PROTEIN ADJUSTMENT IN HEAT STRESSED FINISHING CATTLE

by

Clifton L. Willms

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Approved by:

David Ames

Major Professor

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TABLE OF CONTENTS

LIST OF TABLES

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INTRODUCTION

The thermal neutral zone (TNZ) for an animal is that range of effective temperatures where there is minimum metabolic heat production, the least effort to regulate homeostasis, and more practically, where maximum performance is observed. Effective temperature is the heating or cooling power of the environment measured in terms of dry bulb temperature. Exposure of farm livestock to temperatures above or below the TNZ reduces gains and efficiency. The effect of high ambient temperature on the average daily gain (ADG) of feedlot cattle is described by the function $ADG_{kg} = 1.424 + .1163\ C - .003191\ C^2$. The quadratic decline in gain with increasing temperature above the TNZ is explained by increased net energy for maintenance (NE_m) requirement with concurrent decreases in feed intake. Consequently, the availability of net energy for production (NE_p) is decreased. Protein-to-calorie ratio (g digestible protein/Mcal digestible energy) is increased above optimum so that adequate energy is not available for protein incorporation into new tissue. Thus, protein is deaminated to compensate for increased energy needs. This explains the decline in protein efficiency ratio (PER = g gain/g protein) during heat stress. The objective of this experiment was to determine if digestible protein for production (DP_p) could be matched with expected performance during heat stress. Reduced protein levels should decrease cost of gain, improve PER, and not affect ADG.

LITERATURE REVIEW

Protein Requirements for Maintenance

Folin (1905) concluded that protein metabolism must be consistent with the laws governing the composition of urine. He proposed a theory in which there are two types of protein metabolism - endogenous and exogenous. The endogenous or tissue metabolism tends to be constant. When this constant composition of urine is reached, the total nitrogen eliminated indicates the lowest attainable level of nitrogen equilibrium. Folin further stated that the "protein sufficient to maintain the endogenous protein metabolism is indispensable."

Armsby (1917) developed a maintenance feeding standard for protein using live weight experiments. He estimated maintenance digestible protein to be .6 lb (.27 kg) per 1000 lb (454 kg) body weight. Citing Danish work, Armsby admits the standard may be too high and allows a $\pm$ .1 or .2 lb (.045 or .091 kg) digestible protein in his standard.

Mitchell (1929) clearly showed that a maintenance standard of .6 units of digestible protein per 1000 units body weight includes a large margin of safety. Mitchell reviewed a mass of urinary nitrogen excretion data and proposed that the nitrogen maintenance requirement is approximately .030 g/kg body weight which is equivalent to .19 lb (.086 kg) of conventional protein (N x 6.25) per 1000 lb (454 kg) body weight. This value must be adjusted for biological value to be expressed in a dietary digestible protein requirement.

In an attempt to relate basal metabolism and endogenous nitrogen, Terroine and Sorg-Matter (1927) (cited by Smuts, 1935) measured the sum output of urinary and fecal nitrogen in 5 different species - mice, rats, pigeons, chickens, and rabbits, fed a nitrogen-free diet. Ratios were similar, ranging from 2.3 to 2.9 mg nitrogen per Kcal of basal heat. Since metabolic fecal nitrogen is related to feed intake, Smuts (1935) related endogenous urinary nitrogen to basal metabolism in 5 species - mice, rats, guinea pigs, rabbits, and pigs. Smuts reported that the ratio of 2 mg nitrogen, or 12.5 mg of conventional protein, per Kcal of basal heat tended to be constant for homeotherms. Age did not disturb this relationship. Smuts concluded from this constant ratio that maintenance protein requirement varies with surface area since basal heat production varies more closely with surface area than body weight. Citing work by Brody (1932) on basal heat production, Smuts proposed the calculation of protein requirements for maintenance using $P = (.0125)(70.4)\ W_{kg}^{.734}$, where P is protein per day expressed in grams and W is body weight. Relating this protein requirement in terms of digestible protein, Smuts estimated maintenance protein to be .35 lb (.16 kg) for a 1000 lb (454 kg) animal. Since this method of calculating protein requirements was based on work with nonruminants only, Smuts and Marias (1938) determined endogenous urinary nitrogen excretion on Merino wethers fed a nitrogen-free diet with the expressed intent of determining maintenance protein requirement. They concluded that the formula proposed by Smuts (1935) could be applied to sheep. However, further work by Smuts and Marias (1939) revealed that the percentage deviation of endogenous urinary nitrogen excretion and determined values could be decreased by changing the formula from $P = .88\ W_{kg}^{.734}$ to $P = .74\ W_{kg}^{.734}$. The new formula was more applicable to both mature and young sheep. In agreement, Brody (1945) reported that $W_{kg}^{.72}$ was a good reference point not only for basal metabolism but also for endogenous nitrogen and neutral sulfur excretion. Endogenous urinary nitrogen excretion expressed in mg per day was equal to $146\ W_{kg}^{.72}$. Assuming digestible protein for maintenance is four times the digestible protein equivalent of endogenous urinary nitrogen, Brody reported feeding standards for maintenance in which .699 lb (.317 kg) digestible protein is required for a 1000 lb (454 kg) animal.

In the first of a series of papers on the protein requirements in ruminants, Elliot and Topps (1963a) found digestible nitrogen requirements to be closely related (r = .947) to metabolic body size. The equation $N = 197\ W_{kg}^{.73}$, where N is the nitrogen requirement in mg/24 hr, described the relationship. However, they found the digestible nitrogen requirement for maintenance to be approximately one-third the Brody (1945) standard. Citing concurrent work on the nitrogen metabolism of the same cattle, the ratio of apparently digestible nitrogen requirements for maintenance to endogenous urinary nitrogen is shown to range from 1:2.48 to 1:3.39 with a mean value of 1:2.96. Brody (1945) assumed this ratio to be 1:4 in establishing his standard. Elliot and Topps found from the same concurrent work a mean protein biological value of 82.5 $\pm$ 3.19 for the low protein diet. Elliot and Topps pointed out that if Smuts (1935) would have used a biological value of 80 instead of 50, his estimated digestible protein requirement for a 1000 lb (454 kg) animal would have been .22 lb (.10 kg) rather than .35 lb (.16 kg). The value of .22 lb (.10 kg) is in agreement with that found by Elliot and Topps. This value is also very close to the Mitchell (1929) standard assuming the same biological value.

Using NRC crude and digestible protein requirements for growing-finishing beef and dairy cattle, Preston (1966) expressed maintenance protein in terms of a mathematical model. He reported maintenance crude protein to be $5.86\ W_{kg}^{.75}$, both requirements being expressed in grams. Preston calculated the protein-to-energy ratio (g digestible protein/Mcal digestible energy) for cattle at maintenance to be 20.8 which agrees well with the value of 19.3 reported by Crampton (1964) for a mature cow. However, Preston (1972) pointed out that in fasting animals endogenous urinary nitrogen excretion is elevated (Mitchell, 1929) and that urea transferred to the rumen via saliva or absorption across the rumen wall cannot be utilized due to insufficient energy (Moir and Harris, 1962). Therefore, based on urinary nitrogen excretion data in animals fed their maintenance energy requirement (Brody, 1945; Mitchell, 1929; Elliot, 1963; Elliot and Topps, 1963a, b; Elliot and Topps, 1964; Preston et al., 1965), Preston arbitrarily proposed digestible protein for maintenance to be 1.6 $W_{kg}^{.75}$. He also calculated the optimum protein-to-calorie ratio to be 11.6 g digestible protein/Mcal digestible energy at maintenance.

Protein Requirements for Growth and Finishing

Armsby (1917) considered composition of gain and age in listing protein requirements for growth and fattening. Digestible protein requirements for growth without considerable fattening decreased from .23 lb (.10 kg) to .14 lb (.06 kg) per lb increase in live weight for cattle from 1 month to 30 months of age, respectively. For fattening without considerable growth in early and late stages respectively, Armsby reported the daily digestible protein requirement above maintenance to be .15 and .05 lb (.68 and .02 kg) per lb increase in live weight. Listing requirements in a practical form for feeding standards including maintenance, Armsby recommended 1.3 lb (.59 kg) digestible protein/day for beef cattle 24-30 months of age.

Using a factorial method, Mitchell (1929) based protein requirements for growth and finishing on estimates of rate of nitrogen deposition at different ages and at different weights. Mitchell rejected Armsby's generalized relationship between gain in protein and age of animal and proposed the use of physiological age to relate nitrogen requirements to growth. Mitchell estimated the nitrogen retention of Hereford-Shorthorn type cattle at weights of 700, 800, 900, and 1000 lb (318, 364, 409, and 454 kg) to be 11.3, 9.47, 7.77, and 6.17 g/day, respectively. Establishing a useful feeding standard for Hereford-Shorthorn type cattle, Mitchell reported digestible protein requirements for animals weighing 700, 800, 900, and 1000-1200 lb (318, 364, 409, and 454-545 kg) to be .57, .56, .55, and .54 lb (.259, .255, .250, and .245 kg) per head per day, respectively. The biological value of digestible protein was assumed to be 50% in making these estimates. These values are approximately 60% lower than the Armsby (1917) standard.

Contrary to Mitchell, Morrison (1936) reported increased digestible protein requirements as body weight increased. Standards for rapidly growing beef cattle were 1.10-1.24, 1.17-1.32, 1.22-1.40 and 1.28-1.46 lb (.50-.56, .53-.60, .55-.64, .58-.66 kg) per head per day for 700, 800, 900, and 1000 lb (318, 364, 409, and 454 kg) animals. Requirement for fattening yearling cattle weighing 700-1000 lb (318-454 kg) ranged from 1.41 to 2.17 lb (.64 to .99 kg) digestible protein per head per day.

Analyzing the above standards, Blaxter and Price (1946) found estimates of protein requirements by Mitchell's method to be too low for growing dairy heifers, suggesting Mitchell's standard is low because metabolic fecal nitrogen loss is not considered. Blaxter and Mitchell (1948) emphasized that protein requirements are high for young animals and low for older animals. They indicated that the Morrison (1936) standard tends to underestimate protein requirements of young animals and overestimate protein requirements for older animals. They also reported that Armsby's (1917) standard underestimates the requirement of young animals, although not as much as the Morrison (1936) standard.

Another means of expressing protein requirements, reviewed by Crampton (1964), is in terms of protein-to-calorie ratio. This method of expressing requirements has not been widely accepted in ruminant nutrition since commonly fed rations vary widely in digestible caloric density. Nevertheless, the concept is growing in popularity with increasing numbers of cattle finished on high concentrate rations.

Bosshardt _et al_. (1946) reported that in rats the level of protein intake which resulted in maximum protein utilization coincided with maximum caloric intake per unit of body surface area. They further stated that it could not be deducted from their data that optimal calories are supplied when maximum protein utilization is obtained.

Guilbert and Loosli (1951) stated that if physiologically equivalent age means that the composition of growth increments are closely similar for several species, then the concentration of nutrients in relation to energy should not be different for fast and slow growing species. In contrast, Preston (1966) reported that protein-to-calorie ratio is primarily a function of rate of gain. Calculated values for protein-to-calorie ratio (g digestible protein/Mcal digestible energy) by Preston for growing finishing cattle with gains of .5, 1.0, 1.5, and 2.0 kg were 24.7, 26.4, 27.2, and 27.8 respectively. Using the same method but a different function for protein requirements, Preston (1972) reported slightly smaller values for optimum digestible protein-to-digestible energy ratio. For the same corresponding increments of growth, calculated values were 18.6, 21.7, 23.4, and 24.5. Feeding trials verify this energy-protein relationship. Fontenot and Kelly (1967) fed three levels of crude protein (9.2, 12.9, and 17.0%) and three levels of energy (62, 67, and 73% calculated TDN on air dry basis) in a 3x3 factorial design.

The 12.9% protein level gave higher (P<.05) daily gain than either the 9.2 or 17.0% levels. Feed efficiency, live slaughter grade, and carcass conformation score were lower (P<.05) for the low protein level than for the 12.9 or 17.0% levels. Cattle fed the low energy level had lower (P<.05) rate of gain, live slaughter grade, carcass conformation, and fat thickness than those fed the other two levels. Feed efficiency increased with energy level.

Peterson et al. (1973) used a 4x4 factorial design to study the performance of crossbred steers fed diets of different energy concentrations and protein levels. Four levels of dietary crude protein (9, 11, 13, and 15%) were fed with four ratios of corn silage to high moisture corn (3:0, 1:2, 2:1, and 0:3) on an air dry basis. For the entire feeding period average daily gains responded linearly (P<.01) to an increase in dietary energy concentration and linearly (P<.01) to an increase in protein level. As dietary protein level was increased from 9 to 11 to 13% in the all-concentrate diet, gains increased (P<.05). Between the 13% and 15% protein levels in the all-concentrate diet, gains were similar (P>.05) for the total feeding period.

In contrast, recent work has shown that supplemental protein can be withdrawn at the end of the feeding period without decreasing performance (Harrison, 1974; Putnam et al., 1969). This indicates that total protein intake per day may be more important than crude protein concentration in the ration for meeting protein requirements. Harrison (1974), in three finishing trials with yearling steers and heifers, reported that final average daily gains were not affected (P>.05) by varying rations from 13 or 15% crude protein early in the feeding period to as low as 8.9% in the final 28 days of the feeding period, as compared to a constant 11.1% crude protein level for the entire period. In agreement, Putnam et al. (1969) concluded that finishing rations for cattle from 360 kg to slaughter need not contain more than

8 to 9% crude protein. The above trials indicate a relationship between protein requirement and composition of gain. The NRC (1976) requirements reflect the work done in removing protein near the end of the feeding period. They are calculated using a factorial method which includes endogenous urinary nitrogen ($N_g = .12W^{.75}$), metabolic fecal nitrogen (4 g N/kg dry matter intake), and an adjustment for composition of gain. Composition of gain is assumed to vary from 18 to 9% protein for steers weighing 100 kg to 500 kg, respectively. For corresponding weights in heifers, values for protein in gains are 18 to 7%. Digestible protein values are calculated from nitrogen values by a factor of 6.25 and assuming the biological value to be 77.5%.

Temperature vs. Performance

Exposure of farm livestock to adverse environmental temperatures has been shown to affect performance in all species. Most of the early work concerning livestock-environment interactions was done with poultry. Kleiber and Dougherty (1934) showed that daily growth rate in baby chicks increased (2.74 g to 4.88 g) as environmental temperature decreased (40 to 21 C) and that food consumption increased in proportion to decrease in temperature. However, metabolizable energy, partial efficiency (the increase in net energy per unit of the corresponding increase in food energy), and caloric density of gain were maximal at 38 C. At 21 C caloric density of gain was minimal and water stored was maximal. Kleiber and Dougherty concluded that 38 C was the optimum temperature for baby chicks. Winchester and Kleiber (1938) reported similar results and conclusions.

Studies with older chickens revealed that optimum performance occurs in the temperature range of 60-80 F. Wilson et al. (1957) kept relative humidity constant at 75% while studying the effect of decreasing environmental temperature from 95-25 F on production characteristics in pullets. Lowering air temperature from 95 to 65 F improved body weight gain, lowered the ratio of water to feed intake, and lowered the ratio of manure voided to feed intake. Milligan and Winn (1964) concluded from six trials with 5-10 week old broilers that 60-80 F was optimum for gain, feed conversion, pigmentation, and feathering. At 95 and 100 F with high relative humidity, these performance factors were lowered. In two trials, lowering air temperature from 95 to 80 F improved gain 44% and 26% at high and low humidity, respectively. In agreement, Adams et al. (1962a) showed chicks 6-10 weeks old grew slower (P<.01) and consumed less feed (P<.01) at 90 F than at 70 F. Using 4-8 week old chicks, Adams et al. (1962b) reported that chicks reared at 21 C grew faster and consumed more than those at 29 C. In agreement, Prince et al. (1961) working with cold stress in 4-8 week old chicks found that increasing ambient temperatures from 45 to 75 F significantly decreased intake, improved weight gains, and significantly improved feed efficiency by 12.5%.

A second degree curvilinear regression described the relationship between constant ambient temperature and weight gain in swine ranging from 50-350 lb (22.7-158.9 kg) studied by Heitman et al. (1954). Optimum temperature for maximum weight gain was 73 F for pigs weighing 50-125 lb (22.7-56.7 kg) and 61 F for pigs weighing 150-350 lb (68.1-158.9 kg). Feed utilization had a similar, but inverse relationship to ambient temperature. Fuller (1965) found feed intake increased by 12 $g/kg^{.72}$/week for each 1 C fall in temperature below 30 C in pigs fed at air temperatures of 10, 15, 20, 25, and 30 C. Feed efficiency improved as temperature increased. In agreement, Sugahara et al. (1970) fed young barrows averaging 9.3 kg at ambient temperatures of 7, 23, and 33 C. Feed intake was significantly decreased at 33 C and significantly increased at 7 C as compared to 23 C. Growth rate decreased significantly at 33 C. Barrows tested from 20 kg to 90 kg live weight and fed at 23, 13, and 3-5 C by Fuller and Boyne (1971) had a decrease in growth rate of 17.8 g/day for each 1 C fall in temperature.

Similar effects of thermal stress on performance and related factors have been observed in ruminants. Ames et al. (1971) reported increases ($P<.05$) in oxygen consumption above thermoneutral (25 C) exposures in sheep. A 27% increase in oxygen consumption is reflected in increased net energy for maintenance and therefore reduces net energy for production. Respiratory water losses were most apparent during mild heat stress (30 and 35 C) and cutaneous water loss was more important during severe heat stress (40 and 45 C). Hussain and Bhattacharya (1973) studied the effect of high ambient temperatures on Awasi wethers in three trials. Trial 2 simulated a hot, humid day with a sharp rise in temperature at 7 a.m. to a peak at 2 p.m. and a gradual fall during the night. Heat stress decreased feed intake ($P<.05$) and increased water consumption ($P<.01$) and urine volume ($P<.05$). Digestibility of crude protein, ether extract, and energy were lowered by heat stress although the digestibility of dry matter, crude fiber, and nitrogen free extract were not affected. Metabolizable energy of rations was also depressed during heat stress. Wethers showed increased respiration rate, heart rate, and rectal temperature during high ambient temperatures. In agreement, similar physiological and behavioral responses were observed during heat stress by Appleman and Delouche (1958) in goats and by Owens et al. (1976) in cattle. Owens et al. suggested that cattle in heat stress (32 C) were less comfortable while eating than while lying down or loafing and were anxious to complete the feeding process. This caused the steers to become filled faster, thus reducing their intake below that at 18 C temperature. These responses result in decreased performance as evidenced by feeding trials. Vohnout and Bateman (1972) attributed the decreased dry matter and digestible energy intake and resulting lower growth rate in cattle to increased resting time during heat stress. Ray et al. (1970) reported decreases ($P<.05$) in average daily gain in feedlot steers due to heat stress.

Knox and Handley (1973) reported that cattle fed during the winter months gained less than predicted by the California net energy system (CNES) and those fed during the spring gained more. Animals gained less than predicted as effective temperature decreased. A correction factor ($Y = .356X$, where Y = difference from NE_m of $43W^{.75}$ and X = difference in effective environmental temperature from 46 F; $r^2 = .60$) applied to the NE_m requirement of the animal improved predictability. The most probable reason for both positive and negative differences in predicted and actual gain suggested by Knox and Handley was that the system was developed under a variety of environmental conditions. In agreement, Ames and Brink (1977) reported similar conclusions from results of growing lambs reared at ambient temperatures of -5, 0, 5, 10, 15, 20, 30, and 35 C. Average daily gain was significantly affected by temperature. The relationship between temperature and average daily gain (ADG) was a guadratic function where $ADG_g = 129.94 + 9.72T - .35T^2$ ($R^2 = .29$) with T = temperature in degrees centigrade. The effect of temperature on the deviation of predicted from actual gain was quadratic ($P<.01$). Actual gain was more than predicted at temperatures between 10 and 30 C but less than predicted at -5, 0, 5, and 35 C.

Ames et al. (1975) found average daily gain to have a quadratic relationship to mean ambient temperature over a range of temperatures for both cattle and sheep. However, when data were analyzed separately for cold and heat, average daily gain vs. temperature was linear in cold and quadratic in heat. Analysis of the cattle data for the entire range of temperatures studied gave the relationship $ADG_{kg} = 1.396 + .2535T - .00095T^2$. For cold the relationship was ADG_{kg} = 1.396 + .013T and for heat ADG_{kg} = 1.424 + .116T - $.003T^2$. In all functions T = temperature in degrees centigrade. The difference in response between cold and heat was explained by linear increases in maintenance during cold concurrent with maximum feed intake whereas during heat maintenance increased non-linearly as feed intake decreased.

Protein Level vs. Temperature

Effects of temperature on performance points to variation in nutrient requirements under different environmental conditions. The NRC (1976) requirements do not make allowances for environmental stress. However, the following research supports the hypothesis that protein requirements are related to thermal environment.

Payne and Jacob (1965) fed rats 30 days of age four levels of protein (0, 4, 10, and 25% casein) at two environmental temperatures (15 and 27 C). Rats fed the 4 and 10% diets at 15 C consumed more feed and utilized the resulting additional protein consumed with equal efficiency, therefore increasing gain and nitrogen retention. At both temperatures, animals fed the 25% diet utilized protein less efficiently, gained less weight, and had lower nitrogen retention. The net protein utilization was the same for both temperatures for diets with 4 and 10% protein concentration, despite the difference in actual protein intake. These results show that protein metabolism is independent of temperature and protein efficiency is reduced when energy intake is inadequate to meet needs for thermogenesis and growth. In agreement, Adams et al. (1962b) showed that chicks reared at 21 C grew faster and consumed more feed than those at 29 C. Decreased growth at 29 C could not be attributed to decreased protein intake. High protein diets fed at 29 C allowed for greater protein intake than low protein diets, yet lower growth rate resulted. In a similar experiment, Adams et al. (1962c) reported that grams of sulfur amino acids per gram of gain did not appear to be influenced by environmental temperature in 4 week old chicks. Studying growing lambs in a range of temperatures from -5 to 35 C, Ames and Brink (1977) reported that protein efficiency ratio was decreased ($P<.01$) during thermal stress. Nitrogen retention and percent urinary nitrogen was quadratically ($P<.01$) affected by temperature. Ames and Brink suggest that protein was used for energy during thermal stress and that maximum protein efficiency ratio could be maintained by adjusting dietary protein to match predicted gain over a wide range of temperatures. Grey et al. (1964) observed similar results in Shorthorn and Afrikaner cattle fed at high ambient temperature. Although temperature had no significant effect upon total absolute nitrogen loss via the feces and urine, a trend toward increased urinary nitrogen loss was observed. Urinary nitrogen loss per unit of nitrogen intake was increased ($P<.05$) during heat (93 F) in the Shorthorn cattle. However, Grey et al. offer different conclusions from their results. They explain that increased urinary nitrogen excretion could be a result of increased diuresis and therefore increased protein catabolism and urinary nitrogen loss is not directly affected by heat stress but rather occurs with breakdown in water metabolism.

At all temperatures between 10 and 30 C, young pigs fed ad lib. utilized dietary protein at constant efficiency (Fuller, 1965). For barrows fed at 23, 13, and 3-5 C and feed intake adjusted to a constant level per $W_{kg}^{.73}$, Fuller and Boyne (1971) reported that for each 1 C drop in temperature, nitrogen retention declined .38 $\pm$ .055 g/day. However, temperature did not significantly affect nitrogen retention in response to increasing feed intake. Nitrogen balance increased with feed consumption by .165 $\pm$ .018 g per g/kg$^{.73}$/day. In agreement, Verstegen et al. (1973) reported that nitrogen retention was correlated ($r = .94$) with plane of nutrition and was not influenced by temperature.

These observations relating protein metabolism to environmental temperature indicate that protein levels can be reduced during thermal stress without affecting performance. Ames (1976) adjusted dietary protein levels in growing steers in proportion to the expected decrease in average daily gain due to cold stress. In two trials, Ames reported that .11 and .15 kg/hd/day less supplemental protein was consumed by steers on variable protein levels as compared to constant protein level (12.5%) in control steers. There was no difference (P<.01) in average daily gain between treatments. In agreement, Waibel (1976) studied the performance of growing turkeys at 51 and 72 F environments fed six levels of protein. The data for the entire test period indicate that for the 51 F environment, the lowest dietary protein level fed provided adequate growth.

MATERIALS AND METHODS

A 2x3 factorial design (sex, steers vs heifers; sprinkle, yes vs no; protein, constant vs variable) was used to test the effect of reducing protein levels in proportion to the expected decline in daily gain during heat stress.

Two-hundred-fourteen (104 control, 110 variable protein) crossbred finishing steers and heifers were randomly allotted to 8 (4 control, 4 variable protein) outside feedlot pens (30.5 m x 61 m). Cattle were weighed on test June 3, 1976 averaging 354 kg and were fed 82 days (off test August 23, 1976). The base ration (Table 1) was fed ad libitum twice daily on a pen basis with protein adjustments made for the magnitude of heat stress in the variable protein treatment.

A formula developed from 40,000 feedlot cattle relating ADG as a function of mean daily temperature, ADG (kg) = 1.424 + .1163 - .003191 C^2 (Ames, 1975), was used as the basis for calculating the decline in gain during heat stress. Optimum (C_t = 15 C) and ambient temperatures at time of feeding were substituted into the formula and the decline in gain due to increased environmental temperature above TNZ was calculated. Temperatures were recorded using a deflection hygrothermograph.

Digestible protein for production (DP_p) was reduced in the ration by the same percentage as the decline in gain at a given deviation from TNZ. DP_p was calculated by difference from the total digestible protein (DP_t) intake and digestible protein for maintenance (DP_m). DP_t was based on the preliminary analysis of the ration and daily intake of the previous week. Cattle were weighed weekly by pen to determine metabolic body size and DP_m (g) was calculated as 2.79 $W_{kg}^{.75}$ (Preston, 1966). Adjustments to DP_p from the base ration were then made by isocaloric replacement of milo for SBM. The following example illustrates the procedure described.

Example Protein Adjustment Calculation

Assumptions

Critical temperature = 15 C

Temperature at feeding = 30 C

DP_t = 800 g/day (Ration DP x DM Intake)

Weight = 400 kg ($W_{kg}^{.75}$ = 89.44)

SBM digestible protein = 40%

Milo digestible protein = 8%

Step 1: Decline In Gain

$$\text{Maximum gain} = 1.424 + .1163(15) - .003191(15)^2$$

$$= 2.451 \text{ g}$$

$$\text{Predicted gain} = 1.424 + .1163(30) - .003191(30)^2$$

$$= 2.041$$

$$\text{Decline in gain} = 1 - 2.041 / 2.451$$

$$= .167 \text{ or } 16.7\%$$

Step 2: Digestible Protein For Production

$$DP_m = 2.79\ W_{kg}^{.75} = 2.79 \times 89.44$$

$$= 250 \text{ g}$$

$$DP_p = DP_t - DP_m = 800 - 250$$

$$= 550 \text{ g}$$

Step 3: Replacement Factor

$$RF = 1 - DP\ Milo\ /\ DP\ SBM = 1 - .08\ /\ .40$$
$$= .80$$

Step 4: SBM Replaced

$$SBM\ Replaced = (DP_p)\ (Decline\ In\ Gain)/(RF)(SBM\ DP)$$
$$= (550)(.167)/\ (.80)(.40)$$
$$= 287\ g/hd/day$$

PER as defined by Allison (1959) and ADG were compared within treatments. Data was analyzed using a least square analysis of variance with unequal subclass procedure (Kemp, 1972).

RESULTS AND DISCUSSION

Only the results and discussion concerning the protein treatment of this experiment are reported.

The mean daily temperature, mean daily high, and mean daily heat stress (mean daily high minus 15 C) for the test period was 26, 32, and 17 C, respectively. The highest temperature recorded was 40 C.

Under these conditions, ADG was not affected (P=.37) by protein treatment. ADG was 1.14 and 1.11 kg for variable and control protein cattle, respectively. These results are in agreement with Ames (1976) who suggested that lowered protein levels during thermal stress do not affect ADG. However, ADG was affected (P=.00) by dry matter (DM) intake with adjusted means for variable and control protein being 11.77 and 11.0 kg/day respectively. Cattle with larger initial weights also tended to gain faster (P=.09). No differences (P=.94) were observed in efficiency (gain/feed) between the variable and control treatments likely because the degrees of freedom were greatly reduced due to pen feeding.

An average .13 kg/hd/day supplemental protein (SBM) was removed in the variable treatment. Similar values (.11 and .15 kg SBM/hd/day) were reported in two cold stress trials by Ames (1976). However, variable protein cattle consumed more total protein since they consumed .77 kg more DM/day.

There was no difference (P=.61) in PER, although the variable treatment tended to be higher when DM intake was held constant (Table 2). Theoretically, PER should be higher when protein levels are adjusted for thermal stress. Payne and Jacob (1965) demonstrated that net protein utilization and net dietary protein calories percent of a ration are both independent of temperature provided that energy requirements for maintenance and growth are satisfied. They further showed that there exists a maximum rate, independent of dietary caloric density, at which dietary energy can be utilized at any temperature. Therefore, there exists at any given temperature, a maximum rate of protein anabolism and net dietary protein calories percent value which can be supported. Using 16 and 17-day old cockerals grown at temperatures from 18.3 to 31.1 C, March and Biely (1972) concluded that when metabolizable energy or environmental temperature was increased in rations severely deficient in lysine, the imbalance between effective protein level of the diet and the total caloric input was aggravated. Ames and Brink (1977) reported that over a wide range of environmental temperature, ADG and nitrogen retention in growing lambs were quadratically affected by temperature and that PER declined during thermal stress. They suggest these results occur because maintenance energy increases during thermal stress, and that protein is used as an energy source when energy is limited (Albanese, 1959). Therefore, replacing supplemental protein with energy during thermal stress will maintain a constant ratio of protein-to-energy above maintenance, with protein used for nitrogen needs of new tissue, instead of energy, and PER is improved.

This study does not decisively confirm this theory of protein metabolism since the protein concentration of the control ration (12.22% CP) was higher than NRC recommended levels. NRC (1976) list total protein concentration of rations for 400, 450, and 500 kg steers not to exceed 10.5, 10.4, and 10.0%. Also there was no negative control (constant low level of protein). However, Ames and Brink (personal communication) fed two groups of five lambs each at two environmental temperatures (-5 and 15 C), two levels of protein (10 and 14%). Although none of the differences were significant ($P>.05$) at -5C (cold stress) the 10% protein treatment gained more suggesting that the protein level was adequate. At 15 C (thermal neutral), the 14% protein treatment gained more, suggesting a higher protein requirement.

This system of matching protein levels with thermal environment could result in large economical savings with minor modifications in experimental assumptions. First, NRC (1976) digestion coefficients for each ration ingredient were used to calculate the ration digestible protein, assuming no interactions. The NRC (1976) protein digestibility for milo (4-04-444) is 57%. Eng et al. (1965) showed that protein digestibilities varied (ranging from 62.07 to 78.55%) in grain sorghums of differing compositions. Feeding trials in Oklahoma (Brown et al., 1968; Buchanan-Smith et al., 1968) revealed similar protein digestibilities (ranging from 64.0 to 69.1% and 64.7 to 71.0%, respectively) for high grain sorghum rations. However, considerably lower values have been reported by Arizona workers (Hale, et al., 1966; Husted et al., 1968). Obviously, the protein digestibility of milo reported by NRC (1976) is an average value. If the varieties and conditions of milo grown in Kansas result in higher digestibility than that reported by NRC (1976), then more digestible protein is available for adjustment.

Second, the DP_p available would be larger if DP_m is lower than 2.79 $g/W_{kg}^{.75}$ (Preston, 1966). Considerable work with ruminants points to lower maintenance protein (Mitchell, 1929; Elliot, 1963; Elliot and Topps, 1963a, b; Elliot and Topps, 1964; Preston et al., 1965; Preston, 1972).

Third, more protein should be removed if the effect of environmental temperature on ADG is greater than that predicted by the function $ADG_{kg} = 1.424 + .1163\ C - .003191\ C^2$ used in this trial. Theoretically, this function minimizes the effect of temperature on performance. Data over a five year period was used to relate mean daily temperature to ADG calculated from monthly weights of steers acclimated to the outside environment. Functions relating performance based on shorter weighing intervals to outside environment, or performance to fluctuating temperatures in an environmental chamber which characterize typical summer days and nights, should improve accuracy.

Since performance is a function of energy transfer, Teter et al. (1973b) have developed a computer model that describes metabolizeable energy intake, energy loss, and energy for gain at different effective temperatures to predict daily gain, and the quantity of dry matter feed necessary to support that gain, and feed efficiency. Energy losses are partitioned into requirements for maintenance of body systems, specific dynamic action, exercise, and heat of warming. Gain is calculated by subtracting the energy losses from metabolizeable energy intake, then dividing by the energy necessary for gain. The dependent variables of the model are gain and DM intake while the independent variables are effective temperature, animal weight, and caloric density of the ration.

There is agreement that energy requirements increase in cold stress. However, there is much confusion in the literature concerning the relationship between energy requirements during heat stress. Studies have shown that maintenance energy requirements are increased during heat (Appleman and Delouche, 1958; Ames et al., 1971; Hussain and Bhattacharya, 1973) which is consistent with decreased performance during heat (Wilsin et al., 1957; Milligan and Winn, 1964; Heitman et al., 1954; Ray et al., 1970; Ames et al., 1973a, b; Waldroup et al., 1976). Yet attempts to develop mathematical models have shown heat loss and energy requirements to continue decreasing as temperature increases in heat stress (Teter et al., 1973a, b; Waldroup et al., 1976). More work is needed to accurately understand animal energetics during thermal stress since assessment of these relationships are essential to adjusting rations to various protein levels to maintain an optimum calorie-to-protein ratio above maintenance.

Another approach to varying protein levels has been developed by Waibel (1976). In his model protein levels are adjusted for differences in intake due to temperature and cost of dietary protein. Intake (energy) is assumed to decrease .4% per 1 F increase in mean temperature. Adjustments are made for deviations in mean temperature from 70 F. Protein is removed from the base ration at temperatures below 70 F and added at temperatures above 70 F. Waibel's system contrasts the approach of this study since he considers only intake and does not include energy requirements in assessing the animals' response to environment.

Mathematical models for computer programming are essential to making practical applications of the principles for modifying rations to environmental conditions. With the use of computerized systems of adjustments, large economic savings can be realized in the commercial cattle feeding industry (Brokken, 1971). Potential savings are particularly apparent in growing rations. Not only do growing cattle have higher protein requirements, but larger quantities of low protein roughages are used. Thus, greater quantities of supplemental protein are necessary to obtain maximum performance during TNZ, which allows for greater protein replacement during thermal stress.

TABLE 1. RATION COMPOSITION

Ingredient	%
Sorghum silage (4-04-383)	8.23
Sorghum milo (4-04-444)	84.23
Soybean meal (5-04-604)	3.68
Mineral supplement	3.86
Proximate analysis	
Dry matter	82.76
Protein	12.22
Ether extract	3.21
Crude fiber	4.05
Ash	4.47
Nitrogen free extract	76.05

TABLE 2. EFFECT OF PROTEIN TREATMENT ON SOYBEAN MEAL REMOVED, AVERAGE DAILY GAIN, AND PROTEIN EFFICIENCY RATIO

Treatment	SBM removed (kg/hd/day)	ADG (kg)	PER[a] (g gain/g protein)
Variable protein	.13	1.14	.86
Control protein	.00	1.11	.79
Difference	.13**	.03	.07

** $P<.01$

[a] means adjusted for constant DM intake

SUMMARY

The effect of reducing supplemental protein levels during heat stress on average daily gain and protein efficiency ratio was studied in finishing steers and heifers. There were no differences ($P>.05$) in average daily gain or protein efficiency ratio. A mean .13 kg/hd/day supplemental protein was removed in the variable protein treatment. Ration modifications for environment by use of computer models is discussed.

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APPENDIX

APPENDIX TABLE 1. ANALYSIS OF VARIANCE FOR AVERAGE DAILY GAIN ON INDIVIDUAL WEIGHT BASIS

Source	D.F.	Mean Square	Prob.
Sex	1	1.18243408	.0000
Sprinkle	1	1.41385937	.0000
Protein	1	.03894406	.3712
Initial Weight	1	.14321983	.0870
Residual	209	.04844516	

APPENDIX TABLE 2. ANALYSIS OF VARIANCE FOR GAIN ON WEEKLY PEN BASIS

Source	D.F.	Mean Square	Prob.
Sex	1	27803.8984	.4439
Sprinkle	1	172774.6875	.0589
Protein	1	45740.3945	.3268
Pen Weight	1	66198.8125	.2387
Dry Matter Intake	1	665101.2500	.0003
Residual	74	46932.0391	

APPENDIX TABLE 3. ANALYSIS OF VARIANCE FOR TOTAL EFFICIENCY, SOYBEAN MEAL REMOVED AND PROTEIN EFFICIENCY RATIO ON WEEKLY PEN BASIS

		Gain/feed		Soybean meal removed		Protein efficiency ratio	
Source	D.F.	Mean Square	Prob	Mean Square	Prob	Mean Square	Prob
Sex	1	.00070706	.5716	.00287073	.0608	.17196351	.0000
Sprinkle	1	.00249509	.2891	.00001488	.8913	.02458276	.0275
Protein	1	.00001348	.9377	.22830814	.0000	.00130387	.6062
Pen weight	1	.00105421	.4899	.00222220	.0981	.14725286	.0000
Residual	75	.00218958		.00079212		.00486382	

PROTEIN ADJUSTMENTS IN HEAT STRESSED FINISHING CATTLE

by

Clifton L. Willms

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ABSTRACT

During the summer 1976, two-hundred-fourteen (104 control, 110 variable protein) crossbred finishing steers and heifers, averaging 354 kg initially, were fed ad libitum for 82 days to measure the effect of varying protein levels in proportion to the level of heat stress on average daily gain (ADG) and protein efficiency ratio (PER). Magnitude of heat stress (defined as degrees effective temperature above animal's critical temperature) was used to calculate the expected percent decline in gain using the formula $ADG_{kg} = 1.424 + .1163\ C - .003191\ C^2$ where C is temperature in degrees centigrade. Critical temperature was assumed to be 15 C and temperature at time of feeding was used in calculations. Digestible protein for production was varied by replacing soybean meal (SBM) with milo isocalorically. No attempt was made to lower protein after all SBM was removed. Proximate analysis of the high concentrate control ration was 82.76% DM, 3.21% EE, 4.05% CF, 12.22% CP, 4.47% ash, 76.05% NFE. ADG for control and variable protein treatments were 1.11 and 1.14 kg, respectively. An average .13 kg less SBM and .77 kg more dry matter (DM) was consumed by variable protein cattle. There was no difference ($P>.05$) in PER, although variable protein treatment tended to be higher when DM intake was held constant.