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Level of Energy Intake And Efficiency of Energy Utilization by Steers

T. B. Keith

D. O. Everson

Agricultural Experiment Station

Department of Animal Industries

TEACHING RESEARCH SERVICE

UNIVERSITY OF IDAHO

College of Agriculture

Summary

Computed ADG (average daily gain) was calculated with a curvilinear and a rectilinear equation for determining NE_m (net energy for maintenance) and NE'_g (net energy for gain) of steers fed increasing levels of NE. Data from 4 experimental feeding studies were used to evaluate the equations.

The first and second studies involved 88 steers fed 5 diets containing 25, 33, 50, 66, and 75% alfalfa hay. The third and fourth studies involved 119 steers fed 5 diets containing 33, 50, 66, 75, and 80% alfalfa hay.

The rectilinear equation gave computed ADG 3 to 6% closer to observed ADG in first and second studies (66 and 75% alfalfa hay) and 4 to 5% closer in third and fourth studies for all levels of alfalfa.

Results of these studies do not support the curvilinear relationship of NE intake to rate of gain.

The Authors

T. B. Keith is animal scientist emeritus, Idaho Agricultural Experiment Station. D. O. Everson is station statistician, Idaho Agricultural Experiment Station.

Agricultural Experiment Station

University of Idaho
Moscow, Idaho

College of Agriculture
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Level of Energy Intake And Efficiency of Energy Utilization by Steers

T. B. Keith and D. O. Everson

The relationship between level of energy intake and efficiency of its utilization has been a subject of considerable thought and study since the early work of Armsby and Fries (1918).

This subject has been studied and reviewed by Brody and Proctor (1933), Brody (1944), Kleiber (1961), and Mitchell (1964) and all have agreed that there is not sufficient evidence to support the hypothesis that efficiency of energy utilization decreases as level of intake increases. If this hypothesis were true, a curvilinear relationship concave downward, rather than a single rectilinear equation, would describe the relationship between efficiency of energy utilization (Y) and level of intake (X).

This report compares a curvilinear with a rectilinear equation for computing gains of steers fed diets varying in NE (net energy) intake.

Experimental Procedure

Data used in this study were obtained from 207 steers fed in individual stalls twice daily in uncovered feedlots at the University of Idaho Experiment Station, Caldwell, Idaho (Keith, Johnson, and Lehrer, 1952, 1954). Numbers of steers fed in each experiment are shown in table 1. Composition of the concentrate mixtures, NE_m (net energy values for maintenance), and NE_g (net energy values for gains) of feeds are shown in table 2.

The Caldwell station is located in the Snake River Valley in a desert type environment where average mean daily temperature during feeding periods ranged from 6.5° to -3.0°C (table 3). Original investigations were concerned primarily with levels of alfalfa hay in diets of growing-finishing cattle for most economical returns. An increase in ratio of concentrate to alfalfa hay in diets increases NE. Therefore, these data were adapted to a study on the relation of efficiency of energy utilization to level of energy intake.

Data from 88 steers fed 126 days in experiments 1 and 2 (1948 to 1949 and 1950 to 1951) were combined into one study, since the concentrate mixtures were the same each year and no ratio x year interaction existed.

Table 1. **Number of steers assigned to each ratio of concentrate to alfalfa hay.**

Concentrate: hay ratio	Experiment 1	2	3	4
1:3	10	8		
1:2	10	8		
1:1	10	8	20	
2:1	8	8	19	20
3:1	8	8	19	20
4:1				20
Totals	48	40	59	60

Table 2. **Composition of concentrate mixtures and NE_m and NE_g values of feeds[a].**

Feeds	Experiments 1 & 2	3	4	NE_m	NE_g
	%	%	%	Mcal/kg	Mcal/kg
Barley	46	50	42	1.93	1.27
Oats	22	24	22	1.66	1.12
Beet pulp, dried molasses	22	24	22	1.83	1.21
Cotton seed meal	8			1.40	0.90
Soybean meal			12	1.85	1.23
Salt	2	2	2		
Total concentrate	100	100	100		
Alfalfa hay				1.23	0.70

[a] Lofgreen and Garrett, **J. Anim. Sci.** 27:793

Table 3. **Average maximum, minimum and mean daily temperatures during the feeding periods.**

Experiments	No. days	Temperature (°C) Maximum	Minimum	Mean
1	126	3.5	-9.5	-3.0
2	126	6.0	-4.4	0.8
3	168	13.6	-0.6	6.5
4	161	11.5	-0.4	5.6

The steers were randomized into 5 groups and were fed 1 of 5 diets having concentrate-to-roughage ratios of 1:3, 1:2, 1:1, 2:1 and 3:1 (Keith et al., 1952).

Fifty-nine steers used in experiment 3 (1951 to 1952) were fed 3 ratios of concentrate to alfalfa hay (table 1) and 60 steers in experiment 4 (1952 to 1953) were fed 3 higher ratios (table 1). A 3 x 2 x 2 factorial design was employed in both experiments which involved 2 levels of protein and 2 methods of feeding (Keith et al., 1954). Half of the steers were fed a constant ratio; the other half were fed a graduated ratio (starting with a high alfalfa hay allowance and a low concentrate allowance). Initial and final weights of the steers for all periods of all 4 experiments were taken after the steers were off feed approximately 14 hours. Gain and feed data in experiments 3 and 4 included 161 and 168 days, respectively. Feeding periods were divided into first 84 days and either last 77 or 84. Initial and final weights and total feed consumed by each steer were used to compute ADG (average daily gain). Computed ADG was compared with observed ADG to evaluate NE (net energy) values of feeds and equations used for predicting gains.

Short periods of approximately 3 months were studied in experiments 3 and 4 to eliminate error in computed gains that would result from a low metabolic weight and a high feed intake if the entire period were used. Computed gains were calculated by the use of two equations. Computed values of the curvilinear equation presented by Lofgreen and Garrett (1968) were compared to computed values from the rectilinear equation presented by Lofgreen (1964).

The curvilinear equation was expressed as energy stored in weight gain:

$$NE_g = (52.72g + 6.84g^2)\ (W^{0.75})$$

where g is daily gain in kg and W is body weight in kilograms. From this equation computed ADG was derived by solving the quadratic equation:

$$\text{Computed ADG} = (0.5)\left[\frac{-0.05272}{0.00684} + \sqrt{\left(\frac{0.05272}{0.00684}\right)^2 + \left(\frac{4NE_g}{0.00684 \times W^{0.75}}\right)}\right]$$

Maintenance requirements of NE for the curvilinear equation were determined with the equation $77W^{0.75}$.

The rectilinear equation (Lofgreen, 1964) is expressed

$$NE_{m+g} = 72W^{0.75}\ (1 + 0.827g)$$

where NE_{m+g} is net energy of maintenance plus net energy of gain.

For this equation the computed

$$ADG = \frac{\text{NE available for gain}}{(72\ W^{0.75})\ (0.827\ g)}$$

Values for diet intake were used to compute ADG with the curvilinear equation (tables 4, 6, and 8) and with the rectilinear equation (tables 5, 7, and 9). A least squares analysis of variance (Harvey, 1960) was used to analyze ration differences for observed and computed ADG and ratio of observed to computed ADG for both curvilinear and rectilinear factors.

Table 4. A comparison of computed ADG (curvilinear equation) and observed ADG of steers fed 5 ratios of concentrate to alfalfa hay in experiments 1 and 2.

	Ratio of concentrate to alfalfa hay				
Item	1:3	1:2	1:1	2:1	3:1
No. steers	18	18	18	16	18
Days fed	126	126	126	126	126
Mean liveweight, kg	280	289	298	306	292
Observed ADG, kg	0.63d	0.75c	0.79bc	0.86a	0.79bc
Computed ADG, kg	0.59c	0.69b	0.85a	0.87a	0.84a
Ratio of observed to computed ADG	1.09a	1.10a	0.94c	0.99b	0.95c
Feed intake, kg/day	6.66	7.05	7.46	7.20	6.64
NE_m required, mcal/day	5.26	5.39	5.51	5.62	5.43
Computed NE content of diets:					
NE_m, mcal/kg	1.36	1.41	1.50	1.59	1.63
NE_g, mcal/kg	0.82	0.86	0.93	1.01	1.05
NE available for gain, mcal/day	2.29	2.76	3.53	3.71	3.49
Fiber intake, kg/day	1.58	1.57	1.36	1.09	0.87

a, b, c, d Those ratios with different letter suffixes differ significantly ($P \leq .05$).

Results

ADG computed with the curvilinear equation were less than observed ADG (table 4) for steers fed diets containing 1:3 and 1:2 ratios of concentrate to alfalfa hay (75% and 66.6% alfalfa hay). Observed ADG were lower than computed ADG for steers fed diets containing ratios of 1:1, 2:1 and 3:1 (50, 33.3 and 25% alfalfa hay).

Ratio of the observed to computed ADG ranged from 1.10:1.00 to 0.94:1.00 or a maximum deviation of only 10%. These results indicate that NE_m and NE_g values of 1.23 and 0.70 kcal per kg, respectively, for alfalfa hay are near their true values under these environmental conditions.

Computed ADG showed the same general trend with the rectilinear equation (table 5) as with the curvilinear equation. Ratio of observed to computed ADG ranged from 8% higher for the ratio of concentrate to alfalfa hay of 1:2 to 10% lower for the ratio of 1:1. Computed ADG for the curvilinear equation was not greatly different from computed ADG for the rectilinear equation. Moreover, when the coefficient 77 (77 $W^{0.75}$) was used instead of 72 to calculate the NE requirements for maintenance with the rectilinear equation, the computed ADG did not change more than 0.03 kg.

Significant differences among ratio means for observed ADG illustrate an increased uniform response as NE levels of the ratio increased up to the 2:1 ratio of concentrate to alfalfa hay.

Table 6 compares computed ADG for the curvilinear equation with observed ADG of steers fed 3 ratios of concentrate to alfalfa hay during the first 84 days and last 77 days. Ratios of observed to computed

Table 5. A comparison of computed ADG (rectilinear equation) and observed ADG of steers fed 5 ratios of concentrate to alfalfa hay in experiments 1 and 2.

	Ratio of concentrate to alfalfa hay				
Item	1:3	1:2	1:1	2:1	3:1
No. steers	18	18	18	16	18
Mean liveweight, kg	280	289	298	306	292
Observed ADG, kg	0.63d	0.75c	0.79bc	0.86a	0.79bc
Computed ADG, kg	0.60c	0.71b	0.88a	0.91a	0.88a
Ratio of observed to computed ADG	1.06a	1.08a	0.90c	0.95b	0.92b
Feed intake, kg/day	6.66	7.05	7.46	7.20	6.64
NE_m required, mcal/day	4.95	5.07	5.18	5.28	5.10
NE available for gain, mcal/day	2.48	2.95	3.74	3.93	3.70

a,b,c See table 4

Table 6. A comparison of computed ADG (curvilinear equation) and observed ADG for steers in experiment 3 fed 3 ratios of concentrate to alfalfa hay.

Item	Ratio of concentrate to alfalfa hay					
	First 84 days			Last 77 days		
	1:2	1:1	2:1	1:2	1:1	2:1
No. steers	20	19	20	20	19	20
Mean liveweight, kg	276	278	288	336	344	362
Observed ADG, kg	0.67d	0.77c	0.96a	0.83bc	0.85b	0.89b
Computed ADG, kg	0.52 c	0.54c	0.66a	0.62ab	0.60b	0.65a
Ratio of observed to computed ADG	1.36b	1.47a	1.49a	1.37b	1.44a	1.48a
Feed intake, kg/day	6.08	5.99	6.34	7.62	7.36	7.46
NE_m required, mcal/day	5.21	5.24	5.38	6.04	6.14	6.39
Computed NE content of diet:						
NE_m, mcal/kg	1.40	1.44	1.52	1.40	1.44	1.52
NE_g, mcal/kg	0.84	0.88	0.95	0.84	0.88	0.95
NE available for gain, mcal/day	1.99	2.09	2.68	2.78	2.75	3.13
Fiber intake, kg/day	1.34	1.11	0.96	1.68	1.36	1.13

[a] See table 4.

Table 7. A comparison of computed ADG (rectilinear equation) and observed ADG for steers in experiment 3 fed 3 ratios of concentrate to alfalfa hay.

Item	Ratio of concentrate to alfalfa hay					
	First 84 days			Last 77 days		
	1:2	1:1	2:1	1:2	1:1	2:1
Observed ADG, kg	0.67d	0.77c	0.96a	0.83bc	0.85b	0.89b
Computed ADG, kg	0.54c	0.56c	0.69a	0.64b	0.62b	0.68a
Ratio of observed to computed ADG	1.30b	1.42a	1.44a	1.33b	1.40a	1.42a
Feed intake, kg/day	6.08	5.99	6.34	7.62	7.36	7.46
NE_m required, mcal/day	4.90	4.93	5.06	5.68	5.77	6.01
NE available for gain, mcal/day	2.18	2.28	2.88	3.00	2.98	3.37

a See table 4.

ADG ranged from 1.36:1 to 1.49:1 for the first 84 days and 1.33:1 to 1.44:1 for the last 77 days of feeding. The rectilinear equation (table 7) yielded results which were from 3 to 6% more accurate than those from the curvilinear equation. These differences are not great enough to establish a difference in accuracy of the two equations.

Tables 8 and 9 compare computed ADG of steers fed 3 ratios of concentrate to alfalfa hay (ratios of 2:1, 3:1 and 4:1) with observed gains for the first 84 days and last 84 days of feeding. The curvilinear equation (table 8) gave an estimated ADG 25 to 29% lower than observed values for the first 84 days and 32 to 56% lower for the last 84 days. The rectilinear equation (table 9) gave estimated computed gains 20 to 24% lower than observed for the first 84 days and 28 to 50% lower for the last 84 days.

The rectilinear equation gave estimated computed gains 4 to 5% closer to actual observed ADG than the curvilinear. Again, these differences are not great enough to establish a difference in accuracy of the two equations.

A summary of comparative observed and computed ADG and ratio of the observed to computed ADG are reported in table 10.

Table 8. A comparison of computed ADG (curvilinear equation) and observed ADG for steers in experiment 4 fed 3 ratios of concentrate to alfalfa hay.

	Ratio of concentrate to alfalfa hay					
	First 84 days			Last 84 days		
Item	2:1	3:1	4:1	2:1	3:1	4:1
No. steers	20	20	20	20	20	20
Mean liveweight, kg	287	281	286	352	350	355
Observed ADG, kg	0.70e	0.70e	0.75d	0.85c	0.96a	0.89b
Computed ADG, kg	0.58b	0.57b	0.61b	0.58b	0.71a	0.69a
Ratio of observed to computed ADG	1.26c	1.29c	1.25c	1.56a	1.40b	1.32bc
Feed intake, kg/day	6.16	5.78	5.76	7.12	7.52	7.18
NE_m, required, mcal/day	5.38	5.28	5.36	6.26	6.23	6.30
Computed NE content of diets:						
NE_m, mcal/kg	1.48	1.53	1.59	1.48	1.53	1.59
NE_g, mcal/kg	0.92	0.96	1.01	0.92	0.96	1.01
NE available for gain, mcal/day	2.28	2.23	2.40	2.72	3.32	3.25
Fiber intake, kg/day	0.95	0.79	0.73	1.10	1.03	0.91

a See table 4.

Discussion

In the first two studies with 88 steers the rectilinear equation gave ADG 2 to 3% closer to observed than the curvilinear equation for diets containing 66 to 75% alfalfa hay. However, for steers fed diets containing 25 to 50% alfalfa hay, the curvilinear equation gave computed ADG 3 to 6% closer than the rectilinear equation.

In two subsequent studies involving 119 steers, the computed ADG of the rectilinear equation were 4 to 5% closer to observed ADG than computed ADG of the curvilinear equation for all 5 levels of alfalfa hay.

These results do not support the theory that efficiency represented by NE decreases as the NE intake increases for energy utilization above maintenance. However, they tend to support the conclusion of Armsby and Fries (1918), Mitchell et al. (1932), Kleiber (1961), and Mitchell (1964) that a linear relationship exists.

Brody and Proctor (1933) summarized the literature on the relation of plane of nutrition and efficiency of energy utilization with the statement: "The net energy value per unit feed is thus not a constant but varies with plane of nutrition and many other factors".

Brody and Proctor's conclusions were based on work conducted with apparatus that limited the activity and energy intake. The energy intake above maintenance was not sufficient for maximum gains.

Forbes et al. (1932) were concerned with the possibility of an error in Armsby's assumption: "That the heat increment varies directly as the dry matter; that is, that it is a linear function of the amount of feed". This assumption was subjected to an experiment involving 7 planes of nutrition each with 4 steers. Digestible energy, metabolizable energy, and heat production were determined. Data on retention of dry matter, crude protein, crude fiber, ether extract, nitrogen-

Table 9. A comparison of computed ADG (rectilinear equation) and observed ADG for steers in experiment 4 fed 3 ratios of concentrate to alfalfa hay.

	Ratio of concentrate to alfalfa hay					
	First 84 days			Last 84 days		
Item	2:1	3:1	4:1	2:1	3:1	4:1
Observed ADG, kg	0.70e	0.70e	0.75d	0.85c	0.96a	0.89b
Computed ADG, kg	0.59b	0.59b	0.63b	0.60b	0.74a	0.71a
Ratio of observed to computed ADG	1.21c	1.24c	1.20c	1.50a	1.35b	1.28bc
Feed intake, kg/day	6.16	5.78	5.76	7.12	7.52	7.18
NE_m required, mcal/day	5.04	4.96	5.04	5.88	5.86	5.92
NE available for gain, mcal/day	2.48	2.43	2.61	2.91	3.56	3.92

[a] See table 4.

free extract, carbon, and nitrogen were obtained as well as the oxygen intake and carbon dioxide production (Forbes and associates, 1928, 1930, 1932). From this data they computed the contributions of heat from catabolism of protein, carbohydrate, and fat for the different planes of intake.

They concluded that protein contributed about the same proportion of total heat production at all planes of nutrition, energy of fat synthesis was a minor factor above maintenance, and the proportionate contribution of carbohydrate did not vary greatly at any level of intake above maintenance. However, they did credit the curvature of the line representing the relation of heat production to food consumption of cattle with rise in plane of nutrition from fasting to full feed to be virtually the result of factors related to metabolic functions of utilization of nutrients, heat of fermentation of the carbohydrate nutriment, and physical work of food utilization.

Table 10. A summary of the computed ADG values obtained with the curvilinear and rectilinear equations.

Experiment	No. steers	Ratio C:A	Observed ADG	Computed ADG		Ratio of observed to computed	
				Curvilinear	Rectilinear	Curvilinear	Rectilinear
1 & 2	First 126 days						
	18	1:3	0.63d	0.59c	0.60c	1.09a	1.06a
	18	1:2	0.75c	0.69b	0.71b	1.10a	1.08a
	18	1:1	0.79bc	0.85a	0.88a	0.94c	0.90c
	16	2:1	0.86a	0.87a	0.91a	0.99b	0.95b
	18	3:1	0.79bc	0.84a	0.88a	0.95c	0.92b
3	First 84 days						
	20	1:2	0.67d	0.52c	0.54c	1.36b	1.30b
	19	1:1	0.77c	0.54c	0.56c	1.47a	1.42a
	20	2:1	0.96a	0.66a	0.69a	1.49a	1.44a
	Last 77 days						
	20	1:2	0.83bc	0.62ab	0.64b	1.37b	1.33b
	19	1:1	0.85b	0.60b	0.62b	1.44a	1.40a
	20	2:1	0.89	0.65	0.68	1.48	1.42
4	First 84 days						
	20	2:1	0.70e	0.58b	0.59b	1.26c	1.21c
	20	3:1	0.70e	0.57b	0.59b	1.29c	1.24c
	20	4:1	0.75d	0.61b	0.63b	1.25c	1.20c
	Last 84 days						
	20	2:1	0.85c	0.58b	0.60b	1.56a	1.50a
	20	3:1	0.96a	0.71a	0.74a	1.40b	1.35b
	20	4:1	0.89b	0.69a	0.71a	1.32bc	1.28bc

a See table 4.

Mitchell et al. (1932) did not find a curve that tended downward at high levels of feeding and expressed the opinion with reference to Forbes et al. that: "The significance of the downward trend at the higher levels of nutrition may be questioned both because they are in all cases slight and because they occur at different levels of feeding when noticeable at all".

Marston (1948), working with 5 mature ewes, concluded that a linear equation expressed the relationship between food intake and utilization. Blaxter and Graham (1955), working with 2 sheep fed 8 energy levels, interpreted the relationship between energy balance and metabolizable energy intake not to be linear. Mitchell (1964) agreed with Marston's interpretation but questioned the validity of Blaxter and Graham's, stating that the observations on the 2 sheep were not particularly concordant.

Orskov, Flatt, and Moe (1968), in a study of efficiency of fermentation of volatile fatty acid formations of the dairy cow, conclude that the efficiency of utilization of metabolizable energy was of the order of a linear relationship.

Hendricks (1931) interpreted the physiological efficiency of energy utilization as follows: "It is self-evident that if no feed were required for maintenance and if the fraction of the feed incorporated into the body tissues was always the same chemical composition, the liveweight of a growing animal would be a linear function of feed composition". Garrett, Meyer, and Lofgreen (1959) found a difference between cattle and sheep in plotting energy intake against retention and commented: "The data can be reasonably expressed as linear or an exponential function in a manner chosen to represent these results. In general, the steer data fitted with slightly more accuracy when the exponential expression was used. The sheep data had the opposite tendency. A slightly better fit was obtained with the linear expression".

Titus (1928) reported results of the relation between live weight and feed intake of 183 White Pekin ducklings fed from 7 days of age to 84 days. Seven-day interval weights were taken with no record of number of males and females. It was concluded that the relationship between liveweight and feed intake was expressible by the law of diminishing increment.

Chicks (265 males and 244 females) fed 7 levels of food for 52 weeks were studied by Titus, Morley, and Hendricks (1934). They concluded that there was a diminishing increment between feed consumption and growth.

The results of this study indicate that the NE intake was not high enough to reduce the efficiency of utilization.

So far, there is no published information on efficiency of energy utilization of extremely high levels of NE intake. An extremely high NE intake would be expected to show a depression in efficiency of partial energy utilization. Theoretically, an extremely high intake will not occur because the animal voluntarily stops eating when storage for chemical energy is fulfilled. This should apply to all phases of production.

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