 square inches, when information such as that presented on Figure 4 is considered. Therefore the base value of 8.5 may be something less and the initial value for the other data set may be less as well. The relationship of the other variables in either case and the methodology in equation determination, however, would appear to be similar with the potential difference being an estimation of a steeper slope when re-evaluating the equations presented here with a correct base value. Until some of these calibration factors are resolved though, the extent of the adjustment can not be recommended and a number of basic steps may need to be taken regarding quality control of the images collected such as size of animal when scanned. Temperature may have a fair amount of impact in scan quality as may humidity (Richardson, 1962); therefore even the bias illustrated in Figures 4 and 5 could have been affected, promoting a data shift either up or down.

Table 9. Summary of derived equation effectiveness for describing ribeye area development with independent data set

	Not adjusted	Adjusted
Initial avg. RTUREA measure	9.50 in.^{2}	9.90 in.^{2}
Finished carcass avg. bias	- 0.66 in.^{2}	0.18 in.^{2}
Finished carcass RMSE	0.95	0.38

Implications

The utilization of RTU images along with feedlot performance data appear to provide a means by which the carcass components of REA, BF, and IMF can be monitored while cattle are in the feedlot. This system worked across breeds of varying origin and did not require subsequent RTU measurements. Further testing of this system is in order, but not without consideration to the possible effects that the environment or animal may have on the RTU image. Thus, it appears that for one to obtain consistent images in inconsistent circumstances the primary task is that of equipment engineering.

AN OBSERVATION OF THE VALUE INITIAL ULTRASONIC MEASUREMENTS HAVE FOR SORTING CATTLE AND ESTIMATING THE FINAL STANDARD DEVIATION FOR A LOT IN TERMS OF CARCASS WEIGHT, QUALITY GRADE, AND YIELD GRADE

A paper to be submitted to the Journal of Animal Science.

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Abstract

An observational study regarding the usability of ultrasonic (RTU) evaluation of ribeye area (REA), 12th rib backfat (BF), and percent intramuscular fat (IMF) of incoming yearling feedlot cattle was done to test the effectiveness of RTU in identifying potential differences in a group of cattle being placed on feed which could indicate the expected standard deviation in terms of finished carcass weights (CW), quality grades (QG) and yield grades (YG) for the lot. The identified components contributing to the variability in the final spread of these carcass qualities accounted for 89% of the variability in carcass weight and yield grade standard deviations and 72% of the variability in the quality grade. Ultrasonic measurements were also taken every 28 days to view changes in rank regarding REA, BF and IMF among cattle in the pens. Calculation of the correlation between RTU measured values at these times and final carcass values for REA, BF and IMF revealed that the initial RTU measurements of REA and IMF were as accurate as the later RTU measurements when used to rank animals. The RTU measurements taken later in the feeding period regarding BF, however, were more effective in ranking animals than the initial measurements.

Introduction

Commercial feedlots deal with a wide variation of cattle in terms of their genotypes, maturity, and previous treatment. This can present a number of management challenges in terms of nutrition, cattle flow schedules, and marketing if feed utilization efficiency, facility output, and uniform product marketing are goals of the feedyard. Thus, purchasing cattle or sorting existing cattle into groups composed of similar characteristics is a means by which one can reduce variation. The more common means by which this is already done is to sort by breed i.e. Holstein, Brahman crossbred, etc.; gender, age i.e. calves, yearlings; and frame size. These sorts are somewhat innate management practices used by those feeding or selling cattle and are effective in reducing the variation that would have otherwise occurred. However, variation will exist in terms of the relative fatness or muscling of the animals in the groups after the primary sort occurs. The ability to visually identify these differences in fatness or leanness of the animal also diminishes as animals become more similar in conformation since a bulging appearance is deceptive and can be due to fat or muscle especially if the topline and the rear of the animal is viewed (Berg and Butterfield, 1976). Dolezal et al. (1993) appears to imply this as well in his trial of feeding a number of muscle grades of feeder cattle. He notes that even though the attempt was to feed the cattle to a given point of finish, the heaviest muscled cattle were retained the shortest time and had the least fat cover while the thin muscled animals were held longer and allowed to deposit more fat prior to slaughter.

The nondestructive evaluation capabilities of RTU provide one with a means by which differences between animals in terms of carcass qualities can be detected early. Trenkle and Iiams (1997) have suggested merit in the practice of early RTU analysis of carcass qualities to sort cattle into management groups to maximize carcass yields. Likewise, commercial systems, such as Accu-Trak™ (developed by Micro Chemical, Inc.), already exist which have realized this and utilize RTU scans along with a series of measures including the weight and gross dimensions of the animal to sort animals into various management groups when cattle enter the feedyard and at reimplant time. The later evaluation appears necessary in addressing the individual responses of cattle in the lot, but the amount of this later variation that can be identified by an early evaluation is not mentioned. Houghton and Turlington (1992) in a summary of results regarding RTU evaluation, however, mention the use of RTU for sorting cattle entering the feedyard and when comparing RTU to visual assessment they noted a higher correlation of initial RTUBF to final carcass BF ($r = 0.39$) than visual BF estimate to carcass BF ($r = 0.16$ to 0.33), but when selling cattle there appeared to be some conclusion that the benefit of an initial sort based on RTUBF and frame size may not be significantly better than one based on visual appraisal alone.

The purpose of this paper will focus on the effectiveness of a preliminary live animal evaluation in terms of how well the evaluation of an incoming pen of cattle is in identifying the future spread or standard deviation in carcass weight, QG and YG that will be observed when the given group of cattle is finished. This type of evaluation, unlike evaluations which are used to rank individual animals in a competitive stock show, is to project the uniformity of a given group when finished. The results from this evaluation may then provide some justification for the implementation of an initial sort in order to direct animals through an appropriate channel of production and marketing management.

Materials and Methods

The cattle involved in this study consisted of a crossbred group of 112 August-October born steers of British and Continental beef breeding. The steers were over-wintered and then maintained on pasture during the following year until mid August at the Western Iowa Research and Demonstration Farm at Castana, Iowa. The cattle, which averaged 750 lb. when taken from the pasture, were ultrasonically scanned to estimate the 12th rib ribeye area, 12th rib backfat depth, and intramuscular fat percentage; implanted with Compudose™; given an Ivomec™ injection; and placed into the feedlot (16 groups of 7 steers) at the Castana Farm. The diet, approximately 85 percent concentrate, consisted of shelled corn, ground hay, molasses, and was supplemented with a urea-based 40% crude protein, mineral, vitamin premix containing Rumensin™. Feed DM, NDF and ADF were determined from feed samples taken biweekly (Goering and VanSoest, 1970; VanSoest et al., 1991). Feed allocation treatments were assigned to pens with intake allowances per pen to be ad libitum, 95% of ad libitum, or 90% of ad libitum. Feed delivery was either once a day at 8:00 am or 4:00 PM, or twice with half of the ration being delivered at 8:00 am and the rest being delivered at 4:00 PM. The cattle remained in the feedlot until the pen was estimated, on average, to grade Choice at which time the pen was marketed and processed at the IBP plant in Denison, IA. It should be noted that the cattle were not sorted into pens initially based on RTU or hip height data.

Cattle live weights and ultrasonic images of REA, BF, and IMF were collected approximately every 28 days and within 21 hours prior to slaughter on each animal. The scans, composed of one image used to view REA and BF and one image used to view IMF, were collected and processed by the same individual throughout the trial. The RTU scan processing was done at Iowa State University. The RTUIMF content was determined using the Iowa State University USOFT program (Amin et al., 1997). Feed intake and climatic data were collected daily until slaughter. Dry matter estimations of the feed were taken weekly. Data collection involving ultrasonic images was accomplished using an ALOKA 500V real-time ultrasound machine with an attached 17 cm. linear array transducer. Images were collected and processed at Iowa State University by the same certified technician. Direct measurements of carcass weight, REA, and BF were taken at the packing plant when the cattle were slaughtered. Cattle were graded by the USDA Meat Grading Service after which a slice of the exposed *Longissimus dorsi* muscle from the USDA graded carcasses was then obtained to analyze intramuscular fat content by using the Soxhlet procedure with n-hexane as the solvent.

Development of the equations used to project the standard deviation of YG and QG for a finished pen involved the individual animal measures at the time cattle were started in the feedlot, but due to the goal in projecting group response the individual measures were compiled to arrive at correlations between measures and standard deviations as well as average values for the pen. Data analysis was accomplished by using the regression techniques included in the SAS software package to identify those measured parameters that contribute to the observed pattern of development.

Results and Discussion

The ultrasonic images of REA, BF, and IMF from the cattle when compared to the final actual carcass values of REA, BF, and chemical IMF in terms of rank are displayed in Table 10. As noted in the materials and method section, the cattle in this trial were not sorted into treatment groups based on these measures, but were only documented in regards to existing differences and then observed in regards to their future development. The raw correlation between the RTU image and the carcass measure was calculated rather than using a rank correlation due to the closeness of the measurements, especially at the beginning of the trial where the ranking of animals may be decided on 1/100 square inches of REA or 1/1000 of an inch of BF. Small differences such as these could indeed be legitimate differences between animals, but could easily be due to the data measurement and processing as well.

As indicated in Table 10, the initial measures of REA tended to correlate well with the final carcass REA measures, or the cattle with larger REA at the start had the larger REA at the end. Measures of BF tended to improve as the cattle approached their finished weight while IMF measures were fairly constant throughout. There also seemed to be an improvement in the correlation between REA measurements as the spread between the measured values in the pen was greater. An illustration of this point is shown in Figure 6 where the standard deviation of the day 0 RTUREA values for each lot was plotted along with the corresponding correlation to the final REA. The trend, generally, appears that as the initial spread in REA areas increase in a given pen, the more one becomes capable in correctly identifying later differences between animals. Notice that this is similar to what was described earlier in terms of sorting cattle by frame where when larger differences exist more effective sorting can be done. The difference, though, is that now the RTU allows sorting at the next step where cattle of a similar frame size could be sorted into groups based on degrees of muscling. It should be noted that the day 0 RTUBF and RTUIMF values did not show the same pattern when plotted in the manner of the RTUREA values shown in Figure 6.

Table 10. Comparison between real-time ultrasound measures and carcass measures

	Correlation between day of ultrasound measurement and final carcass value			
Day on feed	RTUREA:REA	RTUBF:BF	RTUIMF:IMF	RTUIMF:QG
0	0.60	0.33	0.40	0.32
28	0.62	0.32	0.25	0.43
56	0.61	0.49	0.17	0.46
84	0.47	0.59	0.23	0.45
111	0.40	0.63	0.34	0.68
139	0.46	0.59	0.33	0.41
Final	0.55	0.62	0.29	0.63

	Average and standard deviations of ultrasound measurements					
	RTUREA		RTUBF		RTUIMF	
Day on feed	Avg. (in.^{2})	SD	Avg. (in.)	SD	Avg. (%)	SD
0	8.46	0.75	0.09	0.04	2.73	0.87
28	8.70	0.76	0.13	0.04	3.13	0.79
56	9.56	0.73	0.19	0.06	4.05	0.96
84	10.49	0.83	0.23	0.06	4.19	0.86
111	10.58	0.89	0.23	0.07	4.89	1.12
139	12.97	0.82	0.34	0.10	3.00	0.54
Final	12.20	1.18	0.29	0.12	5.57	1.00

Final carcass measurements							
REA		BF		IMF		Quality Grade	
Avg. (in.^{2})	SD	Avg. (in.)	SD	Avg. (%)	SD	Avg.	SD
12.99	0.98	0.35	0.12	5.74	1.90	Cho.$^-$	1/3 QG

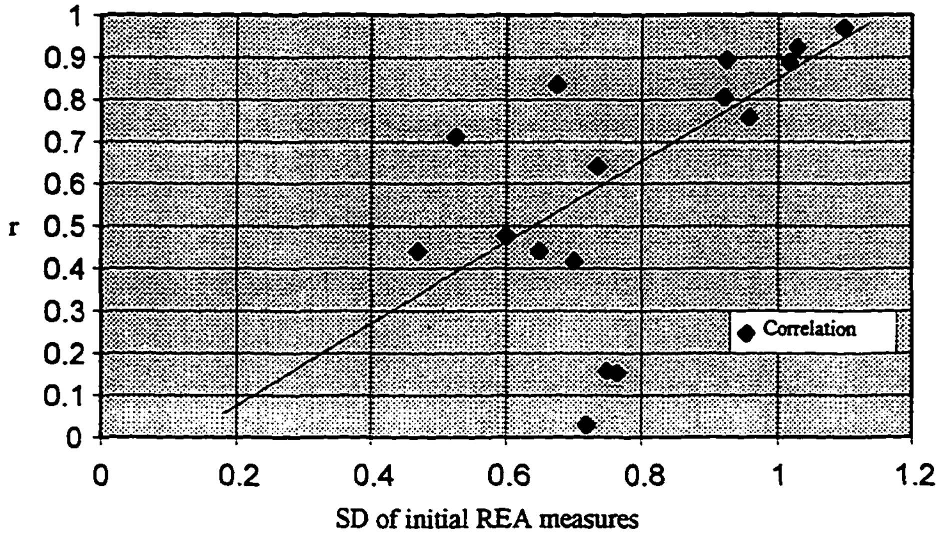

Figure 6. Correlation between day 0 ultrasound measure and final carcass REA measurement as the standard deviation of initial REA within a lot increases

Rather these plots appeared as a round cluster centrally located on the grid and may be a function of the lack of expression of fattening of these cattle at this point in their life combined with the difficulty of measuring a relatively low amount of body fat.

Later RTU measurements would be expected to improve in their correlation with the final carcass measurements, but other than an improvement in RTUBF the evidence for this was not strong. The RTUIMF relationship to chemical IMF and to the USDA quality grade (QG) in the finished carcass is interesting. The comparison to the chemical IMF value appears to decrease while the relationship between RTUIMF and QG appears to increase. The IMF deposits, which tend to develop later and seem to require some degree of animal maturity for expression, would be expected, like backfat accretion, to be more accurately evaluated later in terms of ranking animals. This was the case for QG evaluation, but not for chemical IMF. The effects of temperature may have had some role in this since as the trial progressed average daily temperatures decreased and made it difficult in maintaining data acquisition consistency during a given day. Colder temperatures result in darker images which could have some of the normal detailed speckle pattern lost. Thus, cattle with a more evenly dispersed pattern of IMF could have had a fair amount of undetected IMF due to the darkened image.

Group evaluation was done in a manner to describe the change in the standard deviation of carcass weights, yield grades, and quality grades for each pen from an estimated initial value. Equations 4, 5, and 6 provide the numerical relationships between the variables used in providing the estimates of CW, YG, and QG standard deviations. Tables 11-16 provide a summary of the actual and estimated values from the lots used in equation development. Table 17 then provides an indication of the effectiveness of these equations on two independent groups of cattle raised at the Iowa State University affiliated Rhodes and McNay research stations.

The effectiveness of the regression equations in estimating the standard deviation concerning the CW, YG, and QG in the two independent data sets is somewhat variable, however, the relationship between the variables used and the final outcome does appear to have some relevance. Using the two independent data sets and the variables involved with calculating the quality grade standard deviation, it can be observed that the Rhodes data are more dispersed than the McNay data (Table 17). A positive correlation between initial IMF and initial BF, for instance, indicates less spread in the final quality grade according to the equation. This was the case in the sample data where a more positive correlation between initial intramuscular fat and initial backfat (IBc) can be observed in the less variable McNay data. The correlation between initial intramuscular fat and the initial ratio of live weight to expected Choice weight (IW0c), the ratio of initial live weight to expected weight at Choice (W0) by itself, and the initial standard deviation of the backfat depth (Bfsd) for a pen have relationships that likewise confirm the equation's stance in terms of increasing or decreasing the final QG standard deviation. The observed bias in the sample data, though, reveals that the correct numerical description describing how much these items influence the outcome is yet to be fully decided.

Equation 4. Projected carcass weight standard deviation

$$\mathbf{CWFsd = CWIsd + [(BF \times 0.033 - IMFsd^2 \times 0.001) \times DOF] \times 100}$$

where:

CWFsd = expected standard deviation of carcass weight for pen.
CWIsd = initial standard deviation of carcass weight for pen.
CWI = initial carcass weight calculated on incoming cattle, calculated as: live weight (lb.) x 0.54.
BF = average initial 12th rib backfat depth (in.) for pen.
IMFsd = standard deviation of initial intramuscular fat percents for pen.
DOF = estimated number of days the cattle will be fed.

Table 11. Parameters of slope describing estimated standard deviation of carcass weight

Input	Parameter	R^2	SE	P > F
BF	0.033	0.8481	0.0047	0.0001
$IMFsd^2$	-0.001	0.8920	0.0005	0.0317

Table 12. Carcass weight standard deviation equation accuracy on initial data set summarized over lots

	Avg. CWsd	SD CWsd	Min. CWsd	Max. CWsd	Avg. bias[b]	RMSE[c]	r
[a] Actual CWsd	58	18	37	100			
Estimated CWsd	59	15	32	92	0.65	10.89	0.78

[a] Values provided as pounds.
[b] Bias = (estimated measure - actual measure)
[c] RMSE = root mean square error, $[\Sigma(\text{equation estimate - carcass measure})^2 / n]^{0.5}$.

Equation 5. Projected yield grade standard deviation

YGFsd = YGIsd + (RWr x 0.329 - IW0c x 0.001 - IMFsd^2 x 0.002 - BW0c x 0.001) x DOF

where:

YGFsd = expected standard deviation of yield grade for pen.
YGIsd = initial standard deviation of yield grade for pen.
YGI = initial yield grade on incoming cattle calculated as: 2.5 + 2.5 x RTUBF(in.) + 0.02 + 0.0038 x live weight (lb.) x 0.54 - RTUREA x 0.32.
RWr = average ratio of initial REA(in.^{2}) / initial live weight (lb.) for pen.
IW0c = correlation between initial IMF and W0 for pen.
W0 = initial live weight / expected live weight when carcass has 27% fat as described by Fox et al., 1992.
IMFsd = standard deviation of initial intramuscular fat percents for pen.
BW0c = correlation between initial BF and W0 for pen.
DOF = estimated number of days the cattle will be fed.

Table 13. Parameters of slope describing estimated standard deviation of yield grade

Input	Parameter	R^2	SE	P > F
RWr	0.329	0.7911	0.0502	0.0001
IMFsd^2	-0.002	0.8842	0.0006	0.0050
IW0c	-0.001	0.9093	0.0005	0.0723
BW0c	-0.001	0.9236	0.0006	0.1590

Table 14. Yield grade standard deviation equation accuracy on initial data set summarized over lots [a]

	Avg. YGsd	St.D. YGsd	Min. YGsd	Max. YGsd	Avg. bias	RMSE	r
Actual YGsd	0.52	0.18	0.21	0.97			
Estimated YGsd	0.58	0.21	0.24	0.83	0.06	0.16	0.69

[a] See footnotes for Table 12.

Equation 6. Projected quality grade standard deviation

$$QGFsd = 20.597 - BFsd^2 \times 167.546 - IBc \times 0.838 + IW0c \times 0.928 - W0 \times 28.481$$

where:

QGFsd = expected standard deviation of quality grade for pen.
BFsd = standard deviation of initial backfat depths for pen.
IBc = correlation between initial IMF and BF for pen.
IW0c = correlation between initial IMF and W0 for pen.
W0 = initial live weight / expected live weight when carcass has 27% fat .

Note that quality grade codes used for analysis are as follows:
6 = Select $^+$, 8 = Choice, 10 = Prime $^-$

Table 15. Parameters describing estimated standard deviation of quality grade

Input	Parameter	R^2	SE	P > F
Intercept	20.597		5.357	0.0027
$BFsd^2$	-167.546	0.1401	87.802	0.0828
IBc	-0.838	0.2541	0.182	0.0008
IW0c	-0.928	0.4212	0.220	0.0014
W0	-28.597	0.9236	5.357	0.0045

Table 16. Quality grade standard deviation equation accuracy on initial data set summarized over lots [a]

	Avg. QGsd	St.D. QGsd	Minimum QGsd	Maximum QGsd	Avg. bias	RMSE	r
Actual QGsd	1.18	0.35	0.41	1.62			
Estimated QGsd	1.20	0.29	0.73	1.70	0.02	0.18	0.84

[a] See footnotes for Table 12.

Table 17. Carcass parameter standard deviation equations accuracy on independent data set

[a]	Initial weight	Final weight	YGIsd	CWIsd	DOF	IMFsd
Rhodes: 1 pen, 74 steers	807	1127	0.27	62	83	0.97
McNay: 1 pen, 164 steers	922	1289	0.96	72	120	0.88
Equation:16 pens x 7steers	750	1204	0.22	0.29	157	0.87

Initial values	RBc	Bfsd	IBc	IW0c	BW0c	RWr	BF	W0
Rhodes data	0.28	0.06	0.05	-0.09	0.37	0.01	0.17	0.70
McNay data	0.19	0.08	0.34	-0.06	0.37	0.01	0.25	0.82
Equation data	0.03	0.02	0.08	-0.17	0.16	0.01	0.08	0.61

Finished lots	Actual CWFsd	Actual YGFsd	Actual QGFsd	Bias CWsd	Bias. YGsd	Bias QGsd
Rhodes data	89	0.48	1.77	8	- 0.09	-1.84
McNay data	96	1.00	1.00	62	0.17	-4.17

a. See equations 4-6 for explanation of abbreviations and formulas.

The variables involved in the estimation of YG and CW spread, for the most part, also agree in terms of the influence they may have on the final standard deviation. The equations from which YG and CW are calculated, however, are set up in a manner that includes the existing standard deviation in the calculation of the future variation. The idea that these equations are linear, which was done primarily for simplicity, may be incorrect and does require some additional testing. The ability to measure REA and BF in order to arrive at an estimate of the existing circumstances regarding YG does seem necessary when estimating the final YG standard deviation.

The variables used in the above determinations are primarily relationships between measurable characteristics of the animal. These relationships are group dependent as is the determination of the final spread in the carcass measures they are to represent. There is some logic to their use in that if one considers the quality grades in a pen of slaughtered cattle as an example, both IMF and BF are involved across the whole pen. The QG is based directly on visible IMF and indirectly on BF since it is primarily the BF that determines when cattle are sold. A more positive correlation may then indicate less genetic variation between animals since a similar progression in back fat and intramuscular fat deposition across the pen appears to be occurring that can theoretically be evaluated further in terms by the spread in BF. The use of these relationships may also be somewhat questionable in that these values can change due to circumstances of time and environment. For example, a group of calves may show a strong positive correlation between the BF and REA initially, but after a period of backgrounding the relationship may no longer exists. A situation such as this can be explained probably in terms of maternal effects and then compensatory gain, but would confound our estimations if based on initial inputs.

Implications

An evaluation of incoming cattle capable of projecting the future uniformity of the group in terms of YG, QG, and CW is of merit since cattle are managed and subsequently marketed in terms of the group. An estimated lack of uniformity at finish could therefore be used to justify sorting cattle into management groups prior to placing animals in the feedlot. There appears to be some carcass parameters which one can use to estimate the potential uniformity, but the weight one should place on the parameter under the given circumstances is not clear.

MONITORING LIVE WEIGHT, YIELD GRADE, QUALITY GRADE, AND CARCASS WEIGHT DEVELOPMENT IN FEEDLOT CATTLE

A paper to be submitted to the Journal of Animal Science.

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Abstract

The National Research Council's (NRC) 1996 guidelines regarding beef cattle nutrition provide diet formulation guidelines as well as equations that relate nutrient intake to weight gain. These equations can be adapted to a commercial feedlot to estimate cattle weight gain for analytical purposes with variable accuracy. Carcass weight can subsequently be estimated to a fair degree of accuracy as well if the live weight is known; thus, it becomes possible to assess live animal value both in terms of the measurable live weight as well as the carcass weight. Further evaluation of carcass attributes along with an estimation of internal fat provides the opportunity to calculate quality and yield grades as well.

Introduction

The guidelines provided by the National Research Council (NRC) regarding beef cattle growth and nutrition have been updated as of 1996. There appears to be four main areas to consider when utilizing these new guidelines to update existing systems. The first area would be the contribution that frame size has on growth and the means by which frame sizes can be used to standardize cattle across breed and gender in terms of growth potential. The second area involves the protein component of the diet, which is now presented in terms of metabolizable protein and has been quantified and stated in terms of it's contribution to weight gain, as has been done previously with net energy. Body condition scores for growing and finishing cattle and their implications in terms of compensatory gain represents the third area, and the fourth area deals with the modifiers of the animal's maintenance requirement. The point of these modifications and additions to the NRC guidelines is to more accurately arrive at the correct weight of the live animal, and by this weight, the value may be estimated for cattle sold on this basis. When cattle value is based on carcass merit, however, it is necessary to estimate carcass weight (CW), yield grade (YG), and quality grade (QG) since with the carcass weight, one can estimate the size of cuts. Yield grade provides an estimate of the relative amount of meat, and quality grade provides an estimate of meat acceptability. The focus of this paper deals with the calculation of the primary outputs used to assess a monetary value to cattle being fed and monitored in commercial feedlots. These outputs; consisting of live weight, carcass weight, yield grade, and quality grade then provide the base from which performance can be summarized and compared.

The CW is often represented as some percentage of the live weight and these two weights are highly correlated. Thus, an accurate live weight estimate coupled with a description of muscling and fat accumulation (Berg and Butterfield, 1976) can describe much of the variability in dressing percents between feedlot animals. Gut fill must also be addressed, and this factor appears to be most easily quantified by noting dietary fiber content. High fiber diets which have been fed recently or are still being provided can contribute to the animal's apparent live weight both in terms of the weight of feed in the gut as well as the increase in organ mass required to handle the bulkiness of high roughage diets (Brabander et al., 1983; Hammes et al., 1964; Martz et al., 1996; Zinn et al., 1970). The timing of live weight measurement relative to carcass measurement for purposes of gut clearance can introduce variability in estimates as can mud, variation in weights of removed carcass components and variations in processing. These factors are difficult to quantify however.

The merit of CW estimation is that it allows one to identify carcasses that fit into preferred marketing windows as dictated by packers in terms of weight but also in terms of yield grade. A yield grade, based on the formula, requires an estimation of backfat (BF) and ribeye area (REA) both of which can be determined as described in Chapter 1 of this dissertation. The last remaining component, then, is the percent of KPH (kidney-pelvic-heart fat). Currently it is the KPH value which is the most difficult to estimate. The estimation of

REA and BF has been greatly enhanced through the use of ultrasonic imaging. The estimation of KPH is not as simple since a measurement technique such as RTU is not currently in use. Therefore, one must resort to what has been observed and described in literature. Wellington (1971) provides some insights in terms of differences between breed type and gender with Holstein and Angus cattle as does Kauffman et. al. (1976), with dairy, dual purpose and beef type cattle. The conclusion of these authors is that breeds used for beef generally have lower KPH values than those breeds used for dairy purposes. Also, at some given age under two years, bulls generally have less KPH than steers. Naturally a difference in processing of the carcass in terms of fat trim would impose variability and confound estimations. Carcass perception from one grader to the next could cause similar problems for KPH estimation and it may be, for all practical purposes, not possible to obtain an accurate estimation. Fortunately, the relatively small impact KPH has in the yield grade formula reduces the need for an exact estimate. Considering that being close to the KPH value will suffice, we can then develop the main observations and formulate a model to approximate current KPH values based on breed type and degree of finish. Therefore, if we can identify whether the animal is of dairy, dual purpose, or beef breeding; and then arrive at some conclusion of body fat content, a close estimate of KPH may be likely.

Materials and Methods

Equations were developed for estimating CW and KPH fat by summarizing data provided in the literature with the majority of this literature being taken from Iowa State University Beef Research Reports. The data provided in this literature dealt primarily with feedlot cattle being fed diets of 60 to 90 percent concentrate, but did also have some serial slaughter and pasture cattle data as well. A regression equation with a stepwise option, as specified by SAS, was used to identify the components contributing to the final carcass weight.

Estimation of the KPH value was simplified in calculation by recognizing breed type as dairy, dual purpose, or beef and then providing an appropriate average value of KPH for a finished animal of the specified type as a reference point. Adjustments to the KPH value were made based on animal fatness and weight relative to the estimated weight of the animal when it is composed of 27.5 percent body fat, or in the case of a group of similar animals, this would be the weight at which 50 percent of the cattle graded Choice (Table 18).

Table 18, which provides the reference in terms of average weight when 50 percent of a pen of cattle will grade Choice, also is the primary means by which anabolic implants are accounted for in their impact on weight gain. Note that the table provides values when no implant is given; however, if an estrogen implant is provided, the weight expected at 50 percent Choice shifts by one frame size upward for steers and by almost one frame size for heifers. When an androgen like implant is provided, the weight expected at 50 percent Choice shifts by one and one half frame sizes upward for steers and one frame size for heifers. The use of implants which combine the estrogen-like and androgen-like hormones then shifts the expected weight by two frame sizes for steers and one frame size for heifers. Bulls were not included in these shifts due to the large amount of hormone they already have naturally.

Table 18. Equivalent weights of nine frame sizes in cattle without implants

	Frame Size								
	1	2	3	4	5	6	7	8	9
Steers (lb.)	810	880	955	1030	1100	1175	1250	1320	1400
Heifers (lb.)	670	730	790	840	900	950	1000	1050	1100
Bulls (lb.)	1060	1145	1235	1320	1410	1500	1585	1675	1760

*Adapted from Fox et al., 1992.

The remaining components used to estimate the yield grade and quality grade were based on the equations presented earlier in this dissertation regarding ribeye area, backfat, and intramuscular fat. Live weight estimation was done according to the 1996 NRC guidelines and adjustments to the body condition score were upgraded as cattle were finished based on guidelines adapted from Loy (1983) and 1996 NRC guidelines. The 1996 NRC guidelines used to calculate weight gain are summarized in the form they were used for in this program in Appendix A. The weather and facility data from which a default data base was developed to estimate maintenance requirements when user input is deficient was based on historical weather data from Iowa and is located in Appendix B.

Validation of the equations for live weight gain was done based on: 16 pens of crossbred, yearling steers of British and Continental breeding fed from late summer through mid March at the Western Iowa Research Farm (WIRF) in Castana, IA; 8 pens of Hereford crossbred calves fed from late spring through mid winter at WIRF; and a pen of 147 heifers fed from fall through spring in a commercial feedlot in southwest IA. Carcass, yield grade, and quality grade equation validation utilized the 16 pens of yearling cattle. All cattle were fed a diet near 85 percent concentrate that contained corn grain and dry, ground hay. The group of heifers were provided with distillers grain and corn silage as well.

Results and Discussion

Carcass weight estimation was determined by Equation 7, and the results of this estimate when tested on independent data, consisting of 16 pens of crossbred beef cattle are indicated in Table 19. The equation provided an accurate estimate of carcass weight. It should also be noted that the ribeye area and backfat estimates used in the analysis were projected as described earlier in this dissertation and the live weight used was not the projected weight, but was the final actual live weight of the cattle.

Estimation of KPH fat was determined by Equation 8, and the results of this estimate when tested on independent data are indicated in Table 20. The equation provided an accurate estimate of KPH when the entire lot was estimated, but sensitivity of the equation declined when the lots at the extremes of KPH were evaluated. Combining the estimated values of KPH, carcass weight, backfat, and ribeye area allowed for an estimated yield grade to be calculated. The estimated YG (Table 24) compares quite favorably to the YG calculated from the actual carcass data. One point that should be clarified is that the BF and

REA estimates were calculated from equations that were based on the cattle used to calculate this YG analysis. If independent data were available the revealed accuracy may be different. The same should be noted regarding the QG estimation since the equation used to estimate current IMF was based on the same lot of cattle. The conversion of IMF to a quality grade, however, was based on independent data published by Wilson and Rouse (1994).

Equation 7. Estimation of the carcass weight component

CW = -190.194 + (PC * 0.4445) - (WI * 0.0314) + (W * 0.6559) + (RWr * 9258.1724) + (BF * 44.0220)

where:

CW = current carcass weight (lb.).
PC = percent concentrate in the ration.
WI = initial live weight (lb.).
W = current live weight (lb.).
RWr = current ribeye area(in.^{2}) / current live weight (lb.).
BF = current backfat depth (in.).

Table 19. Carcass weight equation evaluation (using lot averages) [a]

	Avg. CW	SD CW	Min. CW	Max. CW	Avg. bias[b]	RMSE[c]	r
Carcass CW	738	16	711	769			
Equation CW	730	8	715	744	-7.42	14.27	0.60

[a] All data presented in pounds.
[b] Bias = estimated measure - carcass measure.
[c] RMSE = root mean square error = $[\Sigma \text{ (equation estimate - carcass measure)}^2 / n]^{0.5}$.

Equation 8. Estimation of the KPH component

KPHc = (B * WTR) + (BF - 0.3)

where:

KPHc = current percent of kidney-pelvic-heart fat.
B = breed-type
where:
B = 2.00 for beef type cattle.
B = 2.25 for dual purpose type cattle.
B = 2.50 for dairy type cattle.
WTR = current shrunk body weight / estimated shrunk weight when 50% of cattle in lot will grade Choice.
BF = current backfat depth (in.).

Table 20. Percent KPH equation evaluation (using lot averages) [a]

	Avg. KPH	SD KPH	Min. KPH	Max. KPH	Avg. bias	RMSE	r
Carcass KPH	2.2	0.40	1.8	2.9			
Equation KPH	2.2	0.10	2.1	2.3	-0.01	0.29	0.47

[a] All values expressed as percentages. See footnotes with Table 19 for calculation of bias and RMSE.

Weight gain estimation for the live animal based on NRC guidelines deals primarily with the empty body weight. Since this value is not readily obtained from incoming cattle, the shrunk live weight of the animal was used during this analysis. The results of three separate trials using this program during summer, fall, and winter periods generally resulted in a tendency to over estimate weight gains to some degree. Tables 21 and 22 provide the summary of this observation. The bias observed with the calf data (Table 22) generally tended to be greater for reasons that were not clear. The estimated weight at which 50 percent of the cattle in each group would grade choice was quite close to what was the actual weight based on slaughter data for both yearling and calf data sets. The reason for this bias is not easy to isolate, but it may revolve around the maintenance requirement, which, by NRC standards, is primarily adjusted based on cold temperatures and the insulating effectiveness of the hide. Factors that could influence this requirement other than those already accounted for may exist, but are not yet quantified in terms of cause and effect. An adjustment period whereby maintenance energy requirements are increased may be occurring, and based on the calf data, it appears that the time involved here is the first 84 days. The adjustment in this case being a ten percent increase. Figure 7 provides an illustration of the actual weights along with the estimated weights as projected based upon NRC guidelines both with and without adjusting the maintenance requirements during the first 84 days on feed. It can be observed that over estimation occurs early and maintains a fairly consistent spread from the actual weight throughout the time on feed. When the early period maintenance requirement is adjusted, though, (increased by 10% in this example) this early acceleration is more realistic. There is, however, a slight discrepancy at days 28 and 56, where weight gains are under estimated. This has been attributed primarily to the effects of gut fill resulting possibly in part to the higher fiber ration being fed early to bring the light weight calves up to full feed. The data from a heifer feeding trial, shown in Table 23, was used primarily as an observation regarding how well the system would work on heifers and in a pen of considerable variation in estimated finished weights. The frame sizes of the heifers in this pen ranged from 3 to 8 and the background was also variable. Average values for the lot were used across all animals and marketing was done in two groups. The results regarding weight projection were as expected in that those cattle capable of faster growth were under estimated in terms of weight gain while the slower growing cattle were over estimated.

Table 21. Weight gain equation evaluation using lot averages for yearling crossbred steers [a]

	Avg. wt.	SD wt.	Min. wt.	Max. wt.	Avg. bias	RMSE	r
Actual wt.	1205	12	1191	1229			
Estimated wt.	1237	40	1190	1309	31	45	.70

[a] See footnotes for Table 19.

Table 22. Weight gain equation evaluation using lot averages for crossbred steers started as calves [a]

	Avg. wt.	SD wt.	Min. wt.	Max. wt.	Avg. bias	RMSE	r
Actual wt.	1093	69	1012	1176			
Estimated wt.	1149	41	1108	1189	56	64	.96

[a] See footnotes for Table 19.

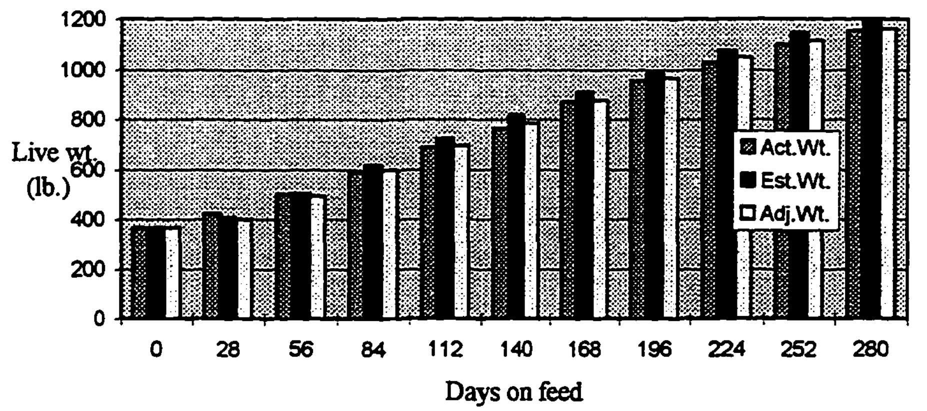

Figure 7. Comparison of weight gains, actual and projected with adjusted weight resulting from increasing maintenance requirement by 10 % during the first 84 days in the feedlot

Table 23. Weight gain equation evaluation using heifer data

Head	Average actual wt.	Average estimated wt.	Bias
93	1011 lb.	996 lb.	- 15 lb.
51	998 lb.	1021 lb.	23 lb.

The results of projecting YG and QG from the equations described here and following the procedure outlined in the materials and methods section of the paper are displayed in Tables 24 and 25. There was a good agreement with the estimated values to the actual values in this set, but further evaluation is in order since some of these results may be slightly biased from the relationship between the equations used to arrive at the IMF, BF and REA and the cattle used to validate the YG and QG projections.

Table 24. Yield grade estimation summary using lot averages [a]

	Avg. YG	SD YG	Min. YG	Max. YG	Avg. bias[b]	RMSE[b]	r
Actual YG	2.06	0.27	1.55	2.43			
Estimated YG	2.07	0.14	1.82	2.42	0.02	0.19	0.71

[a] Calculated yield grade values used.
[b] See footnotes with Table 19 for calculation of bias and RMSE.

Table 25. Quality grade estimation summary [a]

a b	Avg. QG	SD QG	Min. QG	Max. QG	Avg. bias[b]	RMSE[b]	r
Actual QG	7.10	0.64	6.14	8.43			
Estimated QG	7.50	0.52	7.00	8.00	0.40	0.61	0.72

[a] USDA quality grades: 6.00 = Select $^{+}$, 8.00 = Choice, 10 = Prime $^{-}$.
[b] See footnotes with Table 19 for calculation of bias and RMSE.

Implications

Mathematical modeling of physiological response and function, although generally used to map current understanding and outline further courses of investigation, has practical application as discussed above for projecting and monitoring feedlot cattle performance. Although the models are somewhat incomplete in that they do not account for all the observed variability and require a fair amount of computation to obtain a result, they do recognize many significant main effects and results can be readily obtained through the use of the personal computer.

GENERAL CONCLUSIONS

The contents of this dissertation are directed at the estimation of those qualities in growing feedlot cattle from which value can be calculated. Thus, the live animal's weight, the weight of the carcass, the yield grade, and the quality grade are of interest. Development of equations capable of estimating these qualities coupled with an interface that allows for income and cost accounting has been the goal and this goal has now been realized in the release of the Iowa State University Feedlot Monitoring Program for Windows™ Version 1.0 PC software (Dahlke et al., 1996). This software which is based on similar principles developed by Wilson et al. (1986) in the previous versions of the Feedlot Monitoring Program now includes the ability to monitor cattle in terms of carcass value as well.

It has been noted occasionally through this dissertation that more validation of the equations presented is in order since testing of them was limited due to the difficulty in obtaining complete data sets to confirm what may be the necessary parameters to measure and the weight one should place on these parameters. Likewise, it appears necessary that RTU technology must develop further to more readily enable one to obtain consistent readings under variable environmental conditions if this system is to be adapted on a commercial scale. Thus, refinements may be necessary in time as different cattle are observed and improvements in RTU technology occur, but the measurable parameters that have been mentioned and their relationship to one another seem reasonable.

APPENDIX A

EQUATIONS USED TO ESTIMATE LIVE WEIGHT GAIN FOR FEEDLOT MONITORING PROGRAM VERSION 1.0 FOR WINDOWS™ ADAPTED FROM 1996 NUTRIENT REQUIREMENTS OF BEEF CATTLE

Growing Cattle Energy Requirement for Maintenance

NEMR = (((.0426 x WT$^{.75}$) * TYPE x GENDER x PNUT) + PTEMP) + NEMCS

where:

NEMR = daily net energy requirement for maintenance (Mcal).
WT = shrunk body weight (lb.).

TYPE = breed type.	
beef	1.00
dairy	1.15
beef x dairy	1.05
Bos indicus crossbred	0.95

GENDER	
steer	1.00
heifer	1.00
bull	1.15

PNUT = 0.8 + (BCS - 1) x 0.05 = previous nutrition adjustment.
PTEMP = (68 - ATEMP) x 0.00039 = previous temperature adjustment.
MR = (NEMR + NEMCS) / NEMR = maintenance ratio.

---- Note: If MR < 1 then MR = 1 and NEMCS = 0.

BCS = body condition score (9 point system).	
score 1	= very thin
5	= adequate cover
9	= very fat

ATEMP = average temperature for previous month (°F).
NEMCS = [SAREA x (LCTEMP - ((CTEMP-32) x .5556)) / INS] x (NEM / MEM)
= cold stress adjustment.
CTEMP = current environmental temperature (°F).
INS = TISINS + EXTINS = animal insulation.
LCTEMP = 39 - (INS x HEAT x 0.85) = lower critical temperature estimator.
SAREA = 0.053 x WT$^{0.67}$ = animal surface area.

TISINS = tissue insulation.
Yearling = 5.1875 + (0.3125 x BCS)
Adult = 5.2500 + (0.7500 x BCS)

NEM = diet net energy for maintenance (Mcal/lb.).
MEM = diet metabolizable energy (Mcal/lb.)
EXTINS = (7.36 - 0.296 x WIND x 1.6 + 2.55 x HAIR) x MUD x HIDE
= external animal insulation.
WIND = wind speed (mph).

MUD = hide cleanliness.	
dry, clean	1.0
mild dirt	0.8
heavy dirt	0.5
wet	0.2

HAIR = hair coat length.	
summer	0.50
spring/fall	0.80
winter	1.27
heavy winter	2.00

HIDE = hide thickness.	
Bos indicus crossbred	0.80
other cattle	1.00

HEAT = (MEI - RRE) / SAREA = animal heat output.
RRE = (DM - IA) * NEG = remaining available energy.
IA = NEMR / NEM = intake required for maintenance.
NEG = diet net energy for gain concentration (Mcal/lb.).
MEI = daily metabolizable energy intake (Mcal.).
DM = daily dry matter intake (lb.).

---- Note: MR is projected using previous feeding periods daily DM intake.

Growing Cattle Protein Requirement for Maintenance

MPMR = [(.0426 x WT$^{.75}$) x 3.8] x 0.0022046

where:

MPMR = daily metabolizable protein requirement for maintenance (lb.).

Weight Gain Allowed by Energy Intake

ADGE = [(13.91 x RRE$^{.9116}$ x ((WT x.4536) x 1054 / WTC)$^{-.6837}$) * MGA x ION x ANT] x 2.2046

where:

ADGE = average daily weight gain allowed by energy intake (lb.).
WTC = estimated weight (lb.) at which 50% of cattle in pen will grade Choice.
MGA = adjustment for the inclusion of melengestrol acetate in heifer diets.
If 0.25 to 0.5 mg. are fed per head daily, MGA = 1.06; else, MGA= 1.00.

ION = adjustment for the inclusion of an ionophore in the diet.
If 100 to 360 mg. are fed per head daily, ION = 1.02; else, ION = 1.00.

ANT = adjustment for the inclusion of an antibiotic in the diet.
If 70 to 92 mg. are fed per head daily, ANT = 1.03; else, ANT = 1.00.

Weight Gain Allowed by Protein Intake

ADGP= [(((NPG x 453.6) + 29.4 x RE) / 268)] x 2.2046

where:

ADGP = average daily gain allowed from protein intake (lb.).
NPG = net protein found in weight gain.
body weight <= 661 lb. = MPGN x (0.83 - EQEBW x 0.000517)
body weight > 661 lb. = MPGN x 0.492

MPGN = MPT - MPMR = metabolizable protein available for gain (lb.).
MPT = MPB + MPF = metabolizable protein available to animal (lb.).
MPB = MCP x 0.64 = total microbial protein (lb.).
MCP = 0.13 x TDN x $eNDF_{adj}$ = microbial crude protein (lb.).
TDN = TDN intake(lb)
$eNDF_{adj}$ = effective NDF adjustment factor.
ration eNDF > 20% = 1.00
ration eNDF <= 20% = 1.0 - ((20 - eNDF) * 0.022)

eNDF = effective neutral detergent fiber.
EQEBW = .891 x (WT x 1054 / WTC) = equivalent empty body weight (lb.).
MPF = UIP x 0.8 = total undegradable feed metabolizable protein (lb.).
UIP = undegradable intake protein (lb.).
DIP = degradable intake protein (lb.).

---- Note: If DIP < MCP then DIP is substituted for MCP.

$RE = 0.0351 \times EQEBW^{.75} * (0.4336 * ADGE)^{1.097}$ = energy retained per day (Mcal).

Daily Weight Gain (ADG)

If ADGE <= ADGP then ADG = ADGE; otherwise, ADG = ADGP.

Evaluation of Protein Adequacy/Intake

MPRAT = MPT / (MPMR + MPNP)

where:

MPRAT = total mp supplied / total mp required = metabolizable protein ratio.

MPNP = metabolizable protein required to support energy intake for weight gain.

body weight <= 661 lb. $= \dfrac{[ADGE * 0.4536 \times (268 - (29.4 \times (RE / (ADGE \times 0.4536))))]}{(0.83 \times EQEBW \times 0.000517)}$

body weight > 661 lb. $= \dfrac{[ADGE \times 0.4536 \times (268 - (29.4 \times (RE / (ADGE \times 0.4536))))]}{0.492}$

pH = rumen pH due to diet.

eNDF of ration < 24.5%	= eNDF x .04229 + 5.425
eNDF of ration >= 24.5%	= 6.46

---- Note: Buffer effects are not included in calculation of rumen pH.

APPENDIX B

AVERAGE HISTORICAL MONTHLY WEATHER DATA FOR IOWA (SIOUX CITY AND DES MOINES WEATHER STATIONS)

AND

DEFAULT MONTHLY MAINTENANCE RATIOS USED BY FEEDLOT MONITORING PROGRAM VERSION 1.0 FOR WINDOWS™

Maintenance ratios based on average monthly weather data for Iowa [a]

Month	Temperature (°F) Avg.	SD	Wind speed (Avg. mph)	Default monthly maintenance ratios by facility type: Open	Windbreak	Shelter	Confinement
January	14.8	6.4	12	1.70	1.60	1.50	1.30
February	19.0	6.3	11	1.60	1.50	1.40	1.20
March	31.4	5.5	12	1.50	1.40	1.30	1.05
April	46.1	3.7	12	1.30	1.25	1.05	1.00
May	58.4	3.7	13	1.10	1.05	1.00	1.00
June	67.9	3.1	11	1.00	1.00	1.00	1.00
July	72.8	2.7	10	1.00	1.00	1.00	1.00
August	70.4	2.7	9	1.00	1.00	1.00	1.00
September	61.3	3.0	9	1.00	1.00	1.00	1.00
October	49.4	3.8	10	1.04	1.00	1.00	1.00
November	33.1	4.1	11	1.30	1.10	1.10	1.05
December	19.8	5.3	12	1.60	1.40	1.30	1.20
Wind speed	(effective)			60%	25%	10%	1%

[a] Weather data taken from NOAA, Climate Diagnostic Center, 100 year average temperature (1895 - 1995), 7 year average wind speed (1988 - 1995).

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