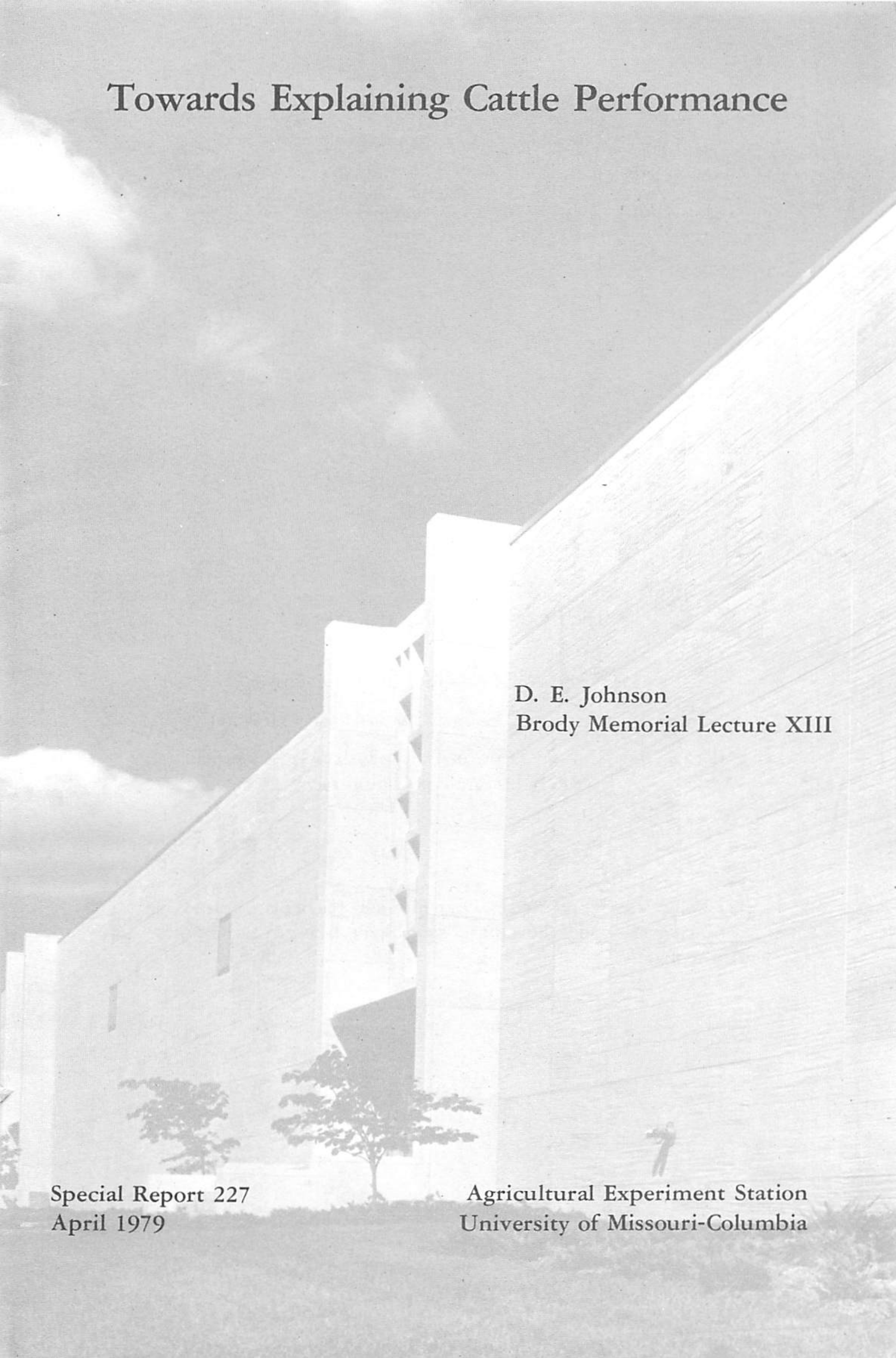
Towards Explaining Cattle Performance



D. E. Johnson
Brody Memorial Lecture XIII

Special Report 227
April 1979

Agricultural Experiment Station
University of Missouri-Columbia

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Towards Explaining Cattle Performance

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Beef production as a subset of food production has been the target of more than its share of questions concerning input-output relationships and product or food maximization.

Input-output relationships of various food producing systems along with the biological and environmental constraints involved are of increasing importance in our present world food supply and demand situation. This importance is leading to reexamination of usual constraints plus the assessment of additional factors largely ignored previously, such as the requirement of cultural or fossil fuel energy and the increased maintenance requirement of open-lot-fed cattle as components of these input-output relationships.

This lecture will concentrate on a few of the many important factors (Figure 1) concerning beef production efficiencies. It will center on climatic factors and then include a few nutritional considerations.

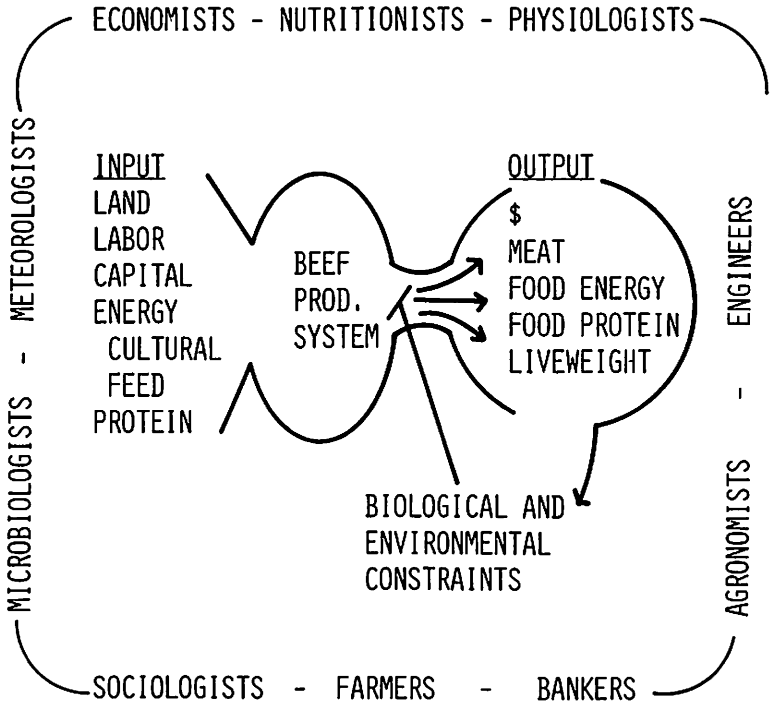

Figure 1. Schematic representation of disciplines involved in assessing input-output and constraint relationships of beef production systems.

Environmental Investigations

Seasonal effects on cattle performance have been noted many times. Henderson (1968) indicated that shelter for feedlot cattle in the midwest would increase gains by 12% in winter and 5% in summer; and data accumulated by Elam (1971) showed a marked seasonal effect on the dollar return and profitability of feedlot cattle in California.

The principle data discussed here are those that we collected in Colorado to extend the observations of Handley (1971), and data collected by a student with whom I had the privilege to work during part of his Ph.D. thesis at the University of Illinois (Petritz, 1972).

The Colorado performance data were based on 20 months of observations of close to 100,000 head of open-lot-fed cattle with batches going in and out each month. The midwest data concerned the performance of 1,500 head of cattle in open lot in Iowa over 10 years in summer and winter batches. Weather data consisted of two- to three-hourly simultaneous observations of wind speed, air temperature, humidity, hours of precipitation, and other variables. These data were obtained from the National Oceanic and Atmospheric Administration (NOAA) for a 10-year period on Iowa and an eight-year period in Denver, Colorado. Additionally two-hourly observations from Colorado State University weather data were obtained for a two-year period in Ft. Collins, Colorado.

The relationship of several performance parameters to weather statistics was examined. These performance parameters included the common average daily gain and feed intake parameters as well as calculated requirements of net energy for maintenance, net energy for gain intake, and the ratio of observed-to-expected gain. The observed-to-expected gain ratio was calculated according to National Research Council (NRC, 1970) equations concerning requirements of fattening beef cattle; and this reference was used as a source of feed values. Requirements calculated according to the NRC equations were integrated over time, assuming a uniform average daily gain over the time interval.

More precisely, then, the net energy for maintenance (NE_m) requirement for each group of cattle was calculated by subtracting the predicted amount of feed required for gain from the total feed consumed, assuming that the rest of the food was used for maintenance. The assigned NE_m requirement for that group of cattle was equal to the feed left for maintenance times the NE_m value of that feed. This specific formula was:

$$NE_m \text{ required (Mcal/day/}W_{kg}\ .75) = \frac{\left[\text{Total diet (kg)} - \left[\left(\frac{NE_g \text{ req. (Mcal/da)}}{\text{Diet } NE_g \text{ (Mcal/kg)}}\right)\right]\right]\left[\begin{matrix}\text{Diet } NE_m \\ \text{(Mcal/kg)}\end{matrix}\right]}{W_{kg}\ .75}$$

$$\text{where } NE_g \text{ req. (Mcal/da)} = (ag + bg^2)\,(W_{kg}\ .75)$$

$$= {}_0\, n \quad (ag + bg^2)\,(Wo + gn)^{.75}\, dt/n$$

$$= \frac{\left(\frac{a + bg}{1.75}\right)\left(W_f^{1.75} - W_0^{1.75}\right)}{n}$$

in which: a and b = .05272 and .00684 for steers

W_0 and W_f = Initial and final liveweight in kg (4% shrunk final wt.)

g = average daily gain in kg

n = number of days in feeding period

Likewise in the calculation of the expected gain according to the NRC formula:

$$g = \sqrt{\frac{a^2 - 2b\ NE_g/W_{kg}{}^{.75} - a}{b}}$$

The NE_m requirement over the feeding interval (0 to n days) was calculated as:

$$= \left[\frac{77}{1.75g} \quad (Wo + gn)^{1.75} - W_0{}^{1.75}\right]$$

Many potential errors exist in these assumptions of requirements or feed values. However, from the overall average of observed vs. expected gain of both extensive sets of data (Table 1) it can be seen that the system fits the performance of average cattle fed over varying seasons of the year rather precisely in that the ratios for both sets of data were averaged out to be just under 100% or .99. Additionally in both sets of data the mean performance in summer exceeded the predicted while the mean performance in winter was considerably lower than predicted.

Various attempts were made to define the effective environment of the cattle. First, the Temperature-Wind Index (TWI) was calculated from the simultaneous temperature and wind speed readings according to the formulas of Siple and Passel (1945), resulting in an effective chill temperature. Likewise, the readings for temperature and humidity were used to calculate the Temperature-Humidity Index (THI) developed by the U.S. Weather Bureau (1959) according to human discomfort.

TABLE 1. Observed Gain as Percent of Expected Gain in Iowa and Colorado Trials 1/

Source	Head	Time Span	Observed/Expected Gain		
			Summer	Winter	Overall
			%		
Iowa 2/	1,500	10 yrs.	109	89	99
Colorado 3/	93,500	24 mos.	106	93	99

1/ Calculated from known weights and feed consumption according to NRC net energy system.

2/ Data from Petritz thesis, University of Illinois, 1972.

3/ Data from Handley thesis, Colorado State University, 1971.

TABLE 2. Comparison of Monthly Average Effective Temperatures (TWI) in Fort Collins and Denver, 1969 and 1970.

Month	Ft. Collins	Denver	Ft. Collins	Denver
	TWI ^{o}F			
Jan	29.8	30.9	29.8	27.9
Feb	32.0	32.1	36.8	35.9
Mar	31.3	28.0	32.4	31.0
Apr	50.5	48.8	41.5	41.3
May	58.0	58.3	58.5	57.9
Jun	60.4	60.1	64.6	64.1
Jul	72.2	73.7	71.4	71.1
Aug	69.7	73.1	71.8	72.3
Sep	62.4	63.2	57.3	57.9
Oct	39.4	37.0	44.8	43.2
Nov	36.7	35.6	38.0	35.9
Dec	31.6	30.4	30.0	30.1
Mean	47.8	47.6	48.0	47.4

In addition, Petritz developed another type of climatic stress index as an attempt to determine the duration and magnitude of chill or heat stress below or above a certain break point in effective temperatures. These are best termed a Temperature-Wind Stress Unit (TWSU) for chill stress and a Temperature-Humidity Stress Unit (THSU) for heat stress. The units of measure on these statistics would be those of degree days below or above some set point in effective chill or heat stress temperature.

Location and Frequency of Weather Conditions Required

The usefulness of easily obtainable weather information from the NOAA station in Denver in describing Ft. Collins climatic patterns was investigated. We compared the TWI calculations from two years of observations at each of these two stations which were located some 60 miles apart. The results indicate very little difference between the monthly mean TWI's of the two stations (Table 2). An approximate comparison was also made of five-month average winter and summer periods for Colorado and Iowa (Table 3). The data indicate that the average temperatures were the same; however, the effective temperature in Iowa is considerably colder during the winter months and considerably warmer in the summer months.

The effect of frequency of simultaneous readings of weather parameters on the resulting stress indices were investigated using the eight years of NOAA data from Denver. This compilation (Table 4) of three-hourly vs. daily vs. monthly means indicated that a daily or monthly mean of temperature and wind speed when combined into an index such as TWI or THI had very little effect on the

TABLE 3. Average Colorado (eight years) and Iowa (nine years) Weather Data.

Index	Colorado (Denver)	Iowa (Sioux City)1/
Mean °F	48.2	48.3
Winter (Nov-Mar):		
TWI	32.0	21.7
TWSU-19 2/	1.1	6.7
Summer (May-Sept):		
THI	61.9	66.1
THSU-69 3/	0.1	1.5

1/ Stress index means are those for actual feeding periods (Petritz, 1972) which occurred largely during these months.

2/ Average degree-days TWI was above 19°F.

3/ Average degree-days THI was above 69°F.

magnitude of the resulting monthly mean of these stress indices. However, frequent simultaneous observations of temperature, wind speed, and humidity are very important when one considers the indices of TWSU 19 or THSU concept. When using these as indices of climatic stress, the use of monthly mean observations virtually erases the extremes and thus erases the measurement of stress occurrence. Therefore observations such as average air temperature and total miles of wind blown for the month combined into a stress index such as TWI would be adequate to use as a basis for calculating the months' representative TWI but would be inadequate for calculating a TWSU index.

These data were examined to characterize the effective temperature of each calendar month and deviations across years over an eight-year period from 1965-1972 in Denver (Table 5). Mean monthly TWI's were reasonably consistent from year to year with standard deviations of approximately 2.5 to 3.5, except for the months of March and October which showed considerably more variation.

Feed intake vs. effective temperature relationship observed in the 10-year Iowa study (Figure 2) indicates a high degree of relationship between these variables for the winter fed cattle. However, caution is urged in the interpretation of this as a cause and effect relationship since the observed feed intakes of the summer fed cattle were not generally lower than the lowest observations of the winter fed cattle. This shows that the relationship of intake to TWI-THI was not continuous over range of observation. Also a false relationship between these two variables is possible since the cattle consuming less would tend to have been kept longer and thus later into the spring and would for this reason also have a higher TWI for their feeding period.

Feed intake of the summer fed cattle was scattered around a mean of 107 g dry matter per kg per day to the .75 power, and the plot of the data indicated very little spread in average THI from year to year. When this data was examined using the stress unit concept or THSU, then the summers became considerably more different from one another and a stronger relationship between increasing heat stress and decreasing dry matter intake was predicted (Figure 3). The breakoff point values of 69 and 73 were those that were shown to bear the strongest statistical relationship between climate and performance patterns.

TABLE 4. Effect of Frequency of Simultaneous Observations on Resulting Indices of Climatic Stress (eight year Colorado means).

		Observation Interval		
Index	Month	3 Hours[1/]	Day[2/]	Month[3/]
TWI	Dec	27.2	27.9	28.4
	Jan	28.2	28.8	29.2
	Feb	29.9	30.5	31.0
	Mar	34.8	35.2	35.4
TWSU-19	Dec	1.64	1.48	.00
	Jan	1.74	1.61	.00
	Feb	.93	.86	.00
	Mar	.90	.85	.00
THI	Jun	62.2	62.2	62.2
	Jul	67.0	67.0	67.0
	Aug	66.0	66.0	66.0
	Sep	58.8	58.8	58.8
THSU-69	Jun	.02	.02	.00
	Jul	.25	.25	.07
	Aug	.12	.12	.00
	Sep	.00	.00	.00

[1/] TWI and THI calculated at each 3-hour observation and TWSU and THSU obtained by subtracting the 24-hour mean TWI or THI from selected critical temperature.

[2/] Mean 24-hour average temperature and 24-hour average wind speed or dew point used to calculate TWI and THI and then resulting TWSU and THSU.

[3/] Mean monthly average temperature and monthly average wind speed or dew point used to calculate TWI and THI and then resulting TWSU and THSU.

TABLE 5. Northern Colorado Climate Characterization (eight year average by months) 1/

Month	TWI		THI		TWSU-19		THWU-69		Rain
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	hrs/da
	------------ °F ------------				------ Degrees per day -----				
Jan	28.2	2.4	37.7	2.1	1.74	1.20	.00		.15
Feb	29.2	3.8	38.9	2.2	.93	1.03	.00		.07
Mar	34.8	5.9	42.2	3.4	.90	1.14	.00		.14
Apr	44.5	3.4	48.9	2.4	.07	.13	.00		1.67
May	54.6	3.3	55.7	1.6	.00		.00		2.03
Jun	63.8	3.5	62.2	1.8	.00		.02	.03	2.04
Jul	70.7	2.7	67.0	1.5	.00		.25	.35	1.76
Aug	69.5	2.5	66.0	1.5	.00		.12	.19	1.32
Sep	59.2	3.5	58.8	2.2	.00		.00		1.67
Oct	47.4	5.0	50.3	2.6	.03	.05	.00		.77
Nov	35.6	3.6	42.8	1.9	.07	.13	.00		.29
Dec	27.2	3.7	36.8	2.3	1.64	2.05	.00		.06

1/ Summarized from NOAA 3-hourly records over the years 1965-1972 for Stapleton Station, Denver.

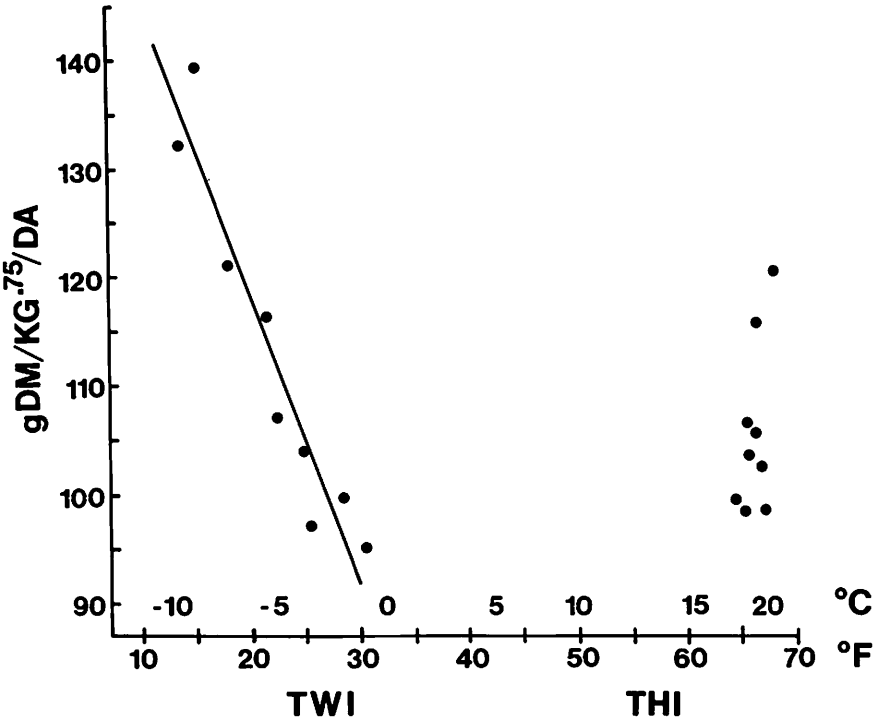

Figure 2. Feed intake vs. "effective temperature" (Iowa).

The relationships between the apparent net energy required for maintenance and climatic indices are shown in Table 6. The best relationships in the Iowa data were obtained when the stress unit concept was used and when this was set at a breakoff point of 19°F (-7°C). This is a 19° TWI which is the effective chill temperature and would, for example, be equal to 32°F combined with a 10-miles-per-hour wind. The apparent NE_m requirements averaged 94 kcal/ $W_{kg}^{.75}$/day for the winter phase cattle fed in open lots during the winter, but averaged only 66 for those fed in the summer. Within the summer fed groups no consistent relationship was found between the energy requirement and the varying measures of heat stress. This differs from results obtained by Ray (1975) in Arizona where summer fed cattle actually had a higher apparent maintenance energy requirement than those fed in the winter.

Reevaluation of the Knox and Handley data in Colorado showed a considerably different statistical relationship between the TWSU 19 than was obtained in Iowa. The regression coefficient indicated that the degree days below 19°F caused a 10 times greater effect in Colorado than in Iowa and the correlation coefficient showed a considerably poorer relationship between the two variables. The breakoff point in the stress concept had to be shifted up to 38°F before the greatest statistical correlation was found between the two variables. The best

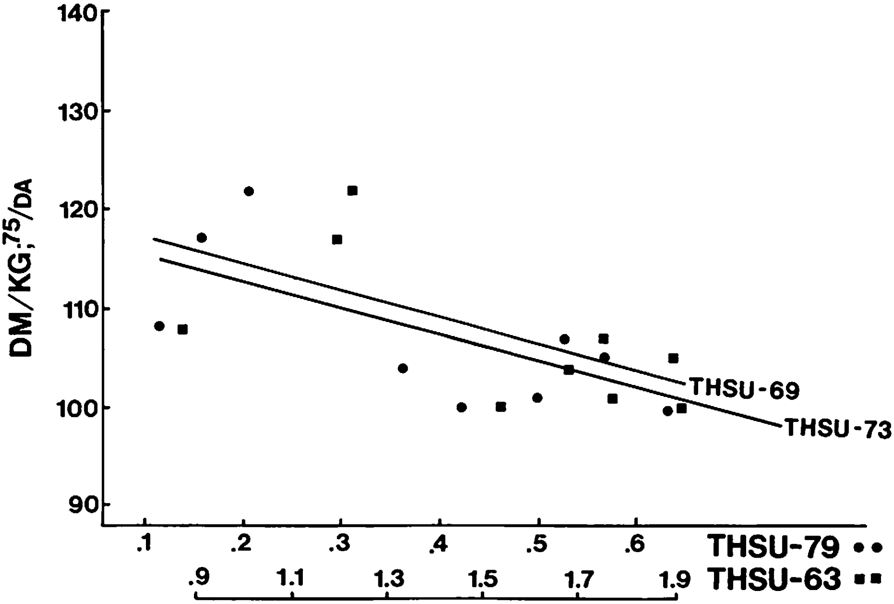

Figure 3. Feed intake vs. heat stress(Iowa).

relationship of climatic variables to NE_m was found with the simpler TWI index. Additionally the relationship between NE_m and TWI was quite similar for both data sets (Figure 4).

The reasons for the disagreement between Iowa and Colorado data when TWSU was used are not immediately apparent. Several possibilities including limited sample sizes of either numbers of cattle or time span are possible. Another is that the cattle in Iowa were subjected to longer and more consistent periods of severe cold and adapted to the situation better than those in Colorado. The batch vs. continuous-in-and-out system of feeding could possibly have altered the way that the cattle responded to periods and/or severities of chill stress.

Evidence for a depressing effect of precipitation was obtained in both studies. Regression coefficients in the Iowa data indicated that one hour of rainfall depressed feed intake by three lb per day; however, this variable was not significantly related to maintenance requirements. This indicated that rainfall had largely an indirect effect on feed consumption rather than a direct effect on heat loss.

General Implications

The general applicability of TWI as an index of climatic effect on performance across areas of the country lends credence to the interpretation by Canadian workers (Young *et al.*, 1975) that maintenance requirements increase gradually as environmental temperature decreases. These gradually changing factors could include an adaptation of the animal resulting in an elevated Basal Metabolic Rate (BMR) and/or depression in digestibility of the diet. Only under a more severe

TABLE 6. Relationship of Maintenance Net Energy Requirements to Climatic Indexes.

Data Source		r^2
Handley (Colo.) [2]	NE_m = 116 - .8133 (TWI)	.622
Petritz (Iowa) [3]	NE_m = 110 - .6537 (TWI)	.452
Handley [4]	NE_m = 104.2 - .754 (TWI) + 3.56 (Hrs.)	.610
Handley [5]	NE_m = 69.7 + 44.68 (TWSU-19)	.364
Handley [5]	NE_m = 66.7 + 7.94 (TWSU-32)	.438
Handley [5]	NE_m = 65.8 + 3.83 (TWSU-38)	.445
Petritz [3]	NE_m = 66.4 + 4.39 (TWSU-19)	.559

1/ NE_m in units of $kcal/kg^{.75}$.

2/ Changed form of Handley (1971) equation:

$$NE_m\ (kcal/lb^{.75}) = (43 + (TWI - 46)(.356)).$$

3/ Recalculated from Petritz (1972) yearly mean data.

4/ Hrs. = hours of precipitation.

5/ Calculated from Handley performance data and two-hourly Ft. Collins weather data.

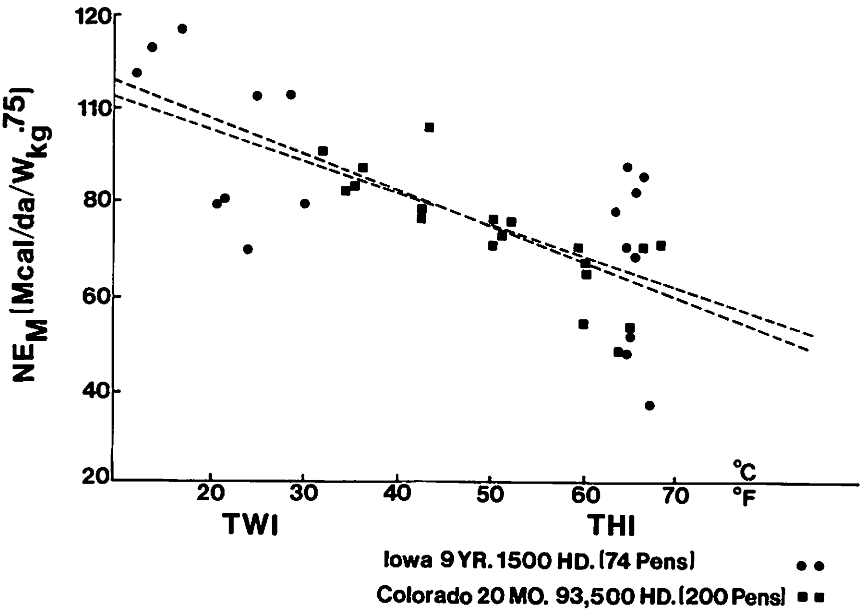

Figure 4. Relationship between net energy for maintenance and TWI for cattle feed in open feedlots in Iowa and Colorado.

chill stress would the direct heat loss become a factor in elevating the energy needs for maintenance. An alternative for a partial interpretation of the general research results is that the critical temperature varies markedly by area due to adaptation and/or other unknown factors. Evidence would suggest that the effective critical temperature in Colorado is about 38°F whereas in Iowa it is 19°F as compared to Canadian work which indicates it to be about -10°F or lower.

Both sets of data indicate that the NRC (1970) energy system overestimates the maintenance requirement of cattle fed in an optimal environment. It appears that there are at least two possible reasons for this.

1. The system was developed under conditions of some environmental stress on the average as is indicated by the cost of gain figures cited earlier from research done by Elam.
2. Gut fill gain was ignored in the development of the system. Data on the weight of gut contents such as those cited by Moulton *et al.* (1922) suggest that the gut fill gain amounts to from 2.5% to about 8.5% of 175 kg live weight gain depending on the concentration of roughage in the diet, starting vs. finishing. It is expected that a usual feedlot situation with yearling cattle would result in gut fill gain of approximately 5% of live weight gain. Thus if it were ignored, total gain would be underestimated by this amount.

TABLE 7. Estimated Maintenance Energy Requirements of Open-Lot Fed Cattle in the North Central Colorado Plains

Month	NE_m (kcal/kg.75/da)
Jan	93
Feb	91
Mar	87
Apr	79
May	71
Jun	65
Jul	65
Aug	65
Sep	67
Oct	77
Nov	87
Dec	93
Mean	78

Our present best estimate of maintenance energy requirements of open-lot fed cattle in northcentral Colorado is an extrapolation of the Handley TWI vs. NE_m relationship to our eight-year summary of the average climatic conditions by month of the year in Colorado. These NE_m values (Table 7) indicate the requirement varies from 65 in the summer months to an average of over 90 in December and January. This relationship is tentative and needs further testing across several years of climatic data as well as other feeding situations. Also, these increased maintenance requirements can not be applied directly to decreased performance and decreased efficiency since the data suggest that the animal will adjust feed intake upward to partially offset the increased requirements due to chill stress.

Some Other Factors of Special Concern to Explaining Cattle Performance

While the overall predictability of cattle performance averaged across seasons is indicated to be high, several factors markedly alter this relationship and thus need to be defined by further research.

1. The associative effect between feedstuffs. This is shown to be quite marked and negative in the case of mixtures of corn grain and corn silage in recent research (Peterson, 1971; Vance, 1971; Byers *et al.*, 1975). The net energy value of corn silage is indicated to fall to about half of its original value when fed as a small part of the diet along with corn grain.
2. Body composition of varying lines of breeding and/or breeds of cattle has marked effects on actual net energy stored as tissue gains. This is indicated

dramatically by heifer vs. steer requirement differential as well as the light cattle vs. heavy cattle differential energy requirements. However, the issue is clouded because of the uncertainty of the efficiency of protein synthesis as compared to fat tissue synthesis in the growing animal.

3. The changing maintenance requirement scheme in contrast to the constant maintenance requirement per metabolic body size assumed by the NRC (1970) system must be resolved. Compensatory gain and/or a variation in requirements of animal depending on the previous nutritional history deserves consideration. Variation in this area has been indicated by recent work of Fox (1973) and of Hahn (1974).
4. The cow and her needs as variables in the total beef production system should be given attention. We have concentrated and studied considerably the energy requirements under varying circumstances and environmental situations for the producing or growing animal. However, we have largely ignored the beef cow and the variations during common systems of management.
5. Also the possibility of increased roughage feeding and what this may do to the input-output relationships associated with climatic effects plus those associated with associative effects of feed need to be considered for future planning.

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