Progressive limit feeding to maximize profit in the feedlot¹

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ABSTRACT: Our objective was to examine the potential of limit feeding that keeps a previously growing animal at a constant size (termed progressive limit feeding) to maximize profit using a 3D surface to integrate the effects of animal size, feeding rate, and time in the feedlot. The constant size contours of the surface were determined using a combination of results. We used data from a study of growing beef cattle being fed to maintain specified sizes coupled with modern growth rate data for animals fed ad libitum in a feedlot. These feed rate contours were best-fit declining exponentials. They shared the same exponent and they originated on the ad libitum curve, thus defining the entire possible growth surface. The asymptotes of these exponentials coincided with the interspecies mean for the metabolic body size of mature animals. This surface also demonstrated the phenomenon of compensatory growth. We proved that the most profitable growth path across this surface is of a particular form under realistic assumptions.

Specifically, we proved that the profit maximizing growth path in the feedlot began with a period of progressive limit feeding and then allowed ad libitum feeding to the same market time as experienced by the standard continuous ad libitum fed animal. The opportunity cost of holding the progressively limit-fed animal longer in the feedlot than the animal fed ad libitum quickly overpowered any profit gained by limit feeding. Consequently the progressively limit-fed animal on the optimal feeding path at sale time was slightly smaller but potentially more profitable than the animal fed ad libitum, both slaughtered at the same time. It may also have an economically favorable body composition. Thus we have demonstrated a process for maximizing profit in the feedlot. The approach involved developing a growth surface to integrate the effects of progressive limit feeding and subsequent compensatory growth. After refinement this same process could be applied to other livestock.

Key words: beef, compensatory gain, economics, feed intake, growth

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INTRODUCTION

Limit feeding is commonly applied to cattle as they transition to a feedlot diet and during the finishing phase (Galyean, 1999). It includes various methods of restricting feed intake relative to actual or anticipated ad libitum intake. Fixed feed restriction percentages of 5% to 15% relative to

ad libitum have generally increased feed efficiency, decreased daily gain, reduced carcass quality grade, and improved carcass yield grade.

Ad libitum fed and fixed percentage limit-fed cattle may be fed for similar times before slaughter (Hicks et al., 1990; Galyean, 1999) or to similar sizes or body compositions before slaughter (Murphy and Loerch, 1994). Alternatively, fixed percentage limit feeding may only occur for a portion of the finishing phase (McGregor et al., 2012).

Recent carcass value data (Hogan et al., 2009; USDA, 2016) suggested that fixed percentage reductions of 3%, 6%, or 10% (Galyean, 1999), or

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11% or 15% (Hicks et al., 1990) in daily feed consumption in the finishing period resulted in 0.5%, 1.6%, 2.7%, 2.5%, and 3.4% reductions in carcass value, respectively. The profitability of fixed percentage limit feeding depends on whether feed savings offset reduced carcass values, which was not evaluated in these studies.

To slaughter at similar size (Murphy and Loerch, 1994), fixed percentage limit-fed animals require longer feeding periods. This reduces feed savings and increases yardage costs. In addition, longer feeding also incurs a prohibitive opportunity cost (Appendix 1). Carcass size and quality grade were also reduced by continuous limit feeding. Fixed percentage limit feeding for only a portion of the finishing phase (McGregor et al., 2012) also extends the feeding period if animals are slaughtered based on backfat thickness goals. Galyean (1999) noted that early short-term feed restriction followed by a longer period of ad libitum feeding had little effect on final carcass quality grade or the growth rate after feed restriction.

Our objective was to examine the potential of progressive limit feeding (feed limitation that changes over time to maintain body size) to maximize profit using a 3D surface to integrate the effects of animal size, feeding rate, and time in the feedlot.

MATERIALS AND METHODS

The Theory of the Growth Surface

Our hypothesis is that a 3D growth surface exists with axes of feeding rate for a single diet (Q , kilograms of DM per day), animal size (S , kilograms), and time (t , days). We assume that an animal will always stay on such a surface whether losing, gaining, or maintaining size. In effect, we are assuming that the future growth path of an animal is independent of its history.

Tudor and O'Rourke (1980), in their figure 2 and tables 3 and 4, "demonstrated that calves can overcome very severe restrictions in growth immediately after birth and still attain a marketable slaughter size with no detrimental effect on growth or feed efficiency." The data of Foot and Tulloh (1977), Koong et al. (1982), and Ferrell et al. (1986) also support this hypothesis for modest changes in body size in relatively short-term experiments with growing cattle, swine, and sheep. In contrast, long-term reduced feeding can result in permanently undersized animals (Lister and McCance, 1967).

The concept of a 3D growth surface (Q , S , t) resulted from an analysis of data reported by Ledger and Sayers (1977). These scientists varied the feeding rate of growing beef cattle to hold them at constant sizes (185, 275, or 450 kg) for 168 d. We found that their results exhibited 2 very interesting features. First, the necessarily declining feeding rate was fit well with an exponential equation in which the fractional rate of decrease (i.e., the change in kilograms of feed intake per day per kilogram of feed intake) was similar in all 5 of their datasets (Figure 1); therefore, we used 0.0329/d (the exponent in equation 1). That this exponent was constant was a surprise, but Turner and Taylor (1983) reported the same result from their analyses of the Ledger and Sayers (1977) data. Second, we found that the asymptotic values of these exponentials were directly proportional to $S^{0.75}$. This result was expected: the asymptotes correspond to the inter-species mean for mature animals of those sizes at equilibrium (Kleiber, 1975; Turner and Taylor, 1983). Thus, we have the equation for the feed rate, Q , in terms of S and t ,

$$Q(S_o, t) = ((Q(S_o)) - C(S_o)) \times e^{(0.0329 \times (t - t_o))} + C(S_o), \quad 1$$

where $Q(S_o)$ is the initial feeding rate (kilograms of DM per day) for the animal selected from the growth curve of ad libitum fed animals of size S_o of the same breed, t_o is the time the animal fed ad libitum reached size S_o , and $C(S_o)$ is the constant energy density feeding rate (kilograms of DM per day) required for maintenance at equilibrium S_o ,

$$C(S_o) = 0.033 \times S_o^{0.75}. \quad 2$$

To create the surface, we needed a data set for the feed rate of the animal fed ad libitum as it grew to various sizes in the associated times (Schroeder et al., 2014). In this data set, both S and Q increased linearly with time in the feedlot. For mean S at the times it was measured, 99.7% of the variation was explained by a line, $P < 0.0001$. The average deviation was 0.08% of the mean S . For mean Q at the times it was measured, 46.3% of the variation was explained by a line, $P < 0.0001$. The average deviation was 3.6% of the mean Q . Each point on this curve yields a Q_o , S_o , and t_o and allows equations 1 and 2 to specify the Q vs. t curve which keeps an animal at a constant size S_o . The collection of these declining exponentials defines the growth surface. The resulting growth surface is shown in Figure 2.

Figure 1. Exponential declines in feed intake (Q , kilograms per day) required to maintain 5 groups of steers at constant size ($S = 185, 275, 275, 450$, or 450 kg) for 168 d (t); data of [Ledger and Sayers \(1977\)](#). The rate constants for each group were similar and averaged $-0.0329/\text{d}$. The inverse of this value, 30.4 d, is equivalent to the lag constant discussed by [Turner and Taylor \(1983\)](#). It is also notable that the asymptotes of these exponentials were directly proportional to $S^{0.75}$, i.e., they approached the interspecies mean for mature animals of those sizes at equilibrium.

Figure 2. The 3D surface was constructed starting with data for growing steers fed ad libitum (closed circles; [Schroeder et al., 2014](#)). Its axes are feed intake (Q , kilograms of DM per day), body size (S , kilograms), and time (0 to 100 d). If, at any time, growing steers being fed ad libitum are instead fed to maintain their current size, then Q declines along corresponding exponentials (see [Figure 1](#)) and yields the convex 3D surface (open circles). A specific progressively limit-fed growth path on this surface is also illustrated (open squares). Theoretically, these steers were initially fed to maintain the size at which they entered the feedlot. This is always the most profitable approach (see proof in text). In this example, steers were progressively limit fed for 14 d and then fed ad libitum for 86 d. For a feed price of 0.34 \$/kg of DM and a carcass value of 2.86 \$/kg, this was also the most profitable path.

We assert that an animal of any specific breed or cross must exhibit a path of growth or decline on this surface regardless of the feeding pattern if the feed energy density is constant throughout the growth period. To represent the effects of a change in feed energy density, we would need to have ad libitum fed data for the various feed energy changes and the associated size changes through time. Using this as the initiating curve for equations 1 and 2, we could generate the appropriate growth surface for different diets assuming that the constant in the exponent of equation 1 is independent of feed composition.

The growth surface ([Figure 2](#)) also demonstrates the well-known phenomenon of compensatory growth ([NRC, 2016](#)), an apparent acceleration of the growth rate (or increase in feed use efficiency) following release from a restricted feeding rate. Restricting the feeding rate slows growth and moves an animal to flatter parts of the surface. At a future time, the animal is allowed to begin eating at the ad libitum fed rate. [Tudor and O'Rourke \(1980\)](#) showed that calves recovering from a period of severe feed restriction in early life could consume the same amount of dry matter per day, ad libitum, as calves that had been on a much greater plane of

nutrition. This capability was also demonstrated for cattle by Abdalla et al. (1988), Wright and Russel (1991), and Sainz et al. (1995).

In this flatter region of the surface, a particular size gain can be achieved with less feed. Or conversely, in that region, a unit of feed consumption yields a greater gain than that experienced by the unrestricted ad libitum fed animal of the same size (i.e., compensatory growth). From the surface, we can see that a shorter initial period of restriction leaves the animal on a steeper part of the growth curve and thus the compensatory effect is smaller. We can also see how loss of size could be traced across this surface. The optimum profit path requires that an animal must begin its progressive (constant-size) limit feeding upon entering the feedlot and, after that, be fed ad libitum for the remainder of the time that it spends in the feedlot. The proof that this type of path maximizes profit is in Appendix 2.

The Search For the Economically Optimal Growth Path

Assuming that enough data have been gathered to define the growth surface outlined above, we should be able to determine an economically optimal animal growth path on this surface. We define this path as the one that produces the greatest discounted profit. Complications immediately appear. As feed restriction increases, the lean carcass fraction of limit-fed animals also increases, resulting in a yield premium. At the same time, this lean portion can have less marbling and a quality discount may be exacted. Furthermore, holding a limit-fed animal in the feedlot longer than an animal fed ad libitum would incur a throughput delay and add a substantial opportunity cost (Appendix 1). Thus, all potential paths were terminated at the same time—the time of ad libitum feeding. As noted above, early short-term feed restriction followed by a longer period of ad libitum feeding would be expected to have little effect on final carcass quality grade.

Any profit calculation must include the discount rate, r , of the feedlot operator. We assumed a trio (5%, 7.5%, and 10%) of such rates to examine the effect of this rate on the profit. Profit also depends on the final selling price, P (dollars per kilogram), facility cost per animal (dollars per day), and feed costs (dollars per kilogram of DM). The profit equation is, therefore,

$$\text{Profit} = P * e^{-r * T} - \sum_0^T (\text{facility cost} + \text{feed cost}) * e^{-r * t}. \quad 3$$

Opportunity cost was not included in equation 3 because both progressively limit-fed and ad libitum-fed animals were fed for equal times. The opportunity-cost equation is given in Appendix 1 for reference. Facility cost was included in the profit equation for completeness, although it does not affect the process of finding the most profitable path.

To evaluate the profit potential of various scenarios, a range of carcass values (USDA, 2016) [similar to Pyatt et al. (2005)] and feed costs were utilized (Elanco Animal Health. Data on file through AgSpan 2011–2016 Benchmark database). These were set to include the middle 80% (second through ninth deciles) of carcass value and feed price for each year from 2011 through 2016, nationwide; 2.42 to 3.53 \$/kg for carcasses and 0.25 to 0.42 \$/kg of DM for feed. Area calculations of Q and S for various paths across the surface were approximated using Riemann sums interpolated with a time step of 0.1 d.

RESULTS AND DISCUSSION

Figure 2 illustrates 2 paths on the Q , S , and t surface: one for an animal fed ad libitum and another for one limit-fed progressively for the first 14 d. This path maintains the animal's current size before being fed ad libitum for the remainder of the 100-d feeding period. This path produces a slightly smaller (1% to 8% less than the size of an animal fed ad libitum for 100 d) but likely more profitable animal. We are assuming here that increased feed efficiency gained by the initial progressive limit feeding is maintained for the rest of the feeding period. This assumption is discussed in detail below.

The effects of finished carcass values and feed costs on the optimum number of days that animals should be progressively limit fed initially to maximize profit, and resulting profits, are in Figure 3a and b.

As feed price increases at any fixed carcass value (Figure 3a), the number of progressively limit fed days to maximize profit increases. As carcass value increases at any fixed feed cost, the number of progressively limit fed days to maximize profit decreases.

As feed price increases at any fixed carcass value (Figure 3b), the premium for progressively

Figure 3. The effects of feed costs and carcass values on the optimum number of days that steers should be progressively limit fed initially to maximize profit (a), and the progressive limit feeding premium (progressive limit fed profit – ad libitum fed profit) (b). Feed prices and carcass values were chosen to include the middle 80% (second through ninth deciles) of values for each year from 2011 through 2016, nationwide (see text). A specific example, for a feed price of 0.34 \$/kg of DM and a carcass value of 2.86 \$/kg, is indicated here and in [Figure 2](#).

limit feeding (progressive limit fed profit – ad libitum fed profit) increases. As carcass value increases at any fixed feed cost, the premium for progressively limit feeding decreases.

For example, with a feed price of 0.34 \$/kg of DM and a carcass value of 2.86 \$/kg, profit was maximized when the initial progressive limit feeding period was 14 d and yielded a premium for progressive limit feeding of 27 \$/animal. This progressively limit-fed animal was predicted to be about 5% smaller than an ad libitum fed animal at 100 d.

Depending on feed cost and carcass value, profit was maximized by progressive limit feeding for 2 to 23 d and then feeding ad libitum for the final 98 to 77 d of the 100-d feedlot period ([Figure 3a](#)). It should also be noted that, during progressive limit feeding to maintain initial body size, Q decreases continuously (3.29%/d). This means that Q after 2, 14, or 23 d of progressive limit feeding is 94%, 63%, or 47% of its starting value.

Dynamics of Compensatory Growth After Progressive Limit Feeding

Compensatory growth follows reduction of the maintenance requirement which, in turn, is likely related to the effects that growth has on the sizes and metabolic activities of internal organs, and empty body composition ([Hannon and Murphy, 2016](#)). The typical expected duration of compensatory growth after a period of fixed-percentage limit feeding has been listed as 60 to 90 d ([NRC, 2016](#)), or possibly up to 110 d ([Ryan, 1990](#)), depending on the extent and duration of restriction and feeding during recovery. [Ryan \(1990\)](#) concluded that the maintenance requirement decreases whenever animal size is maintained or lost. We modeled the maintenance of body size during progressive limit feeding ([Figure 2](#)) followed by compensatory growth while being fed ad libitum for the rest of the time in the feedlot. For animals progressively

limit-fed initially, growth efficiency (gain:feed) during ad libitum feeding was assumed constant and based on how much the maintenance requirement had been reduced while progressively limit feeding. This assumption demonstrates an upper bound premium for progressive limit feeding; therefore, we now examine its limitations.

Few cattle data are available that address directly the dynamics of maintenance and efficiency of growth following a period of limit feeding. [Armstrong and Blaxter \(1984\)](#), [Ryan \(1990\)](#), and [NRC \(2016\)](#) all cited [Schnyder et al. \(1982\)](#) as relevant to this issue; however, [Schnyder et al. \(1982\)](#) measured changes in total, and not fasting, heat production rate after a period of feed restriction was lifted. The fact that total heat production rate increased rapidly during recovery was expected because animals were being fed ad libitum after a period of feed restriction. Changes in heat increment (definitely) and maintenance (potentially) were confounded in their measurement of total heat production rate.

[Foot and Tulloh \(1977\)](#) examined the effects of 2 paths of size change in steers fed a mixed ryegrass-clover hay diet. From their data ([Foot and Tulloh, 1977](#); [Figures 2 and 3](#)), we calculated that growth efficiency (gain:feed, a variable related to potential changes in the energy required for maintenance) declined rapidly for 6 steers during a 42-d period of ad libitum feeding following a 100-d period of size loss; averaging 0.225, 0.117, and 0.049 kg/kg for days 101 to 110, 111 to 120, and 121 to 130, respectively. Only mean body sizes and feed intakes were available, which precluded any statistical assessment of these values. The duration of compensatory growth was apparently short in their experiment; however, this may have been more a function of physical limitation of intake on a relatively low energy diet than a rapid increase in the maintenance requirement. We consider extrapolation of these results to the feedlot situation too speculative.

In discussing changes in the maintenance requirement during realimentation after limit feeding, [Armstrong and Blaxter \(1984\)](#) and [Ryan \(1990\)](#) suggested the sheep data of [Wainman et al. \(1972\)](#) indicated there was no lag phase in the change in heat production rate following a change in intake of a dried grass diet. Ninety-eight percent of the response was complete within 9 d. Sheep had been given constant feed for at least 3 wk prior to the change and total heat production rate was determined for 7 consecutive days after the change in intake and then 9 d later for 5 more days. Fasting was

not listed in this part of their protocol. Here again, changes in heat increment and perhaps maintenance heat production were confounded. It cannot be ascertained whether or not the fasting heat production rate was altered.

[Graham and Searle \(1975\)](#) studied weaned sheep during and after 4- or 6-mo periods of progressive limit feeding a mixed diet. Realimentation involved 4 wk of ad libitum feeding followed by 2 wk of feeding at approximately 20% of ad libitum intake. Fasting heat production rate was measured both before and after realimentation. Reanalysis of their individual sheep data ([Graham and Searle, 1975](#); [Figure 2](#)) indicated that fasting heat production rate per unit metabolic body size increased 10% (from 57.4 to 62.9 kcal·kg^{-0.75}·d⁻¹; $P < 0.05$) during the 6 wk of realimentation.

A similar study was then conducted, again using weaned lambs fed a mixed diet ([Graham and Searle, 1979](#); [Searle et al., 1979](#)). Body size (fasting, shorn) increased rapidly from 15 to 23 kg (Stage 1), decreased to 16 kg over 21 wk of underfeeding (Stage 2), and then increased to 27 kg after 24-wk periods of ad libitum feeding (Stage 3). Fasting heat production rate went from 81.3 to 74.1 kcal·kg^{-0.75}·d⁻¹ during normal growth (Stage 1), was 69.3 kcal·kg^{-0.75}·d⁻¹ after prolonged undernutrition (Stage 2), and then 83.6 and 71.7 kcal·kg^{-0.75}·d⁻¹ during and after realimentation (Stage 3). Although [Ryan \(1990\)](#) noted the 21% increase in fasting metabolism after 1 mo of realimentation, he made no mention of its subsequent 14% decrease during the second month of realimentation. We calculated, based on the reported standard error and sample size ([Graham and Searle, 1979](#)), that fasting heat production rate per unit metabolic body size after 2 mo of realimentation did not differ from that immediately after underfeeding ($P > 0.20$).

In another study, sheep were fed a high-grain diet ([Gingins et al., 1980](#); [Thomson et al., 1980](#)). Fasting heat production rate was measured after 28 d of maintenance feeding (66.7 kcal·kg^{-0.75}·d⁻¹), again after 119 d of undernutrition (59.5 kcal·kg^{-0.75}·d⁻¹), and finally after 51 d of realimentation (70.3 kcal·kg^{-0.75}·d⁻¹). The fasting heat production rate per unit metabolic body size after realimentation did not differ from that after maintenance ($P > 0.05$); however, both were greater than after the period of undernutrition.

[Koong et al. \(1982\)](#) and [Ferrell et al. \(1986\)](#) demonstrated that fasting heat production rate per unit metabolic body size of both swine and sheep could be affected substantially by previous

nutrition. It was greatest in animals growing most rapidly at a given body size. Fasting heat production rate was only measured at the end of these experiments; therefore, their data do not address directly energy dynamics during compensatory growth.

After further analyses of their sheep data, [Koong et al. \(1985\)](#) suggested that fasting heat production rate was best estimated when the body size exponent was a linear function of rate of gain. In the beef feedlot data we used in this study ([Schroeder et al., 2014](#)), rate of gain was constant; therefore, this approach suggests that the fasting heat production rate in our model system would increase, and gain:feed decrease, immediately after progressive limit feeding ceased but both would then remain constant throughout the phase when animals were being fed ad libitum. The net effect is that the fasting heat production rate equation of [Koong et al. \(1985\)](#) does not allow compensatory growth. It is not clear, then, why the [NRC \(2016\)](#) suggested [Koong et al. \(1985\)](#) was among those providing a mathematical description of compensatory growth.

[Graham et al. \(1974\)](#) and [Corbett et al. \(1987\)](#), on the other hand, did suggest a formulation which allowed compensatory growth. They predicted fasting heat production rate for lambs and young sheep using an equation which also incorporated rate of gain. In this case rate of gain was defined vaguely as that “over the previous few weeks,” not the current rate of gain. They noted that “the basal metabolism of growing animals depends upon, but changes rather slowly with, the plane of nutrition” ([Corbett et al., 1987](#)). That said, their approach does not describe quantitatively the time course of changes in fasting heat production rate as animals transition between progressive limit feeding and ad libitum feeding ([Figures 1 and 2](#)).

In summary, data are either extremely limited (cattle) or equivocal (sheep) regarding the dynamics of fasting heat production rate during realimentation after its reduction following a period of progressive limit feeding. We consider the existing literature inadequate to justify altering our important assumption: that reducing the maintenance requirement by progressive limit feeding on entry to the feedlot was effective for the remainder of their time in it. This is equivalent to failing to reject the null hypothesis. We recognize that efficiency of growth (gain:feed) must surely decline at some point and adversely affect profit. Even if changes in efficiency of growth during realimentation were known, they would affect identification of the maximum profit path. How much and when the maintenance requirement increases during ad libitum

realimentation after a period of progressive limit feeding to keep the body size of cattle constant are questions pointing to the need for additional research.

General Conclusion

With our hypothesis that a growth surface can be constructed for any animal fed a single diet, we have defined a growth surface and identified the optimum profit path for a particular beef animal. That path requires progressive limit feeding immediately upon arrival in the feedlot with ad libitum feeding for growth the rest of the time that the ad libitum animal would have spent in the lot. Because this progressive limit feeding would occur in the earliest part of the limit-fed animal's time in the feedlot (see proof, [Appendix 2](#), and discussion above), it was assumed that body composition at slaughter would differ little from that of the ad libitum animal ([Galyean, 1999](#)). Another advantage of this approach is that it helps avoid overconsumption and intake variation, or both, as cattle adapt to their feedlot diet ([Galyean, 1999](#)). Feed costs and carcass values determine both the optimum number of days that cattle should be progressively limit fed initially to maximize profit and the progressive limit feeding premium (progressive limit fed profit – ad libitum fed profit).

Future Research Needs

Two key but poorly understood elements of this process are the degree of reduction in fasting metabolic rate (as a consequence of decreased organ size) elicited by restricted feeding on entry to the feedlot, and the degree and pattern of loss of this change during ad libitum feeding for the time remaining in the feedlot.

The GI tract, liver, and other internal organs under conditions of ad libitum feeding act as though they anticipate the need for a larger future body size. The functioning of these organs is very energy intensive. Under conditions of restrictive feeding, they do not maintain this “anticipatory” size that the same animal would under ad libitum feeding conditions. Consequently animals released from restricted feeding grow more efficiently in terms of feed energy needed per unit of added size (compensatory growth). Progressive limit feeding does 2 things: reduces early stage feeding costs and makes later stage ad libitum feeding more efficient. We believe that the surface in [Figure 2](#) tracks this phenomenon accurately. However, we are unsure of

the coefficients in equations 1 and 2 and research is needed to accurately determine these coefficients for a variety of domestic species and conditions. Our largest uncertainty though is the rate of loss of digestive efficiency produced by progressive limit feeding during the remainder of their time in the feedlot. Past research is ambiguous on this point. We propose that experiments be directed specifically toward establishing the degree and pattern of this loss.

Secondly, the economic implications of changes in body composition resulting from feed restriction are not fully understood. There is evidence from [Ledger and Sayers \(1977\)](#) that, under conditions of constant size feeding, the lean mass carcass fraction grows compared with that of the animal fed ad libitum. Possibly even if the feed restriction is less severe and does not continue until equilibrium size is reached, some increase in lean mass percentage is achieved and sustained until the animal reaches market size. But we do not know how much. Additional research is needed on body composition changes under progressive limit feeding regimens. Accordingly, we have proposed a series of experiments on swine to determine the equations for their growth surface and determine if various feeding regimens keep the animal on this surface.

SUPPLEMENTARY DATA

Supplementary data are available at *Journal of Animal Science* online.

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