AN ABSTRACT OF THE THESIS OF

Ariel Santos for the degree of Master of Science

in Animal Science presented on August 1, 1978

Title: THE EFFECT OF DIFFERENT LEVELS AND SOURCES OF CRUDE PROTEIN ON THE VOLUNTARY INTAKE OF LOW QUALITY ROUGHAGES

Abstract approved: Redacted for Privacy

Dr. D. C. Church

A study was made of the voluntary intake of low quality roughages when given different amounts of supplementary crude protein (0, 1, 2, 3, and 4 g CP/kgW$^{.75}$/day). Three trials were conducted. Grass hay (basal diet) and cottonseed meal (protein supplement) for the first trial, wheat straw (basal diet) and soybean meal (protein supplement) for the second, and wheat straw (basal diet) and a liquid protein supplement for the third. The nitrogen in the liquid supplement was of non-protein (NPN), allowing to compare NPN to the nitrogen content of the soybean meal.

Voluntary intake of low protein roughages was increased by the addition of 1 g CP/kgW$^{.75}$/day except when the crude protein was in the form of non-protein nitrogen. Feeding additional crude protein did not have any effect on roughage consumption ($P > .05$). A series of variables used in multiple regression analyses were found to explain most of the variation in intake. Nonetheless, interrelationships of feeds and dietary composition were very complex.

Increased allowances of dietary protein generally corresponded with higher intakes of total feed and digestible energy. For trials I and II, the results indicate that the voluntary intake of digestible energy by cattle would be adequate to meet their maintenance energy needs if they are offered diets similar to those used in this study, which furnish minimal protein needs for maintenance. When non-protein nitrogen was used, the intake of digestible energy was not enough to meet the animals' energy maintenance requirements even at the highest level of supplementation (4 g CP/kgW$^{.75}$/day).

The apparent digestibility of CP was negative when wheat straw was offered ad libitum without nitrogen supplementation. The addition of 1 g/kgW$^{.75}$/day changed the digestibility drastically and continued to increase until it plateaued at 3 g CP/kgW$^{.75}$/day. When grass hay was offered ad libitum (trial I), the apparent crude protein digestion coefficients increased significantly ($P<.05$) at 1 g CP/kgW$^{.75}$/day, but at 2 g CP/kgW$^{.75}$/day digestibility declined to the original value.

Dry matter and acid detergent fiber digestion coefficients responded to nitrogen supplementation throughout the experiment regardless of nitrogen source. Digestibility of both components improved significantly ($P<.05$) when 1 g CP/kgW$^{.75}$/day was supplied and declined thereafter.

The results indicate that nitrogen content of low quality roughages, a characteristic which is easily determined in the laboratory, may be a useful index for predicting voluntary intake, and that the voluntary intake of digestible energy would be adequate to meet their maintenance energy needs if they are offered diets which furnish minimal protein needs for maintenance.

The Effect of Different Levels and Sources of Crude Protein on the Voluntary Intake of Low Quality Roughages

by

Ariel Santos

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed August 1, 1978

Commencement June 1979

APPROVED:

Redacted for Privacy

Professor of Animal Science in charge of major

Redacted for Privacy

Head of Department of Animal Science

Redacted for Privacy

Dean of Graduate School

Date thesis is presented August 1, 1978

Typed by Alanna K. Johnson for Ariel Santos

ACKNOWLEDGEMENTS

The author wishes to thank Dr. D. C. Church, my major professor for his assistance, advice and friendship throughout my graduate study. Also, thanks are extended to Dr. J. E. Oldfield and Dr. G. H. Arscott for serving as members of the graduate committee and Dr. R. C. Youmans for serving as a graduate council representative.

Special gratitude to CONACYT for their financial support throughout my graduate study.

A very special thank you to my wife, Laura, deep gratitude and appreciation are expressed for her patience and encouragement during the course of my studies. To my fellow graduate students who, in one way or another, contributed to this research project.

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INTRODUCTION

In the past 20 years production of cereal crops has increased tremendously around the world. Between 1950 and 1970 production of wheat in Mexico, to cite one example, increased from 300,000 tons per year to 2.6 million tons (Wellhausen, 1976). While the grain is used mainly for human consumption, the remainder of the plant is often wasted because of its low nutritional value as an animal feed.

Low quality roughages, especially the crop residues like cereal straws, provide an important source of energy in ruminant rations in overpopulated developing countries where production of food crops has priority over that of feedstuffs. In countries with solvency in food and feed crops, on the other hand, these cereal residues may pose a disposal problem. In many areas a solution has been to burn the straw in the fields, causing great palls of smoke for several weeks each year. Grass seed producers of the Willamette Valley in Oregon and rice growers in California's Central Valley are finding that enforcement of air pollution laws make it imperative to change current disposal practices. In most cases, straw is not plowed under because it increases requirements for nitrogen fertilization and makes cultivation more expensive, and it cannot be ploughed into perennial crops. Therefore it must be removed from the field.

Roughly three-fourths of straw is cellulose plus hemicellulose; together they should make up an excellent energy source for ruminants. The inability of ruminants to avail themselves of the energy from these carbohydrate sources is explained by one or more of the following factors: lignin acts as an inert barrier between the carbohydrate and the digesting enzyme (Tomlin et al., 1965); the cellulose is too highly crystalline to be quickly available to enzyme action (Cowling and Brown, 1969); or silica inhibits carbohydrate digestibility (Van Soest and Jones, 1968).

Considering the increasing demand for feed in today's world, a reexamination of this poor quality roughage for maximum exploitation of its energy for practical livestock production is inevitable.

A number of factors may be involved in causing a relatively low straw intake. It is highly probable that the nitrogen content of the straw is the first factor limiting rate of fermentation in the rumen and also the rate of passage through the digestive tract. The data derived in this study support this hypothesis and, the author hopes, will contribute to a better understanding of the relationships between the nitrogen content of the feed, its voluntary intake and its utilization.

LITERATURE REVIEW

In many areas of the world, where animal production is based mainly on the grazing ruminant, poor quality roughage is the only fodder normally available for a considerable period of the year. The productivity of animals grazing on these inferior materials is frequently further depressed by low ad libitum intakes (Egan and Moir, 1965).

Restrictions on feed intake, whether they arise inherently from chemical and physical characteristics of the feed or the anatomy and physiology of the ruminant, represent the most obvious practical limitation on any kind of animal production (Conrad et al., 1964).

Low quality roughages are fibrous, unpalatable and often deficient in nitrogen, phosphorus, vitamin A and possibly trace minerals. There are plausible reasons, therefore, for poor animal performance on these diets, but nitrogen deficiency, which may in turn cause a low voluntary intake of digestible energy, has been suggested as the most limiting factor (Lyons et al, 1970).

Evidence has been presented relating the low voluntary intake of poor quality roughages to a slow rate of digestion and rate of disappearance of digesta from the digestive tract (Campling et al., 1962; Balch and Campling, 1962). Egan (1965b) has also shown that the animal's protein status may be important in determining its voluntary intake of roughages low in nitrogen. Increases in the voluntary intake of poor quality roughages, which have been observed to occur when nitrogen-containing materials were given, have accordingly been attributed to an effect of the nitrogen on the cellulolytic microflora of the rumen with a resultant increase in the rate and extent of roughage digestion and rate of passage of feed residues along the gut, or to a direct effect on nitrogen status (Campling et al., 1962; Campling and Murdoch, 1966).

Rumen capacity, rate of passage and dry matter digestibility, together, regulate intake of rations of low digestibility, whereas production requirements, digestibility and unknown factors which affect appetite become the controlling influences on intake of rations of higher digestibility (Oh et al., 1969).

The provision of supplementary protein has been shown to improve the utilization of low quality roughage in many experiments such as those of Smith (1962) and Ammerman et al. (1972). These authors used roughages of 3.6 and 4.6% crude protein (CP), respectively. Casein (4.5 g nitrogen per day) infused per duodenum resulted in a 42% increase in intake of a chaffed oaten hay (3.5% CP) diet. Mean retention time of food in the alimentary tract was not altered, but the digestibility of the dry matter and the rate of cotton thread digestion in the rumen were depressed. Urea (4.5 g nitrogen per day) given per duodenum gave a 12% increase in intake, associated with a greater rate of cotton thread digestion in the rumen and a consistently shorter mean retention time of residues in the alimentary tract (Minson and Pigden, 1961; Egan, 1965a).

Raleigh and Wallace (1963) as well as Horton and Holmes (1976) found no evidence of an increase in intake with meadow hay (5.5% CP) and barley straw (4.1% CP), respectively, when the crude protein content of the diet was increased by low levels of supplement. This is contrary to the results of Moir and Harris (1962), Blaxter and Wilson (1963), Campling and Murdoch (1966) and Andrews et al. (1972). In Horton's work (1976) cellulose digestion was maximal with a diet containing 8.7% crude protein but straw intake was lower than on straw alone.

Supplementation with urea and other cheap sources of non-protein nitrogen (NPN) has been used to offset the nitrogen deficiency of low quality roughages. The extra nitrogen balances the energy eaten for the purpose of stimulating rumen bacterial growth (Falen et al., 1968). Adding sulfur to NPN rations to give a recommended nitrogen-to-sulfur ratio of 10:1 further stimulates microbial growth (Bray and Hemsley, 1969), resulting in an additional response in intake and nitrogen retention (Coombe et al., 1971; Kennedy and Siebert, 1972).

With these very low quality roughages, maximum intake appears to be obtained when small amounts of supplement containing a starch type carbohydrate (as opposed to cellulose) are fed in addition to supplemental nitrogen (Crabtree and Williams, 1971; Fishwick et al., 1973), irrespective of whether the supplemental nitrogen is in the form of NPN or protein.

Urea has been used as a nitrogen source because of the ability of ruminants to utilize non-protein sources of nitrogen as protein replacements. Despite considerable response under pen (Peirce, 1951) and small paddock conditions (Winks and Laing, 1972), urea feeding has not always produced anticipated results under extensive grazing management (Peirce et al., 1955). The different frequency with which urea is taken by the animal in each situation could be an important factor affecting the response (Tudor and Morris, 1971; Romero et al., 1976).

The most consistent effect of urea is the stimulation it produces with regard to the voluntary consumption of hay. Large increases in this type of diet have been observed when urea has been used to correct nitrogen deficiency in sheep (Coombe and Tribe, 1963) and cattle (Campling *et al.*, 1962) rations. Additions of urea frequently but not invariably increase digestibility of dry matter and organic matter (Bhattacharya and Pervez, 1973; Barry and Johnstone, 1976). Therefore, with low-protein diets improved intake is not necessarily accompanied by increased digestibility (Elliott and Topps, 1963). However, Markley *et al.* (1959) found that addition of urea increased crude fiber digestibility when the feeding of roughages was restricted to 80% of *ad libitum* consumption.

In some cases additions of readily available energy (as molasses, starch, or cereal grains) were necessary before urea had any effect upon roughage intake (Coombe, 1959; White *et al.*, 1973). Coombe and Tribe (1963) found that urea added to straw and molasses at the level of 3% of the amount of straw, increased *ad libitum* feed intake, rate of cellulose digestion (cotton thread) in the rumen, and rate of passage of food through the gut. When different amounts of urea were fed, the highest levels of intake, rate of cellulose digestion, and rate of passage occurred with 6-16 g urea per sheep per day.

EXPERIMENTAL PROCEDURE

Three experimental trials were conducted in the beef cattle research facilities at Oregon State University. The effects of feeding different quantities of crude protein on voluntary intake of roughage were studied in each of three trials. Protein supplement portions were fed in fixed amounts, according to the metabolic weight ($W^{.75}$) of the animals, and these amounts provided different levels of crude protein (nitrogen) as shown in table I.

TABLE I. DISTRIBUTION OF TREATMENTS

Trial	Nitrogen level[1]	Basal diet	Nitrogen source
First	0	grass hay	----
	1	grass hay	cottonseed meal
	2	grass hay	cottonseed meal
Second	0	wheat straw	----
	1	wheat straw	soybean meal
	2	wheat straw	soybean meal
	3	wheat straw	soybean meal
	4	wheat straw	soybean meal
Third	0	wheat straw	----
	1	wheat straw	liquid supplement[2]
	2	wheat straw	liquid supplement
	3	wheat straw	liquid supplement
	4	wheat straw	liquid supplement

[1] g/kg$W^{.75}$/day from protein supplement.
[2] Ammonium polyphosphate 6.7%; urea 16.5%; cane molasses 76.6%; trace minerals 0.2% and 66000 units of vitamin A per kg.

Common Procedure for all Trials

The animals were fed individually until uniform intake was reached in each treatment (approximately two weeks), with water and mineral salt provided *ad libitum*. Protein supplements were given once each day at 4 p.m.; these were eaten readily and no refusal occurred. The basal ration was offered to the animals in quantities which were approximately 30% above anticipated intake for any day. These daily allowances were found necessary to ensure that roughage was available at all times. Roughage which was refused was removed and weighed back daily.

Apparent digestibility of feed components was calculated by the indicator method using lignin as the indicator (Schneider and Flatt, 1975). Fecal samples from each animal were collected for three consecutive days at the end of each treatment. They were dried and pooled together. Feed samples as well as fecal samples were analysed for crude protein (CP), dry matter (DM), acid detergent fiber (ADF), lignin and for their gross energy content. Dry matter was determined by heating a sample to constant weight at 105 C, and crude protein by a macro-Kjeldahl method (A.O.A.C., 1960)(Table II). Lignin and ADF were determined by the Van Soest (1963) method, and an oxygen bomb calorimeter (Parr, 1300 plain calorimeter) was used to estimate the gross energy content.

The animals were weighed before the start of each treatment. The metabolic body weight of each animal was used to calculate individual protein allowances. This scale of feeding was then adhered to for the ensuing two weeks irrespective of body weight changes.

A completely randomized design was used for the analysis of variance of the results, and multiple regression analyses were conducted to show dependency of voluntary intake upon diet protein (Steel and Torrie, 1960).

First Trial

Five Holstein heifers averaging 231 kg were used. Grass hay (7.16% CP) was offered to all animals *ad libitum* as a basal ration. Cottonseed meal (47.31% CP) was fed in fixed amounts according to metabolic body weight and these amounts provided the heifers with three levels of CP (0, 1, 2 g/kgW$^{.75}$/day).

Second Trial

Four Herefords and one Holstein heifers were used. Wheat straw (3.8% CP) and soybean meal (51.94% CP) were offered as a basal ration and protein source, respectively.

As in trial 1 wheat straw was fed *ad libitum* and protein supplements were given according to metabolic body weight, but this time five treatments were used. No soybean meal was offered during the first treatment, an equivalent of 1 g CP/kgW$^{.75}$/day during the second and so on up to 4 g CP/kgW$^{.75}$/day.

Third Trial

The same animals from trial 2 were utilized. Wheat straw (2.59% CP) was fed *ad libitum*, but instead of soybean meal, a liquid protein supplement (30% CP as fed) was used. As in trial 2, this consisted of five treatments; liquid protein supplement was given in amounts that varied from 0 to 4 g CP/kgW$^{.75}$/day.

TABLE II. DIET COMPOSITION

Trial no.	Feeds	Composition, %			
		DM	CP[1]	ADF[1]	Lignin[1]
First	grass hay	90.48	7.16	35.15	4.04
	cottonseed meal	91.70	47.31	19.44	7.04
Second	wheat straw	91.07	3.80	48.99	7.85
	soybean meal	90.30	51.94	9.34	1.28
Third	wheat straw	92.63	2.59	53.06	8.90
	liquid supplement	62.26	48.19	---	---

[1]% of dry matter.

RESULTS

The primary object of this study was to assess the effect of CP on dry matter and digestible energy intake. Since these factors are known to vary according to metabolic body size, all results of feed and nutrient intake have been expressed in grams or Kcal intake per $kgW^{.75}$ per day where W is the body weight of the animal.

First Trial

Intake of Grass Hay

The addition of CP supplements did not show a significant (P>.05) effect on grass intake (table III). Grass intake data of animals when given the CP supplements were subjected to regression analysis to ascertain the response of grass intake to changes in the independent varieties of CP, dry matter digestion coefficient (DM-DC) and ADF digestion coefficient (ADF-DC). The actual amounts of CP eaten by the heifers, rather than the treatment levels were used in these analyses. Various regression models were tested, but the following form was found to be most appropriate:

$$Y = a + b_1CP + b_2DC + b_3CP^2 + b_4DC^2 + b_5CP \times DC$$

where Y is the intake of hay and CP is the intake of crude protein, both in $g/kgW^{.75}/day$. DC is the digestion coefficient for dry matter or ADF, expressed in percentage. The second order terms (CP^2 for protein and DC^2 for digestion coefficient) were only included if they showed statistical significance ($P<.05$). Equations which describe the relationship are:

1. $Y = -44.69 - 6.28\ CP + 4.78\ DM\text{-}DC - 0.92\ CP^2 - 0.076\ DM\text{-}DC^2 + 0.51\ CP \times DM\text{-}DC$

2. $Y = 32.72 + 7.81\ CP + 0.4\ ADF\text{-}DC - 0.91\ CP^2 - 0.037\ ADF\text{-}DC^2 + 0.35\ CP \times ADF\text{-}DC$

Total variance accounted for by each regression was 92.66% and 94.09%, respectively. Crude protein intake explained 62.44% of the variation in grass intake, as is shown in equation 3. The second order term (CP^2) was not significant ($P>.05$); this was probably because treatment levels were not increased sufficiently to show a significant decrease in grass hay consumption

3. $Y = 49.42 + 6.11\ CP$

Where Y is grass hay intake and CP is crude protein intake with both expressed in $g/kgW^{.75}/day$.

Intake of Total feed

Mean intakes of feed (grass plus protein concentrate) are given in table III. Highest intakes occurred when 1 g $CP/kgW^{.75}/day$ was added to the grass hay. Feed intake was much less at the lowest level of CP supplementation, which suggests that deficiency of protein may have impaired intake.

TABLE III. EFFECTS OF PROTEIN INTAKE ON THE VOLUNTARY INTAKE OF DRY MATTER AND DIGESTIBLE ENERGY FOR TRIAL I

Item	Nitrogen level 0	Nitrogen level 1	Nitrogen level 2	SEM[3]
CP intake[1]	6.58[a]	8.56[b]	9.07[b]	0.28
% increment	---	30	6	
Grass intake[1]	91.93[a]	104.77[a]	99.62[a]	3.86
% increment	---	14	-5	
Total intake[1]	91.93[a]	107.03[b]	103.72[ab]	3.83
% increment	---	16	-3	
Digestible energy intake[2]	246.44[a]	342.62[b]	239.87[a]	10.83
% increment	---	39	-30	

[1] g/kgW$^{.75}$/day.
[2] Kcal/kgW$^{.75}$/day.
[3] Standard error of a treatment mean calculated from error mean square. Means in the same row bearing different superscripts are different (P<.05).

Intake of Digestible Energy

Gradually increasing the amounts of protein supplementation to the heifers affected them favorably. Higher digestible energy consumption occurred when 1 g CP/kg$W^{.75}$/day was offered; thereafter the intake of digestible energy declined, which suggests that the cottonseed meal supplied to the animals did not provide enough energy to compensate for the reduction in the intake of grass hay.

Regression analyses, similar to those used to obtain relationships of hay intake to changes in protein, were also carried out on digestible energy intake. Equations which describe these changes are:

4. $Y = 2.47 - 29.99\ CP + 6.20\ DM\text{-}DC - 1.54\ CP^2 - 0.11\ DM\text{-}DC^2 + 1.35\ CP \times DM\text{-}DC$

5. $Y = 117.34 + 5.31\ CP - 0.95\ ADF\text{-}DC - 1.12\ CP^2 - 0.03\ ADF\text{-}DC^2 + 0.86\ CP \times ADF\text{-}DC$

Total variance accounted for by each regression was 98.52% and 98.92%, respectively. Dry matter and ADF digestibilities were significantly correlated with digestible energy intake ($P<.01$), accounting for 74.20% and 69.41% of its variance, while CP intake explained only 15.20% and did not show significance.

Table IV indicates the mean changes in dry matter, ADF, CP and energy digestion coefficients due to the addition of protein to the grass hay ration, and table V shows correlation coefficients for those parameters involved in trial I.

Dry Matter, Acid Detergent Fiber and Energy Digestibilities

The analysis of variance showed a significant response in digestibilities due to the addition of supplemental nitrogen ($P<.05$). Dry matter, acid detergent fiber and energy digestion coefficients increased ($P<.01$) at the 1 g CP/kgW$^{.75}$/day level, and their mean increments were 21%, 36% and 19%, respectively. The use of 2 g CP/kgW$^{.75}$/day caused the digestion coefficients to drop significantly ($P<.01$), their mean increments were -30%, -52% and -28% for DM, ADF and energy, respectively (table IV).

TABLE IV. EFFECTS OF DIFFERENT LEVELS OF CRUDE PROTEIN INTAKE ON THE APPARENT DIGESTION COEFFICIENT OF DRY MATTER (DM-DC), CRUDE PROTEIN (CP-DC), ACID DETERGENT FIBER (ADF-DC) AND ENERGY ON TRIAL I

Item	Nitrogen level			SEM^2
	0	1	2	
CP intake[1]	6.58^a	8.56^b	9.07^b	0.28
% increment	---	30	6	
DM-DC (%)	57.03^a	69.06^b	48.05^c	1.12
% increment	---	21	-30	
CP-DC (%)	38.65^a	56.54^b	35.21^a	1.88
% increment	---	46	-38	
ADF-DC (%)	43.27^a	58.00^b	28.10^c	1.56
% increment	---	34	-52	
Energy-DC (%)	58.49^a	69.57^b	50.08^c	1.09
% increment	---	19	-28	

[1] $g/kgW^{.75}/day$.

[2] Standard error of a treatment mean calculated from error mean square. Means in the same row bearing different superscripts are different ($P<.05$).

TABLE V. CORRELATION COEFFICIENTS FOR THE FIRST TRIAL

	Total intake	DE intake	CP intake	DM-DC (%)	CP-DC (%)	ADF-DC (%)	Energy DC (%)	Diet[3] DE
Grass intake[1]	.998**	.707**	.789**	.271	.369	.242	.223	.226
Total intake[1]	---	.656**	.876**	.191	.327	.150	.146	.150
DE intake[2]	---	---	.390	.861**	.845**	.833**	.840**	.842**
CP intake[1]	---	---	---	-.089	.145	-.159	-.118	-.113
DM-DC (%)	---	---	---	---	.864**	.994**	.995**	.995**
CP-DC (%)	---	---	---	---	---	.831**	.859**	.861**
ADF-DC (%)	---	---	---	---	---	---	.989**	.989**
Energy-DC (%)	---	---	---	---	---	---	---	.999**

[1] $g/kgW^{.75}/day$.
[2] $Kcal/kgW^{.75}/day$.
[3] Kcal/g.
**Coefficient is significant at P<.01.

Second Trial

Grass consumption in the first trial was not affected by protein supplementation, probably because the CP content of the hay was sufficiently high to avoid deleterious effects on feed intake. For the second trial therefore, a lower protein roughage was choosen. Wheat straw and soybean meal provided the basal ration and protein supplement, respectively.

Wheat Straw Intake

Table VI shows the relationship between CP intakes and consumption of wheat straw, total dry matter, and digestible energy. Straw intake was significantly increased ($P<.05$) by the addition of soybean meal, and peak consumption was attained when 1 g CP/kgW$^{.75}$/day were used to complement the straw.

As in trial I, actual amounts of CP eaten by the animal and not treatment levels were used to compute the changes in dry matter intake due to different levels of CP consumption. Crude protein intake accounted for 64.22% of the variation of straw intake (equation 6). The second-order term did not contribute significantly to the equation ($P>.05$), neither for ADF nor dry matter digestion coefficient, as was the case in trial I. Correlations between intake and the other parameters are shown in table VII.

6. $Y = 47.44 + 3.98\ CP$ $\qquad R^2 = .6422$

where Y is wheat straw intake and CP is crude protein intake, both expressed in grams/kgW$^{.75}$/day.

Total Dry Matter and Digestible Energy Intakes

Total dry matter intake behaved similarly to straw intake, but highest consumption was obtained when soybean meal was supplemented at a level of 2 g CP/kgW$^{.75}$/day (table VI). Total intake was not affected when larger amounts of supplement were given ($P>.05$).

Digestible energy intake increased steadily with the addition of the protein supplements. The last three treatments did not show a significant different ($P>.05$); however, they still showed a slight improvement. Apart from CP, intake of digestible energy was also correlated with some other parameters (table VII), but CP intake explained most of the variation (70.90%) in the intake of digestible energy. Equations which describe these changes are:

7. $Y = 100.77 + 13.56\ CP$ $\qquad R^2 = .7090$

$Y = -11.99 + 13.29\ CP + 2.26\ DM\text{-}DC$ $\qquad R^2 = .7994$

$Y = -36.71 + 16.88\ CP + 2.73\ ADF\text{-}DC$ $\qquad R^2 = .7949$

where Y is intake in Kcal DE/kgW$^{.75}$/day and CP is crude protein intake in g/kgW$^{.75}$/day. DM-DC and ADF-DC are digestion coefficients of dry matter and acid detergent fiber, respectively. There was some evidence of curvilinearity in each of these equations, but they did not show any significance (P>.05). Correlation coefficients are shown in table VII.

Apparent Crude Protein Digestion Coefficient

Increasing the CP of the diet resulted in a highly significant improvement (P<.01) on its digestion coefficients. When wheat straw was not supplemented, the apparent digestion coefficient of the CP was negative (-6.23%), but when 1 g CP/kgW$^{.75}$/day from soybean meal was supplied, the CP digestion coefficient increased to 33.75%. This is a good example of how a negative balance of nitrogen due to a low protein ingestion could be changed drastically if protien is supplemented. Differences due to treatment levels are shown in table VIII.

Apparent crude protein digestibility was subjected to regression analysis to ascertain the response in digestibility to different crude protein intakes. The equation which describes the relationship is:

10. $Y = -69.34 + 38.48\ CP - 2.92\ CP^2$ $\qquad R^2 = .894$

where Y is the apparent crude protein digestion coefficient, and CP is the crude protein intake in g/kgW$^{.75}$/day.

Dry Matter, Acid Detergent Fiber and Energy Digestibilities

As in trial 1, DM, ADF and energy digestibilities responded in the same way to the addition of supplemental nitrogen. All three parameters showed statistical increments ($P<.05$) in their coefficients when 1 g CP/kgW$^{.75}$/day was offered (table VIII). When 2 g CP/kgW$^{.75}$/day were fed, the digestion coefficients for the three parameters decreased ($P<.05$), but further addition of nitrogen did not cause any significant changes.

TABLE VI. EFFECTS OF DIFFERENT LEVELS OF PROTEIN INTAKE ON THE VOLUNTARY INTAKE OF DRY MATTER AND DIGESTIBLE ENERGY FOR TRIAL II

Item	Nitrogen level					SEM[3]
	0	1	2	3	4	
CP intake[1]	2.03[a]	3.45[b]	4.76[c]	5.92[d]	6.89[e]	0.10
% increment	---	70	38	24	16	
Straw intake[1]	53.4[a]	63.1[b]	69.6[b]	72.6[b]	70.4[b]	2.54
% increment	---	18	10	4	-3	
Total intake[1]	53.4[a]	65.1[b]	73.6[c]	78.7[c]	78.5[c]	2.54
% increment	---	22	10	7	-.2	
Digestible energy intake[2]	116.6[a]	167.3[b]	164.1[b]	180.2[b]	188.1[b]	6.39
% increment	---	44	-2	10	4	

[1] $g/kgW^{.75}/day$.
[2] $Kcal/kgW^{.75}/day$.
[3] Standard error of a treatment mean calculated from error mean square. Means in the same row bearing different superscripts are different (P<.05).

TABLE VII. CORRELATION COEFFICIENTS FOR THE SECOND TRIAL

	Total intake	DM intake	CP intake	DM-DC (%)	CP-DC (%)	ADF-DC (%)	Energy DC (%)	Diet[3] DE
Straw intake[1]	.983**	.884**	.801**	-.057	.685**	-.523**	.018	.020
Total intake[1]	---	.910**	.898**	-.024	.778**	-.562**	.042	.053
DE intake[2]	---	---	.842**	.346	.814**	-.245	.449*	.455*
CP intake[1]	---	---	---	.054	.893**	-.576**	.090	.119
DM-DM (%)	---	---	---	---	.325	.730**	.903**	.894**
CP-DC (%)	---	---	---	---	---	-.364	.312	.341
ADF-DC (%)	---	---	---	---	---	---	.629**	.597**
Energy-DC (%)	---	---	---	---	---	---	---	.993**

[1] g/kgW$^{.75}$/day.
[2] Kcal/kgW$^{.75}$/day.
[3] Kcal/g.
$r_{.05}$ = .396
$r_{.01}$ = .505
*Coefficient is significant at P<.05.
**Coefficient is significant at P<.01.

TABLE VIII. EFFECTS OF DIFFERENT LEVELS OF CRUDE PROTEIN INTAKE ON THE APPARENT DIGESTION COEFFICIENTS OF DRY MATTER (DM-DC), CRUDE PROTEIN (CP-DC), ACID DETERGENT FIBER (ADF-DC) AND ENERGY IN TRIAL II

Item	Nitrogen level					SEM[2]
	0	1	2	3	4	
CP intake[1]	2.03^{a}	3.45^{b}	4.76^{c}	5.92^{d}	6.89^{e}	0.10
% increment	---	70	38	24	16	
DM-DC (%)	47.24^{a}	55.84^{b}	49.03^{ac}	48.56^{ac}	51.89^{c}	1.06
% increment	---	18	-12	-1	7	
CP-DC (%)	-6.23^{a}	33.75^{b}	43.72^{c}	55.35^{d}	58.62^{d}	2.70
% increment	---	118	30	27	6	
ADF-DC (%)	46.05^{a}	49.74^{b}	43.45^{ac}	40.83^{c}	43.27^{ac}	1.04
% increment	---	8	-13	-6	6	
Energy-DC (%)	47.20^{a}	55.54^{b}	48.11^{ac}	49.36^{ac}	51.69^{c}	1.21
% increment	---	18	-13	3	5	

[1] $g/kgW^{.75}/day$.
[2] Standard error of a treatment mean calculated from error mean square. Means in the same row bearing different superscripts are different ($P < .05$).

Third Trial

Straw Intake and Digestible Energy Intake

Although there was a slight improvement, addition of liquid supplement did not affect wheat straw consumption statistically ($P>.05$). This non-significant relationship was also seen when regression analysis was tested between wheat straw intake and CP intake. Nitrogen intake explained 23% of the variation in wheat straw consumption, but this relationship was not significant ($P>.05$). Correlations between straw intake, dry matter and ADF digestion coefficients were not significant (table IX).

Neither total intake nor digestible energy intake was affected by treatment levels ($P>.05$). As in the other trials an attempt was made to relate the intake of digestible energy to other variables such as CP intake and/or digestion coefficients of dry matter and ADF. Neither of these regression analyses showed statistical significance ($P>.05$), and therefore they are not included in the results.

Apparent Crude Protein Digestion Coefficient

The apparent crude protein digestibility was negative (-42.42%) when straw was fed alone. It became positive with the addition of 1 g CP/kgW$^{.75}$/day (25.94%).

This increment is highly significant ($P<.01$) as well as the increment obtained when the next treatment level was applied (2 g CP/kgW$^{.75}$/day). Supplementing 3 g CP/kgW$^{.75}$/day also improved the apparent crude protein digestion coefficient but only at the $P = .05$ level; the next treatment level did not show any improvement

Apparent crude protein digestibility was subjected to regression analysis to determine the response in digestibility to different CP intakes. The equation which best describes the relationship is:

11. $Y = -107.88 + 75.40\ CP - 8.70\ CP^2$ $\qquad R^2 = .9006$

where Y is the apparent crude protein digestion coefficient, and CP is the crude protein intake in g/kgW$^{.75}$/day.

Dry Matter, Acid Detergent Fiber and Energy Digestion Coefficients

Digestion coefficients of dry matter and ADF responded in the same way to the addition of supplemental nitrogen. Peak increments were attained when 1 g CP/kgW$^{.75}$/day was supplied. Subsequent treatment levels depressed the digestion coefficients significantly ($P<.05$), returning them to their starting point. Energy digestion coefficients were not affected by treatment levels, (table XI).

TABLE IX. EFFECTS OF DIFFERENT LEVELS OF PROTEIN INTAKE ON THE VOLUNTARY INTAKE OF DRY MATTER AND DIGESTIBLE ENERGY FOR TRIAL III

Item	Nitrogen level					SEM[3]
	0	1	2	3	4	
CP intake[1]	1.12[a]	2.15[b]	3.25[c]	4.31[d]	5.26[e]	0.11
% increment	---	92	51	33	22	
Straw intake[1]	43.32	44.34	48.35	50.82	51.42	4.41
% increment	---	2	9	5	1	
Total intake[1]	43.32	46.40	52.52	57.07	59.61	4.41
% increment	---	7	13	9	4	
Digestible energy intake[2]	71.25	84.88	90.16	100.70	94.49	8.96
% increment	---	19	6	12	-6	

[1] $g/kgW^{.75}/day$.
[2] $Kcal/kgW^{.75}/day$.
[3] Standard error of a treatment mean calculated from error mean square.
Means in the same row bearing different superscripts are different (P<.05).

TABLE X. EFFECTS OF DIFFERENT LEVELS OF CRUDE PROTEIN INTAKE ON THE APPARENT DIGESTION COEFFICIENTS OF DRY MATTER (DM-DC), CRUDE PROTEIN (CP-DC), ACID DETERGENT FIBER (ADF-DC) AND ENERGY IN TRIAL III

Item	Nitrogen level					SEM[2]
	0	1	2	3	4	
CP intake[1]	1.12^{a}	2.15^{b}	3.25^{c}	4.21^{d}	5.26^{e}	0.11
% increment	---	92	51	33	22	
DM-DC (%)	40.56^{a}	45.55^{b}	41.82^{a}	$44.22^{a,b}$	39.33^{a}	1.14
% increment	---	12	-8	6	-11	
CP-DC (%)	-42.43^{a}	25.95^{b}	39.31^{c}	51.23^{d}	51.73^{d}	2.99
% increment	---	264	52	30	1	
ADF-DC (%)	39.99^{a}	44.61^{b}	42.23^{b}	43.16^{b}	38.87^{a}	1.12
% increment	---	12	-5	2	-10	
Energy-DC (%)	38.05	43.37	40.66	42.57	38.23	1.50
% increment	---	14	-6	5	-10	

[1] g/kgW$^{.75}$/day.
[2] Standard error of a treatment mean calculated from error mean square.
Means in the same row bearing different superscripts are different ($P<.05$).

TABLE XI. CORRELATION COEFFICIENTS FOR TRIAL III

	Total Intake	DE intake	CP intake	DM-DC (%)	CP-DC (%)	ADF-DC (%)	Energy DC (%)	Diet[3] DE
Straw intake[1]	.967**	.931**	.481*	.078	.225	-.038	.184	.167
Total intake[1]	---	.931**	.688**	.024	.427*	-.078	.156	.108
DE intake[2]	---	---	.555**	.366	.419*	.254	.494*	.458*
CP intake[1]	---	---	---	.136	.832**	-.160	.019	-.099
DM-DC (%)	---	---	---	---	.188	.952**	.936**	.943**
CP-DC (%)	---	---	---	---	---	.191	.302	.187
ADF-DC (%)	---	---	---	---	---	---	.860**	.863**
Energy-DC (%)	---	---	---	---	---	---	---	.992**

[1]g/kgW$^{.75}$/day.
[2]Kcal/kgW$^{.75}$/day.
[3]Kcal/g.
*Coefficient is significant at P<.05.
**Coefficient is significant at P<.01.

DISCUSSION

Voluntary intake of a low-protein roughage by cattle was affected both by the level of supplementary nitrogen provided to them and by the source of nitrogen. When increasing amounts of nitrogen were fed to the animals, they ate progressively more roughage up to a point where the nitrogen had no effect, beyond which point the consumption declined. These inter-relationships of dietary composition and feed consumption were, however, complex and in some cases could only adequately be expressed by equations of the form:

$$Y = a + b_1CP + b_2CP^2 + b_3DC + b_4DC^2 + b_5\ CP \times DC$$

where Y is the intake of feed, CP is the intake of crude protein both expressed in $g/kgW^{.75}/day$, and DC is the digestion coefficient for dry matter or acid detergent fiber.

That the level of protein in the diet, below approximately 10% CP, affects voluntary intake of feed by ruminants is now well established (Campling _et al._, 1961, 1962; Blaxter and Wilson, 1963; Elliott and Topps, 1963a). Confirmation of this finding was obtained in the present study in the first two trials (tables III, IV). There was some evidence of curvilinear response in the heifers' total intake to successive additions of protein; however, increments of treatment levels were not high enough to show a significant reduction in feed intake ($P>.05$).

For the three trials there was a significant ($P<.05$) linear correlation between intake and nitrogen supplementation, but only a low correlation between intake and dry matter digestibility (tables V, VII, XII). With low-protein feeds therefore, improved intake is not necessarily accompanied by increased digestibility, a conclusion which is consistent with the findings of Elliott and Topps (1963). It is most likely that with protein-deficient feeds, such as those used in trial II and III, the nitrogen content of the digesta is the major factor limiting rate of fermentation in the rumen and also the rate of passage through the digestive tract.

One of the objects of the present study was to investigate whether, when feeding certain fixed amounts of supplementary nitrogen and allowing animals free access to roughage, the energy intake of the cattle was adequate to meet their energy requirements for maintenance. No measurements were made of the animals' energy requirements but Blaxter (1962) suggests that a value of approximately 136 Kcal of digestible energy per $kgW^{.73}$/day be taken as the digestible energy required for maintenance. Data in table III show that even animals which were fed on grass hay with no additional protein ate on the average more than this amount, but when wheat straw was used as a basal roughage, the animals could not meet their energy requirements unless a protein supplement was offered (tables VI and X). In the second trial when soybean meal was supplemented, the level of 1 g CP/kgW$^{.75}$/day was more than enough to overcome this deficiency. When liquid protein supplement was given to complement the wheat straw, not even at 4 g CP/kgW$^{.75}$/day did the animals reach the level of 136 Kcal/kgW$^{.73}$/day. Thus, in trial III the animals were in a constant negative energy balance throughout the experiment. These relationships are better seen in figures I, II, and III.

Elliott and Topps (1963a) concluded that when cattle are fed sufficient protein for maintenance, i.e. as little as 1.3 g of digestible crude protein per kgW$^{.73}$ daily, they will eat enough roughage of low quality value (3.4% CP) to satisfy their energy requirements for maintenance. This is in accord with the first two trials, but contrary to the results of the third one. However, the CP supplement in trial III was of non-protein origin (urea and ammonium phosphate), and in general ruminants have not responded as well to urea nitrogen as to protein nitrogen when their rations contained little or no protein and were possibly low in available energy (Minson and Pigden, 1961; Raleigh and Wallace, 1963; Helmer and Bartley, 1971; Barry and Johnstone, 1976).

Energy is very important in urea utilization. The function of carbohydrates in converting ammonia to microbial protein is to make energy and carbon skeletons available for microbial syntheses. The least effective carbohydrate seems to be cellulose; the most effective is starch. Starch is also superior to molasses or simple sugars (Helmer and Bartley, 1971).

Despite both *in vitro* and *in vivo* metabolism studies indicating that molasses promotes less urea utilization than starch, many investigators have attempted to improve animal performance by adding molasses to urea-containing rations. Bohman *et al*. (1954) conducted growth studies with dairy heifers to determine the utilization of urea with molasses as a carbohydrate supplement to a low quality hay ration. Nitrogen balance data indicate that molasses apparently was not an adequate carbohydrate for the utilization of urea when fed with little or no starch carbohydrate. This probably was the case in trial III where no starch was present in the ration and no effects on straw and digestible energy intake were found ($P>.05$).

Apparent crude protein digestion coefficients were highly correlated ($P<.01$) with CP intake during trial II and III (tables VII and XII). The digestion coefficients were negative in both trials when no protein supplement was offered, but they changed rapidly with the addition of 1 g CP/kg$W^{.75}$/day to the diet. The apparent digestion coefficients rose rapidly at first and then more gradually with increasing amounts of crude protein. Figures IV, V and VI show the response in the crude protein digestion coefficients due to different CP intakes.

Responses in the crude protein apparent digestion coefficients due to treatment levels in trial I, although significant, ($P<.05$) were not highly correlated with crude protein intake. An explanation could be that the treatment levels were not high enough; also the CP of the grass hay was relatively high (7.16%). The apparent digestion coefficients were significantly ($P<.05$) improved with the addition of 1 g CP/kgW$^{.75}$/day, but when the next treatment level was applied, digestibility decreased to its starting point; consequently, linear correlation showed no significance ($P>.05$), as was the case in trials II and III.

These results are in agreement with several other reports (Egan, 1965a; Lyons et al., 1970; Andrews et al., 1972; Devendra, 1975; and Schneider and Flatt, 1975). Schneider and Flatt (1975) reported that protein level increased protein digestion even when the protein added was supplied by urea. Its addition also had a significant effect ($P<.05$) in increasing the digestibility of crude fiber and dry matter.

Increments in dry matter and ADF digestion coefficient were observed in all trials when 1 g CP/kgW$^{.75}$/day was offered (tables IV, VIII and XI). Greater supplements of CP did not increase the digestion coefficients; on the contrary, they decreased to their starting point. Ellet and Holdaway (1917), quoted by Schneider and Flatt (1975), state that in a low protein ration the digestibility of all nutrients is lower than in a ration having a high protein content. In the present study, the nitrogen supplied when 1 g CP/kgW$^{.75}$/day was given to the animals probably increased the viability of the rumen microflora, thus increasing the rate of fermentation which in turn increased the digestion coefficients of the dry matter and ADF. This improved well fare of the rumen microflora caused a higher diet intake, leading to a more rapid rate of passage which in turn lowered the digestion coefficients.

These results show that the voluntary intake of low protein roughage by cattle is closely related to the nitrogen content of the feed. The close relationship found between intake and nitrogen content of low protein feeds in the present study indicates that nitrogen content, which is easily determined in the laboratory, may be a useful index for predicting voluntary intake in the case of low-protein feeds.

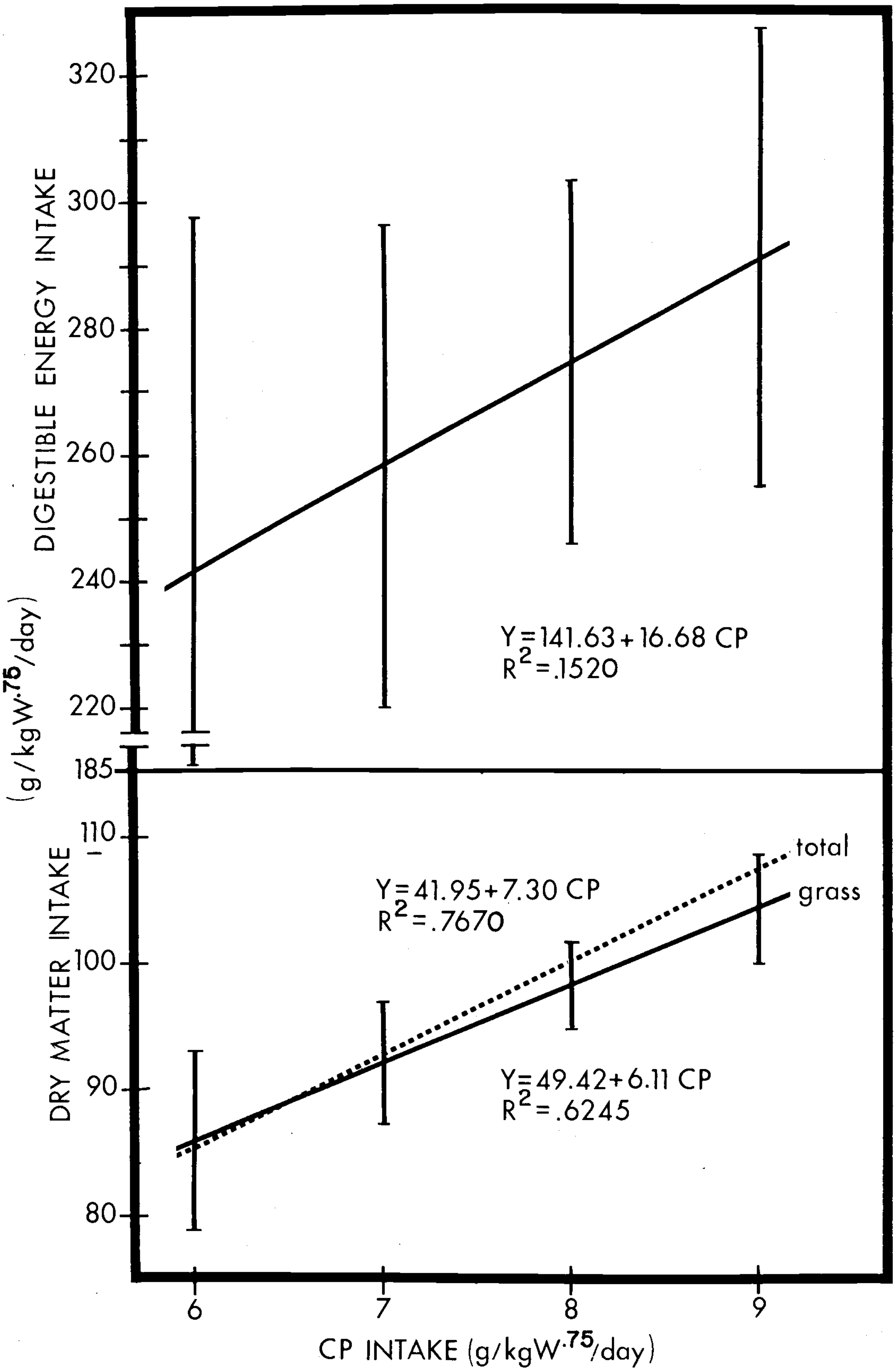

Figure I. Changes in dry matter and digestible energy intakes at different levels of crude protein consumption for Trial I.

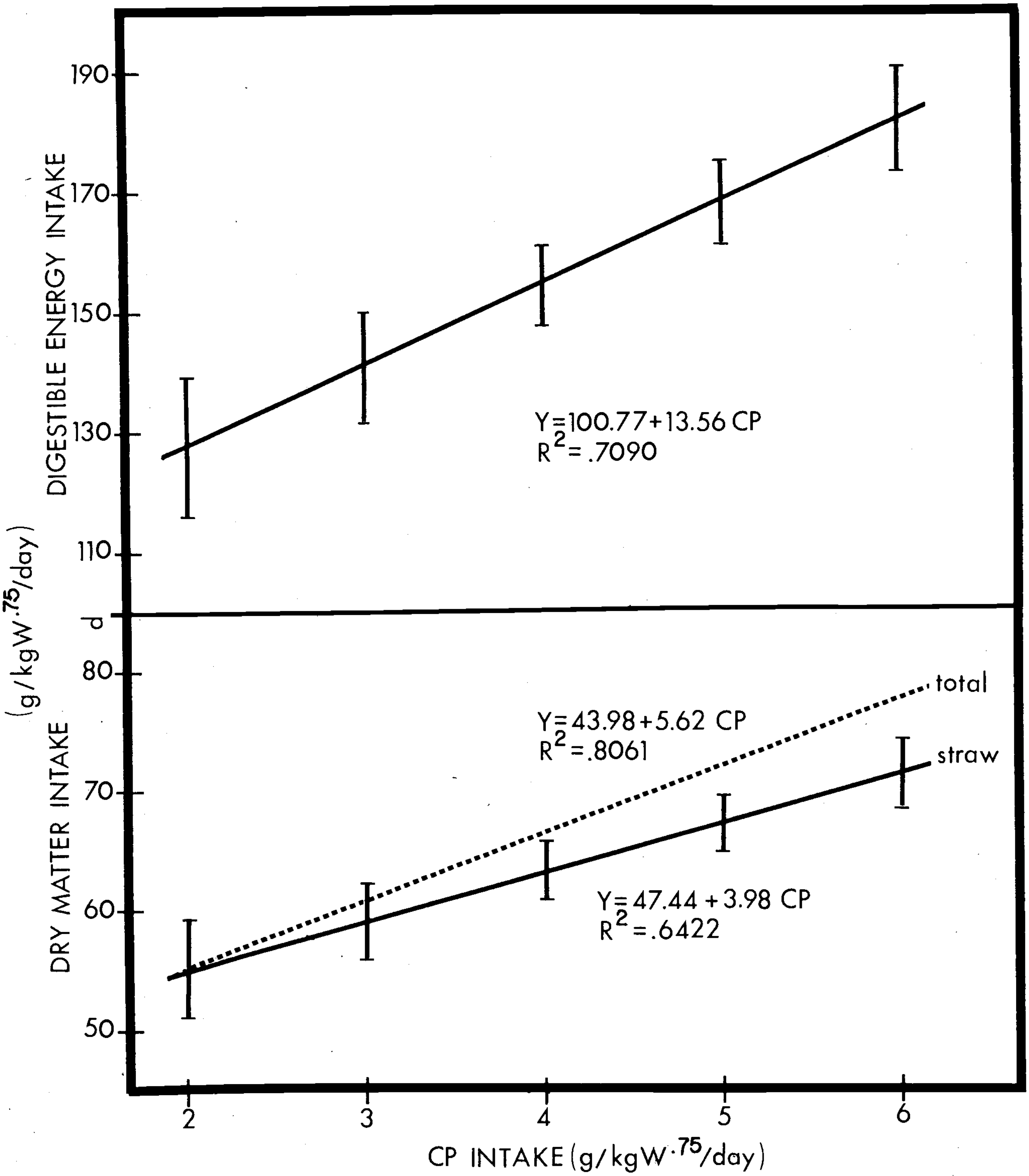

Figure II. Changes in dry matter and digestible energy intakes at different levels of crude protein consumption for Trial II.

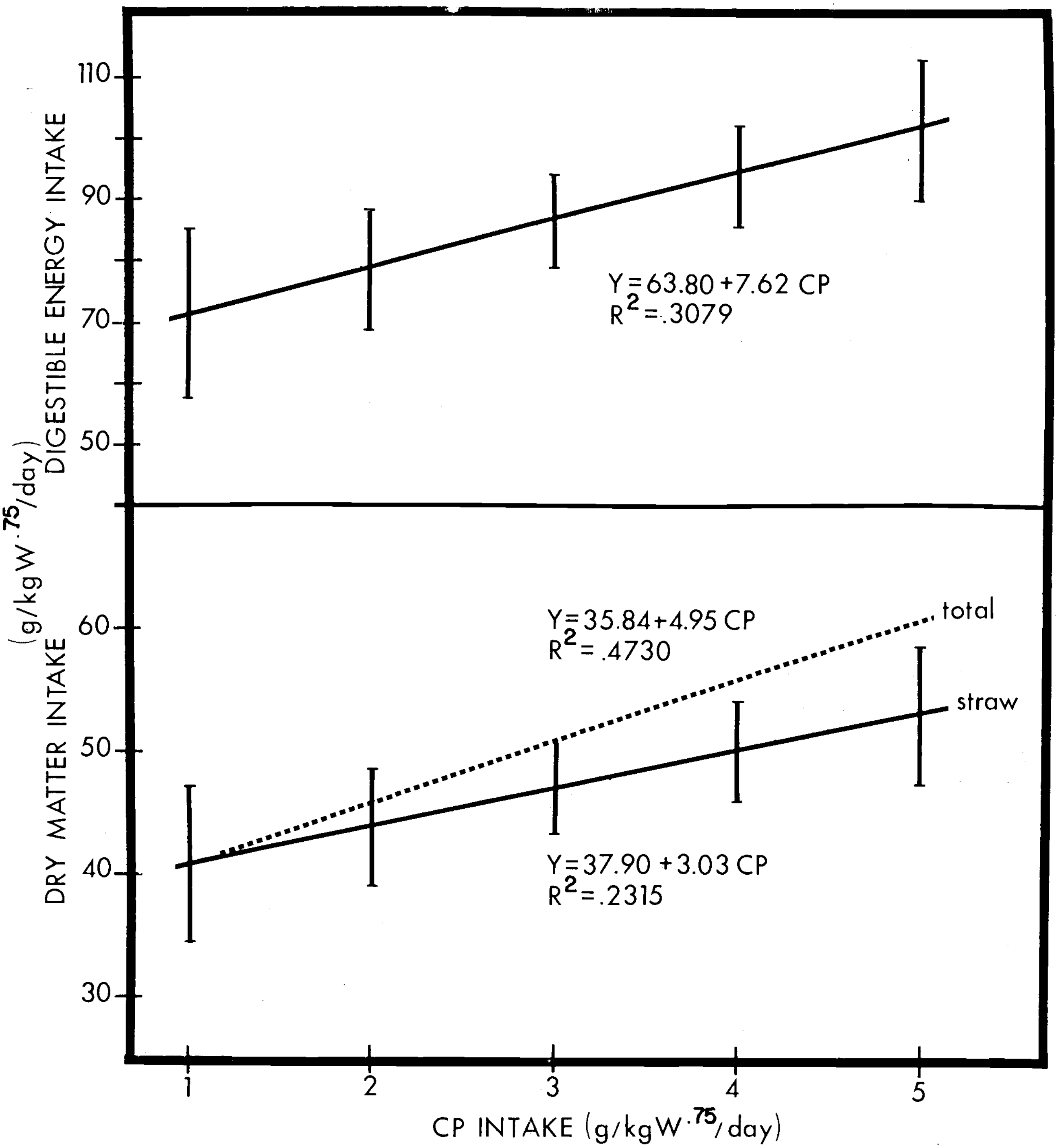

Figure III. Changes in dry matter and digestible energy intake at different levels of crude protein consumption for Trial III.

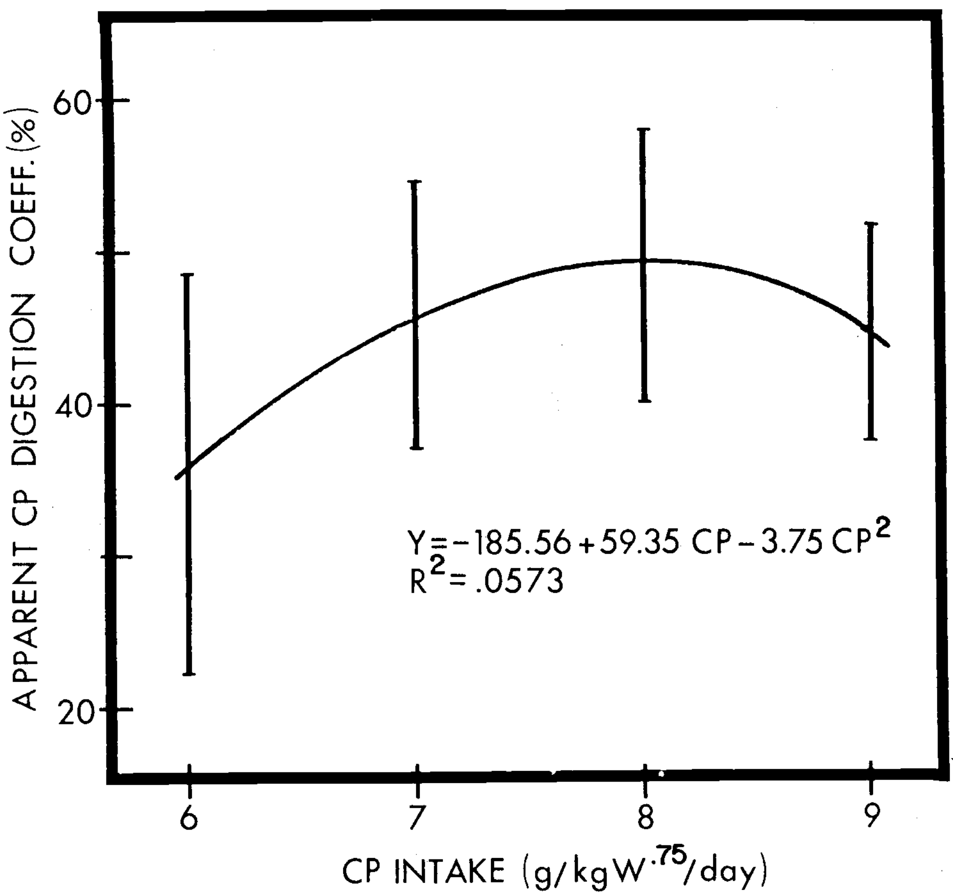

Figure IV. Crude protein intake and apparent crude protein digestibility relationship for Trial I.

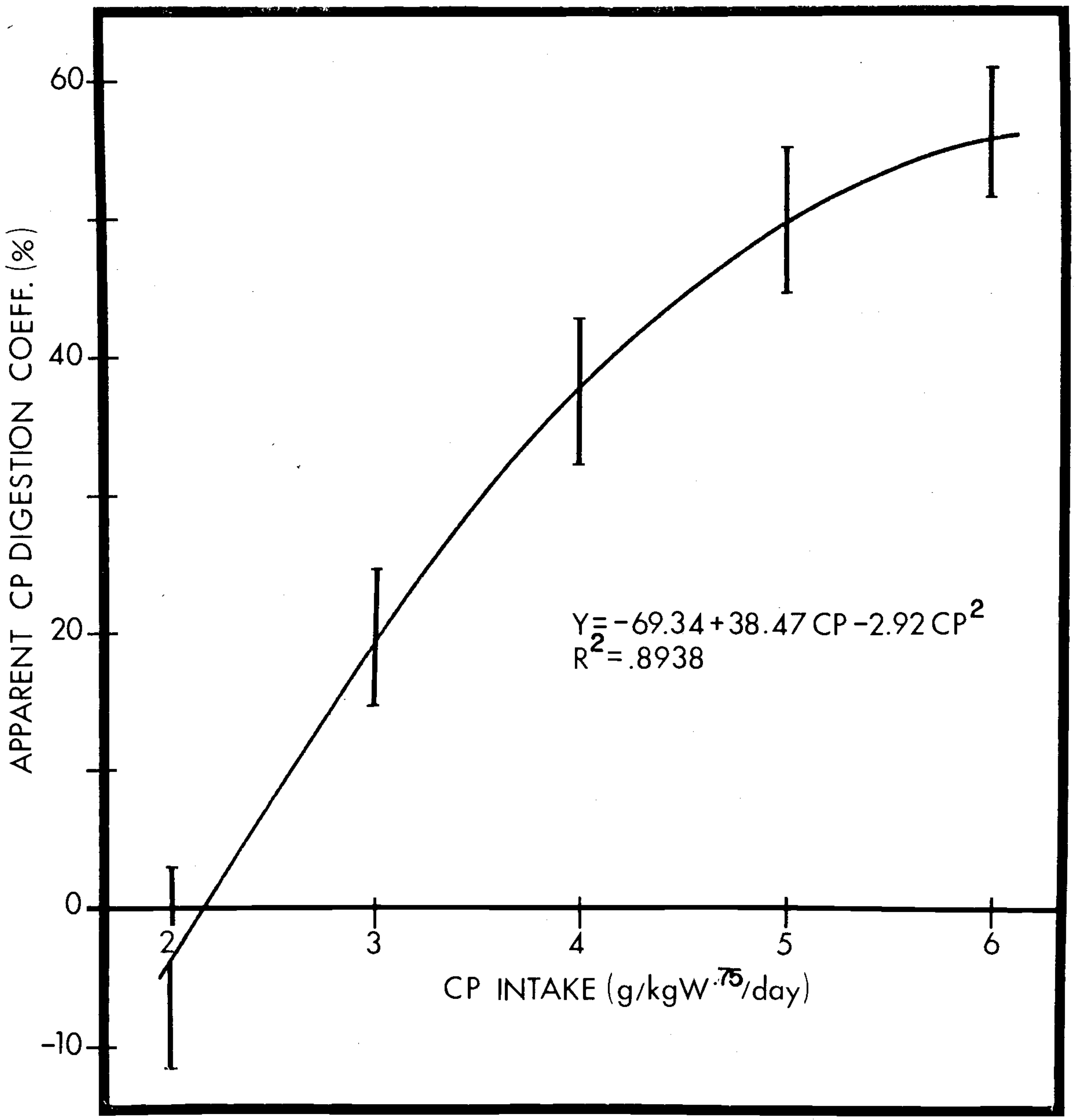

Figure V. Crude protein intake and apparent crude protein digestibility relationship for Trial II.

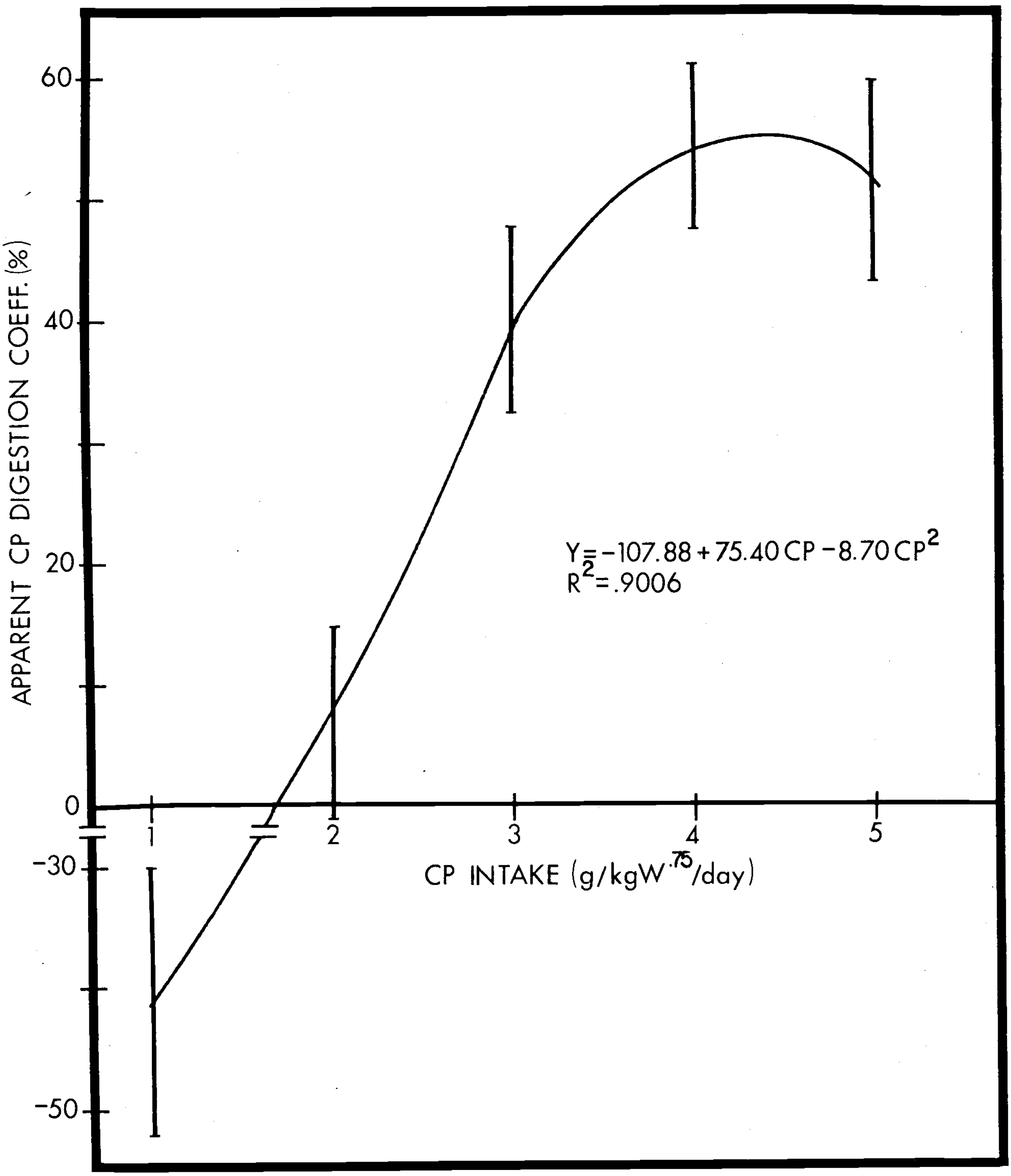

Figure VI. Crude protein intake and apparent crude protein digestibility relationship for Trial III.

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