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To the Graduate Council:

I am submitting herewith a dissertation written by Jerry Wright Williams entitled "Factors related to voluntary dry matter intake by beef cattle fed primarily corn silage." I have examined the final electronic copy of this dissertation for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

Karl M. Barth, Major Professor

We have read this dissertation and recommend its acceptance:

S. L. Hansard, M. J. Montgomery, J. A. Corrick Jr., L. H. Keller

Accepted for the Council:

Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

To the Graduate Council:

I am submitting herewith a dissertation written by Jerry Wright Williams entitled "Factors Related to Voluntary Dry Matter Intake by Beef Cattle Fed Primarily Corn Silage." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Doctor of Philosophy, with a major in Animal Science.

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Sam L. Hansard

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FACTORS RELATED TO VOLUNTARY DRY MATTER INTAKE BY BEEF CATTLE FED PRIMARILY CORN SILAGE

A Dissertation

Presented for the

Doctor of Philosophy

Degree

The University of Tennessee

Jerry Wright Williams

December 1975

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ABSTRACT

The objectives of this study were to determine the influence of ration characteristics and body characteristics on voluntary feed intake of beef heifers and to determine the influence of voluntary ration intake on animal gains and feed efficiency when corn silage was fed as the primary ration constituent.

Corn silage ad libitum and 2.72 kg of various concentrates per animal per day were fed to 432 beef heifers, initially weighing 204-227 kg, during three one-year periods. The experiments were from 110 to 140 days in length and each experiment was divided into four periods of approximately one month each. Body weights and sonaray measurements of fat thickness were determined initially and at monthly intervals throughout the experiment. These measurements provided the basis of the body characteristic variables (percent fat and percent lean) and for the calculation of average daily gain (ADG) for each experimental period. Daily amounts of feed offered, refused and consumed by each pen of animals provided the basis of the voluntary intake variables and for the feed efficiency variables for each experimental period.

Factors known or suspected to affect voluntary intake (VI) were used, and their effects on voluntary intake were determined using simple correlation coefficients with period measurements used as repeat observations.

The independent variables, percent dry matter (DM) from silage, percent digestible energy (DE) from silage, mid-period weight and

elapsed days, were utilized to establish useful multiple regression equations to predict voluntary feed intake.

Simple correlation coefficients between various voluntary intake measurements and other factors known or suspected to influence either ADG or feed efficiency (DM intake, kg per body weight gain, kg) were calculated.

Multiple regression equations were also developed to determine the influence of voluntary intake and other variables (percent DM from silage, percent DE from silage, voluntary DM intake per day, voluntary DE intake per day, elapsed days and mid-period weight) on animal performance (ADG and feed efficiency) with period measurements used as repeat observations.

Voluntary intake of dry matter (VI-DM) and of digestible energy (VI-DE) was highly correlated with either variable which characterizes the ration, namely percent of either DM or DE from silage (r = approximately 0.8). Therefore, VI increased as the proportion of silage in the ration increased, The other expressions of VI (VI per body weight, VI per metabolic size and VI above maintenance) were also positively correlated with percentage of either DM or DE contributed by silage.

There were highly positive correlation coefficients between VI and body weight. When VI was expressed per body weight, it was negatively correlated with body weight. Expressing VI per metabolic body size reduced the influence of body weight to approximately 7% of the total influence of body weight.

ADG was positively correlated with VI in some experimental periods only. This was due to lower than expected gains in one period while VI was as high as expected. Feed efficiency (higher numbers represent lower efficiency) was positively correlated with VI, VI per body weight, VI per metabolic size and VI-DE above maintenance.

There was a high positive correlation between estimated fat percentage of the carcass and VI-DM and VI-DE. Almost all coefficients within periods were also positive (VI-DM, period 1-4: .60, .62, .31, and .46; VI-DE, periods 1-4: .59, .64, .20, and -.05). The fatter animals consumed more DM and more DE even within a period probably because they were also the heavier animals.

The more meaningful prediction equations for VI were as follows: VI-DM, kg/day = -1.73 + 0.0806 (%DM from silage) + 0.00902 (mid-period weight, kg) - 0.00274 (elapsed days); VI-DI, kcal/day = -1321 + 327 (%DE from silage) + 3.04 (mid-period weight, kg) + 24.1 (elapsed days). The more meaningful prediction equations for animal performance were as follows: ADG, kg = 0.756 + 0.0167 (%DE from silage) - 0.0000530 (VI-DE, kcal/day) - 0.00278 (elapsed days) + 0.00136 (mid-period weight, kg); DM efficiency = -1.06 + 0.0608 (%DM from silage) + 1.01 (VI-DM, kg/day) + 0.0338 (elapsed days) - 0.0130 (weight, kg).

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CHAPTER I

INTRODUCTION

The basis for beef cattle production in much of the United States is the utilization of large quantities of corn silage and other forages which can be economically produced.

In addition to digestibility, voluntary dry matter intake of these feeds is an important criterion to determine their nutritive value. It has been shown that certain hypothalamic centers within the brain play an important role in the regulation of feed intake. Considerable research has dealt with the various signals mediated through the central nervous system which inform the animal that satiety has been reached.

Due to the chemical composition, moisture content and physical form of the various feeds ingested by the ruminant animal, gastro-intestinal fill or rumen load has been suggested as a primary factor in regulating voluntary intake. In addition, level of production, body weight and matabolic size of the animal have a direct effect on dry matter intake as does the digestibility of the dry matter content of the ration.

The objectives of this study were to determine the influence of ration characteristics and body characteristics on voluntary intake, and to determine the influence of voluntary ration intake on animal performance and carcass characteristics in beef heifers when corn silage was fed as the primary ration constituent.

CHAPTER II

REVIEW OF LITERATURE

I. Regulatory Mechanisms Involved in Voluntary Intake

Since one of the essentials for maximum animal performance is adequate feed intake, voluntary intake (VI), or the amount of food an animal will voluntarily consume when not given a choice of feeds (Montgomery, 1965), has gained considerable interest in the past few years. It has been stated (Moore, 1966) that voluntary intake may be the most important biological criterion of forage nutritive value, except for actual animal performance. It has also been suggested that the voluntary intake of a forage has a greater effect on animal response than its digestibility (Crampton, Donefer and Lloyd, 1960; Byers and Ormiston, 1962; Ingalls et al., 1965).

The brain appears to be the control mechanism of feed intake (Anand, 1961). The control centers involving the central nervous system have facilitory and inhibitory mechanisms stemming from the higher nerve activity levels which are superimposed on reflex actions operating by way of lower nerve activity levels. The majority of the mechanisms of homeostasis, the tendency of an organism to maintain stability (Arey et al., 1957), operate in similar ways. An example of this is the regulation of respiration and the pattern of nervous regulation of most of the visceral and autonomic activities, including those of the cardiovascular system, digestive system, and body temperature, which are quite similar. The arrangement of the central nervous system for the regulation of feed intake follows a similar pattern. The cerebral cortex and limbric system are concerned with feeding behavior, prejudices, selection preferences and other complex integrations which determine what and how much the animal will eat (Hetherington and Ranson, 1939). The "centers" within the hypothalamus are directly involved in the regulation of feed intake and in satiety (Baile, Mahoney and Mayer, 1967; Baumgardt, 1969).

Within the hypothalamus the ventromedial nuclei have been referred to as the "satiety center," and the lateral hypothalamic nucleus the "feeding center." The regulation of food intake appears to be mediated via the hypothalamic "centers" in the following manner (Larsson, 1954). In the normal animal, feed is consumed until some type of signal is relayed to the ventromedial nuclei, or "satiety center," causing a stimulation in this area or a feeling of satiety. When the food in the gastro-intestinal tract is disposed of, through the conversion to heat, work, or stored energy, a deactivation of the satiety center results. Certain signals are then relayed to the lateral hypothalamic nuclei and in turn a feeling of hunger is produced. As sufficient food is consumed, other signals are relayed to the "satiety center" and the process repeats itself (Larsson, 1954).

It has at one time been thought that oropharyngeal regulation or regulation origination in the mouth area of the animal may be possible (Bell, 1959). It was reported by Bell (1959) the goats showed taste discrimination in the four classes of taste: sweet (glucose), bitter (quinine), salt (sodium chloride) and sour (acetic acid). However, it was reported that smell was of very little significance in stall-fed sheep and that the animals would consume fecal-contaminated feed if they were accustomed to the smell of feces. It appears that in the ruminant animal taste and smell play only a minor role in intake regulation (Balch and Campling, 1962), as does any type of metering mechanism in the mouth as determined by fatigue of the jaw muscles (Balch, 1958; Campling and Balch, 1961). Baumgardt (1969) stated that the "metering of feed in the mouth, pharynx, or esophagus is not an important signal in the normal regulation of feed intake."

An energy-balance change in an animal produces a feedback signal which is integrated in the hypothalamus. There are two general classes of signals which may be discerned. These are signals which are triggered by distension or filling of the digestive tract and those which are more closely related to metabolism classified as either chemostatic or thermostatic (Baumgardt, 1969).

Gastro-Intestinal Fill

During the time of eating there is an increase in the volume of rumen content despite the increase in rate of emptying of the rumen (Phillipson and Ash, 1965). It has been suggested that food intake in the ruminant animal is regulated by rumen load, which is a function of the rate of degradation of cellulose and hemicellulose, which in turn depends upon the rate of passage of the forage (Wright, 1929; Blaxter, 1958; Crampton et al., 1960; Blaxter, Wainman and Wilson, 1961; Balch and Campling, 1962). When diets consisting mainly of roughages were used, physical distension of the reticulo-rumen was a very important factor in regulating voluntary intake (Baumgardt, 1969). When the animal consumes a certain amount of feed, or when gastro-intestinal fill has reached a certain level, a particular signal is relayed to the ventromedial nuclei of the hypothalamus which results in satiety. After the food is digested there is a deactivation of the ventromedial center of the hypothalamic nucleus causing this area to be stimulated resulting in the feeling of hunger (Balch and Campling, 1962; Montgomery, 1965; Conrad, 1966).

Chemostatic Regulation

In addition to the distension receptors found within the gastro-intestinal tract, there are also certain chemostatic receptors which are special regions of nervous sensitivity that are activated by certain (usually one or more) chemicals (Balch and Campling, 1962). It was first suggested by Carlson (1916) that stomach contractions resulted in sensations making the regulation of feed intake possible. Gastric contractions were later produced in dogs by decreasing the blood glucose level and then abolished by hyperglycemia (Bulato and Carlson, 1924). One of the first workers to propose that glucose played an important role in feed intake by animals was Mayer (1953) who suggested that the hypothalamus possesses glucoreceptors sensitive to blood glucose levels. In the non-ruminant animal it is believed that blood glucose regulates feed intake, however, in the ruminant there is less blood glucose and more acetate than observed in non-ruminants. Since acetic acid is the major end product of cellulose breakdown, it may be possible that acetic acid acts as a substitute for glucose in regulating intake (Manning et al., 1959). The minor or insignificant role of glucose in ruminant feed intake may be explained on the basis that a major proportion of the ingested carbohydrates are degraded into volatile fatty acids which are absorbed into the blood stream via the ruman wall (Manning et al., 1959; Baile and Forbes, 1974).

A chemoreceptor mechanism for regulation of feed intake in ruminants may depend on any of several metabolites. One possible mechanism of intake regulation that has been reported is the absorption of acetic and propionic acid into the blood stream which, at certain levels, cause a chemoreceptor response, thereby reducing feed intake (Dowden and Jacobsen, 1960). This is in agreement with results reported by Montgomery, Schultz and Baumgardt (1963), wherein it was found that the infusion of acetic acid intraruminally significantly decreased hay consumption. Since significantly larger amounts of acetic and propionic acids are found in silages, the above phenomenon may account for the observation that dairy cows consume less forage in the form of silage than in the form of hay.

Thermostatic Regulation

The conclusion that animals generally eat more when they are cold, and markedly reduce intake when under heat stress has led to the suggestion that appetite may be controlled by changes in body heat production (Brobeck, 1960). This suggestion is that receptors in the anterior hypothalamus might actuate feeding when a certain heat load minimum or temperature depression was reached, and that satiety would develop when a certain heat load was reached. Work by Anderson and Larsson (1961) supported this observation by showing that the cooling of the hypothalamus of goats by means of a surgically-inserted probe resulted in hyperphagia, and that warming resulted in aphagia. These induced temperature changes (8°- 9° C) were probably greater than could be considered physiologically normal (Baile, 1968). During, or at the termination of a meal, no increased hypothalamic temperature was observed in goats (Baile et al., 1967; Baile and Mayer, 1968 a,b). Horn temperature, which is a measure of vasodilation, did not increase nor were there appreciable deep body temperature changes. Hypothalamic temperatures in goats appeared to be related to physical activity rather than to food consumption per se (Dinius, Kavanaugh and Baumgardt, 1970). During the actual eating process, when the animals were more active, the temperature increased, but when the animals layed down temperatures decreased. The temperatures of other areas, such as rectum, horns, ear and chest, were not related to feed consumption, nor were there apparent correlations between volatile fatty acid concentrations and body temperatures at these locations. In cattle, however, the intra-ruminal infusion of cold (5°C) water at 30 minute intervals caused an increase in feed consumption by 24%, while warm (49°C) water infusion caused a depression of intake by 9% (Bhattacharya and Warner, 1968). These data indicated, therefore, that hypothalamus temperature changes were probably not related to appetite. Nevertheless, this does not mean that rumen and peripheral temperature changes do not influence appetite. A considerable decrease in feed consumption by cows has been reported with atmospheric temperatures of 90°F and 40% relative humidity and 90°F and 50% relative humidity, while animals exposed to colder temperatures tended to increase consumption (Davis and Merilan, 1960).

II. Factors Affecting Voluntary Intake

Digestibility of Ration

It appears that physical and physiological factors regulating feed intake change in importance with increasing digestibility of dry matter. When high-roughage rations of 67 to 80% dry matter digestibility were offered, voluntary dry matter intake decreased with increasing digestibility. At low digestibility, the physical and physiological factors regulating intake included body weight, undigested residue per unit of body weight per day and dry matter digestibility. Dry matter intake also appeared to be dependent upon metabolic size and level of production (Conrad, Pratt and Hibbs, 1962, 1964).

The balance of energy by the animal body is determined by the difference between energy input in the form of feed consumed and energy output in the form of fecal material, urine, and heat plus the energy expended for maintenance, milk production, reproduction, and activity. A positive energy balance results in an increase in feed-energy input over energy output, a decrease in output, or a combination of these. Likewise, a decrease in feed-energy input or an increased energy output results in a negative energy balance. Especially in the young animal, which exhibits marked variation in growth rate, the feed intake must be adapted to energy expenditure. When the energy content of a ration is decreased by dilution with an indigestible material, the animal will adjust the amount of feed eaten so that digestible caloric intake remains fairly stable (Baumgardt, 1969). Ruminants adjust the amount of voluntary intake in relation to the physiological demand for energy, when fill does not limit their intake. Rations that are low in nutritive value, because of low digestibility or high bulkiness, are consumed at a low level of digestible dry matter because the digestive tract becomes distended and thus dry matter intake is inhibited before the demand for digestible energy has been satisfied. As the nutritive value of the ration increases, feed and digestible energy intake increase until the energy level reaches the physiological demand of the animal. Continued increases in the nutritive value of the ration are accompanied by a reduction in feed intake of a magnitude to allow approximately stable digestible energy intake. The majority of nonruminant rations fall into the stable energy category, whereas most ruminal rations are of the type in which energy intake is limited by gastro-intestinal tract distension (Blaxter et al., 1961; Blaxter and Wilson, 1962; Van Soest, 1965; Blaxter et al., 1966; Baumgardt, 1969; Baile and Forbes, 1974).

The possibility that two separate regulatory forces may be present within the system, with one taking over when the other stops, may be indicated when considering the data reported by Montgomery and Baumgardt (1965a) and Cowsert and Montgomery (1969), which indicated consumption to be reduced at some point at which the energy demand is probably satisfied. Similar results were reported in other publications, including those of Elliot (1967a,b) Owen, Davis and Ridgman (1965, 1969), Boling et al. (1967, 1969), Montgomery and Baumgardt (1965b), Forbes, Raven and Irwin (1969), McCullough (1969) and Dinius and Baumgardt (1970). Data published by Cowsert and Montgomery (1969), and

Dinius and Baumgardt (1970), using rations differing in digestible energy, indicated that the increased intake by animals seen as the proportion of grain in the ration was increased, was a reflection of demand for energy and not for added protein.

The point at which an animal will have satisfied its energy demand may be expected to be somewhat variable with different classes and species of animals (Church et al., 1971). Energy needs therefore, will vary with productive functions (Baumgardt, 1969). Therefore a lactating cow has a greater demand than a pregnant non-lactating cow which, in turn, has a higher requirement than an animal that is neither pregnant nor lactating. Rapid growth stimulates a greater need for energy as do various environmental factors and stress situations (Church et al., 1971). Therefore, it is most difficult to pinpoint a precise value at which increasing caloric density of a ration would result in a reduced intake of dry matter or energy. As an example, Conrad et al. (1964) reported that 66.7% digestible dry matter was the lowest ration digestibility at which lactating cows could regulate energy intake, whereas Montgomery and Baumgardt (1965a) found that energy intake of dairy heifers was maintained when the ration was above 56% digestible dry matter.

Moisture Content of Ration

It has been suggested that differences in fermentation resulting from various moisture levels in forages when ensiled appear to be the major determinants of the amounts of dry matter voluntarily consumed rather than the dry matter content of the silage *per se*, even though there was a positive relationship between dry matter content of silages and the rate of their consumption (Thomas et al., 1961). Higher voluntary dry matter intake has also been observed with increasing levels of dry matter within and among alfalfa silages. Intake response was less precise however when dry matter content was above 50% (Gordon et al., 1965). The close relationship between dry matter intake and dry matter content of silage dictates that moisture content be held constant or corrected for when evaluating silages for cattle (Ward et al., 1965).

Management

Various previous investigations show that voluntary forage intake by cattle is related to certain factors of management and environment, as well as the physiology of the individual animal.

Although the animal may possess certain physiological mechanisms for regulating voluntary feed intake, the domestic animal is not always permitted to make use of this mechanism because the animal is, much of the time, offered a limited amount of feed. This limitation is, of course, desirable when feeding for maintenance only, but lactating dairy cows and finishing beef cattle often have difficulty in meeting their total energy needs even when offered a high-grain ration.

One of the more important external factors affecting voluntary forage intake by cattle is forage quality. The stage of maturity of herbage used for hay or silage and the subsequent voluntary intake of the preserved forage are closely correlated (Stone et al., 1960).

The concentrate level of the ration has also been shown to affect forage intake of dairy cows, with a decline in forage dry matter intake of 0.24 unit for each additional unit of concentrates consumed (Mather et al., 1960).

A change in voluntary feed intake may be caused by individual versus group feeding, in that cattle and sheep consume slightly more feed when fed in groups than when fed individually. This increase is said to be due to the behavioral effects of competition (Balch and Campling, 1962; Clark and Barth, 1968; Baumgardt, 1969).

Frequency of feeding also influences voluntary intake. When animals are offered rations frequently (8 to 10 times per day) they eat slightly more than when fed once or twice per day (Campbell et al., 1963; Baumgardt, 1969). In some management situations, feed consumption has been reported to have been improved by the addition of various flavoring components such as molasses or sugar (Balch and Campling, 1962; Goatcher and Church, 1970). The addition of protein supplements may also be important to an increase in feed intake, especially when low quality forages are fed (Clark, Hall and Felts, 1967). The use of urea has received much attention during the past few years because it may be used in some management practices to replace part of the protein requirement of the ruminant animal. It has been reported by Plummer, Miles and Montgomery (1971) that the feeding of a 2% urea concentrate six times daily versus twice daily did not significantly affect total dry matter intake, silage dry matter intake or concentrate intake.

The combination of feeds may also affect voluntary intake. When two types of unlike forages (grass-legume silage and succulent pasture) have been evaluated singly and in combination to determine the combining effect on voluntary intake and forage consumption, voluntary intake of the combination of forages were significantly greater than expected (Miller et al., 1965).

When cattle are exposed to rising air temperatures there is a decline in total feed consumption (Brody, 1956). Ragsdale et al. (1950) reported that the consumption of total digestible nutrients (TDN) at 35°and 37.8°C was, respectively, one-half and one-third of the level consumed at 21.1 C. It must be assumed that part of this decline must reflect reduced appetite for forages. The exposure to extreme cold temperatures likewise influences forage intake. McDonald and Bell (1958) showed an average difference of 2.4 kg in daily hay intake when cows were subjected to moderate (daily minimum of 4.4°C) or very cold (daily minimum of -17.8°C) temperatures. The colder the weather, the greater the appetite for forage, and at the same time, gross efficiency of feed utilization declined by 10%.

Relative humidity, wind velocity, and solar radiation also have contributory effects on voluntary intake, mainly in situations of heat stress. In general, any of these climatic factors that add to an animal's heat load will cause a lowering of the temperature at which feed consumption begins to decline, and any action that tends to subtract from the heat load causes this critical temperature to rise (Ragsdale et al., 1953; Brody et al., 1954a; Brody et al., 1954b).

Individual cows show widely differing appetites for forage, even when under controlled conditions. Stone et al. (1960) found that only 25% of the total variation in forage intake could be accounted for by the measurable variables of milk production, body weight, and weight changes. It is notable that individual cows in their report tended to maintain the same ranking with respect to appetite when offered different forages (early-cut hay, late-cut hay, and hay-crop silage) or when observed over the lactation period. The repeatability of the weekly forage dry matter intake was 0.70 on a within-forage treatment, within-year basis.

For maximum animal performance, maximum feed intake is essential, and can be obtained only by feeding nutritionally balanced rations to animals that are in good health. Rations that are not properly balanced are consumed at below maximum levels due either to impaired digestion or impaired tissue metabolism (Mayer, 1964). Animals that are not healthy do not possess the desire to consume feed at the maximum rate. For this reason the animal producer strives to maintain the animal in a state of proper nutrition because "the common denominator in animal nutrition and physiology is homeostasis" (Baumgardt, 1969) and should the ration being fed not be compatible with homeostasis, the animal voluntarily reduces its intake in attempting to return to a homeostatic condition.

CHAPTER III

EXPERIMENTAL PROCEDURE

I. Experimental Design

Data consisting of voluntary feed intake, ration characteristics, body characteristics and animal performance variables were utilized in this study to establish useful prediction equations.

Experiments dealing with feeding of mainly corn silage to heifers during three one-year periods (72 animals in 1969-70, 180 animals in 1970-71 and 180 animals in 1971-72) were conducted. Data were compiled from the roughage phase of the feeding trial. Factors known or suspected to directly affect voluntary feed intake were used, and their individual and combined effects on voluntary feed intake were determined using simple correlation coefficients and multiple regression equations. The effect of voluntary feed intake on animal performance and body characteristics was also determined using simple correlation coefficients and multiple regression equations.

Animals

Hereford heifer calves, initially weighing 204-227 kg (450-500 lb) with the initial type grades of Choice, Good and Medium were used as experimental animals. These animals were obtained at area feeder-calf auctions at approximately six to nine months of age. The pretrial treatment consisted of corn silage fed *ad libitum* and 1.36 kg (three pounds) of hay per animal per day for approximately three weeks prior to the onset of the trial.

II. Conduct of Trial

A total of 432 feeder heifers were used during the three years of the experiment. In 1969-70, there were four ration treatments and three pens of six heifers each per ration treatment. In 1970-71 and 1971-72, there were five ration treatments per year, three feeder calf grades (Choice, Good, and Medium) per ration treatment and two replicate pens of six heifers each per ration-grade treatment group.

Lengths of the experimental periods during the three years were as follows: 1969-70, period 1 = elapsed days 0 to 28; period 2 = elapsed days 29 to 57; period 3 = elapsed days 58 to 83; period 4 = elapsed days 84 to 111; 1970-71, period 1 = elapsed days 0 to 26; period 2 = elapsed days 27 to 53; period 3 = elapsed days 54 to 80; period 4 = elapsed days 81 to 110; 1971-72, period 1 = elapsed days 0 to 28; period 2 = elapsed days 29 to 73; period 3 = elapsed days 74 to 93; period 4 = elapsed days 94 to 140.

All animals were offered a daily ration consisting of corn silage fed ad libitum plus six pounds of concentrate daily for 110 to 140 days. The proximate analysis (A. O. A. C., 1965) of the corn silage for each of the three years is presented in Table 1.

The five concentrate treatments and their composition and dry matter percentage were as follows: 1) cracked shelled corn; 2) cracked shelled corn and 0.6% cottonseed meal; 3) cracked shelled corn and 0.1% urea; 4) cracked shelled corn and 1.2% cottonseed meal; and 5) cracked shelled corn and 0.2% urea. Treatment 3 was not used in 1969-70. Dry matter percentages of the concentrate mixtures were

TABLE 1

PROXIMATE ANALYSIS OF CORN SILAGE[a]

	Average percent composition		
	1969-70	1970-71	1971-72
Dry matter	35.0	27.6	28.5
Crude protein[b]	14.1	13.4	13.2
Ash[b]	6.12	5.33	6.00
Ether extract[b]	2.14	2.44	2.64
Crude fiber[b]	23.7	24.9	25.4
N. F. E.[b]	54.0	53.9	52.8

[a]Urea and limestone added at the rate of 10 lb each per ton at the time of ensiling.

[b]Dry-matter basis.

available for one year only. Therefore, they were used for the other two years as well. These dry matter percentages for treatments 1 to 5 were as follows: 1) 85.0; 2) 88.4; 3) 87.0; 4) 88.6; and 5) 87.0.

Corn silage was offered ad libitum twice daily except on Sunday, when, for the morning feeding, each pen of animals was fed 1-1/2 times the amount usually fed to that pen. There was no evening feeding on Sunday. One-half of the daily concentrate supplement was poured over the silage at each feeding and mixed sufficiently by hand. A mineral box, with two compartments, was kept in each feed trough. Dicalcium phosphate and granulated loose salt was fed free choice and separately in these mineral boxes. All feed troughs were cleaned and weighbacks of any remaining feed were made immediately before the afternoon feedings on Tuesday, Thursday and Saturday.

Body weights and somascope measurements (Swain, Ramsey and McLaren, 1966) of fat thickness were determined initially and approximately every 28 days throughout the test period. These measurements were collected before the morning feeding. Water had been withheld overnight. These measurements provided the basis of the body characteristics variables and for the calculation of average daily gain for each experimental period.

Daily records of the feed offered, refused and consumed by each pen of animals were kept by the feeder. These were tabulated at the end of each experimental period. These tabulations provided the basis of the voluntary intake variables and for the animal performance variables for each experimental period. These variables were as follows: voluntary DM intake/day, voluntary DM intake/day/kg body weight, voluntary DM intake/day/metabolic size, voluntary DE intake/day, voluntary DE intake/day/kg body weight, voluntary DE intake/day/ metabolic size, voluntary DE intake/day above maintenance, average daily gain, and gain/DM intake.

The original objectives of the feeder heifer trials were different from the objectives of this study. Many of the ration treatments and the full-fed phase of all treatments from the original trials were not used in this study. Other results from the original trials were published by Corrick and Hobbs (1970a,b) and Corrick, Hobbs and Butts (1972).

III. Methods of Calculating Variables

1. Voluntary Intake (various expressions)

   a. Total ration DM, kg/day

      As-fed corn silage, kg/day x DM% = Corn silage DM, kg/day.

      As-fed concentrate, kg/day x DM% = Concentrate DM, kg/day.

      Corn silage DM, kg/day + concentrate DM, kg/day = Total ration DM, kg/day.

   b. Total ration DM, kg/body weight, kg

      $$\frac{\text{DM consumed, kg/day}}{\text{Average body weight, kg}}$$

      (Average body weight = Body weight at the start of a particular period plus one-half of the body weight gain during that period.)

c. Total ration DM, kg/metabolic body size/day

$$\frac{\text{DM consumed, kg/day}}{\text{Average body weight, kg}^{.75}}$$

(Metabolic body size = $W^{.75}$; Lofgreen, 1964.)

d. Total ration DE, kcal/day

As-fed corn silage, kg/day x DE, kcal/kg = Corn silage DE, kcal/day.

As-fed concentrate, kg/day x DE, kcal/kg = Concentrate DE, kcal/day.

Corn silage DE, kcal/day + concentrate DE, kcal/day = Total ration DE, kcal/day.

(DE of corn silage = 2910 kcal/kg; DE of ground shelled corn = 4012 kcal/kg; DE of CSM = 4056 kcal/kg; Crampton and Harris, 1959, pp. 560, 563 and 581, respectively.)

e. Total ration DE, kcal/kg body weight

$$\frac{\text{DE consumed, kcal/day}}{\text{Average body weight, kg}}$$

f. Total ration DE, kcal/metabolic size/day

$$\frac{\text{DE consumed, kcal/day}}{\text{Average body weight, kg}^{.75}}$$

(Metabolic body size = $W^{.75}$; Lofgreen, 1964.)

g. Total ration DE, kcal/day above maintenance

DE consumed -76 (average body weight, $\text{lb}^{.75}$), kcal/day.

(DE for maintenance = 76 $W^{.75}$; Garrett, Meyer and Lofgreen, 1959.)

2. Ration Characteristics

a. $\frac{\text{Corn silage DM intake, kg/day}}{\text{Total ration DM intake, kg/day}}$ = % DM from corn silage

b. $\frac{\text{Corn silage DE intake, kcal/day}}{\text{Total ration DE intake, kcal/day}}$ = % DE from corn silage

3. Body Characteristics

a. Amount of separable lean in carcass, kg = 39.16 - 1.40 (fat thickness at 12th rib, mm) + 0.2266 (carcass weight, lb) x 2 x .4536

(lb of separable muscle in one beef side = 39.16 - 1.40 (fat thickness at 12th rib, mm) + 0.2266 (carcass weight, lb); Cole, Ramsey and Epley, 1962.) (Dressing percentage is known to be related to fat thickness. For the calculation of carcass weight from live weight and fat thickness, the following corresponding fat thickness and dressing percentages were used; 2-3 mm, 56%; 3-4 mm, 57%; 5-6 mm, 58%; 8-10 mm, 59%; and 10 mm, 60%; Backus, 1974.)

b. Amount of fat in carcass, kg = carcass weight, kg - (amount of separable lean, kg + amount of bone, kg).

(Amount of fat in carcass was considered to be amount of fat at the start of a particular period plus one-half of the increase in amount of fat during that period.)

(Amount of bone in carcass = 14% of carcass; Cole Ramsey and Hobbs, 1964.)

c. Percent lean in carcass = $\frac{\text{Amount of separable lean, kg x 100}}{\text{Carcass weight, kg}}$

d. Percent fat in carcass = $\frac{\text{Amounr of fat, kg x 100}}{\text{Carcass weight, kg}}$

4. Animal Performance

a. Average daily gain, kg = $\frac{\text{Weight gain, kg}}{\text{Elapsed days}}$

b. Feed (DM) efficiency = $\frac{\text{DM consumed, kg/day}}{\text{Weight gain, kg/day}}$

A summary of voluntary intake and various ration, animal performance and body characteristic data by period within treatment is presented in Appendix Tables 7, 8 and 9. Overall means and standard deviations are presented in Appendix Table 10.

IV. Statistical Analysis

Simple correlation coefficients between various expressions of voluntary intake and body characteristics (weight and fat thickness) and animal performance (ADG and feed efficiency) were calculated with period measurements used as repeat observations.

Multiple regression techniques according to Draper and Smith (1966) were used to study the influence of various ration and body characteristics on voluntary intake and to study the influence of voluntary intake on body characteristics (weight and fat) and animal performance (ADG and feed efficiency) with period measurements used as repeat observations. The multiple regression equations were fitted, using the IBM 360/65 computer and the Statistical Analysis System program prepared by Barr and Goodnight (1972).

CHAPTER IV

RESULTS AND DISCUSSION

Data were compiled from the roughage phase of the feeding trial within experiments dealing with feeding of mainly corn silage to slaughter heifers. The data were studied on a period basis within the experiment.

I. Simple Correlations Between Voluntary Intake and Ration Characteristics

Simple correlation coefficients between the various expressions of voluntary intake and ration characteristics are presented in Table 2. Correlation coefficients between any of the voluntary intake (VI) variables with either the percentage of ration DM contributed by silage or the percentage of ration DE contributed by the silage were of similar magnitude. However, in every case percent DE from silage was somewhat more highly correlated with VI variables than percent DM from silage. This was the case even when percentage of DE contributed by silage was correlated with voluntary DM intake variables. This result was reasonable, since DE is a more exact expression of the nutritive value of rations than is DM.

All expressions of VI were highly correlated with the two variables which characterize the ration (% of either DM or DE from silage). Therefore, VI increased as the proportion of silage in the ration increased. In this experiment, only corn silage and concentrates were fed to the heifers. Therefore, if more DM or DE was contributed

TABLE 2

COEFFICIENTS OF SIMPLE CORRELATION BETWEEN VOLUNTARY DRY MATTER AND DIGESTIBLE ENERGY INTAKE PER DAY AND OTHER VARIABLES[a,b]

	Voluntary DM intake/day			Voluntary DE intake/day			
	kg	Per kg body weight, kg	Per metab. size, kg	kcal	Per kg body weight, kcal	Per metab. size, kcal	Above maint., kcal
Ration characteristics							
DM from silage, %	0.820	0.335	0.557	0.794	0.451	0.637	0.803
DE from silage, %	0.830	0.349	0.572	0.799	0.460	0.646	0.809
Animal performance							
Mid-period weight, kg	0.662	-0.557	-0.266	0.666	-0.395	-0.087	0.523
ADG, kg	-0.253	0.367	0.234	-0.474	0.037	-0.135	-0.424
DM intake, kg per gain, kg	0.579	-0.129	0.079	0.735	0.172	0.394	0.699
Body characteristics							
Mid-period fat, %	0.703	-0.476	-0.182	0.683	-0.336	-0.032	0.551
Mid-period lean, %	-0.703	0.476	0.182	-0.683	0.336	0.032	-0.551

TABLE 2 (continued)

	Voluntary DM intake/day			Voluntary DE intake/day			
	kg	Per kg. body weight, kg	Per metab. size, kg	kcal	Per kg body weight, kcal	Per metab. size, kcal	Above maint., kcal
Voluntary DM intake per day							
Total, kg	1.000	0.250	0.544	0.894	0.309	0.559	0.864
Per kg body weight, kg	0.250	1.000	0.948	0.124	0.852	0.729	0.275
Per metabolic size, kg	0.544	0.948	1.000	0.400	0.839	0.815	0.521
Voluntary DE intake per day							
Total, kcal	0.894	0.124	0.400	1.000	0.418	0.683	0.984
Per kg body weight, kcal	0.309	0.852	0.839	0.418	1.000	0.949	0.572
Per metabolic size, kcal	0.559	0.729	0.815	0.683	0.949	1.000	0.801
Above maintenance, kcal	0.864	0.275	0.521	0.984	0.572	0.801	1.000

[a]Values above .11 and below -.11 are significant ($P<.05$); values above .15 and below -.15 are highly significant ($P<.01$).

[b]N=288 means from 6 animals per pen during 4 periods each of 3 years and intake-efficiency observations from these pens.

by silage, less was contributed by concentrates. This resulted in a higher forage ration. Several workers (Conrad et al., 1964; Montgomery and Baumgardt, 1965a,b; Cowsert and Montgomery, 1969) also studied VI of DM or of energy with rations varying in forage:concentrate ratios. The results of the present experiment agree with those reported by the aforementioned authors, who hypothesized that animals increase their DM intake when the forage makes up a larger portion of the ration in order to compensate for the lower availability of energy in higher-forage rations, as long as rumen fill is not a limiting factor.

There were highly positive correlation coefficients between either percent DM from silage or DE from silage with VI per animal per day, accounting for either 67 or 69%, respectively, of the total variation in VI. The percentage of silage in the ration increased during the course of the experiment as the heifers' requirement for energy increased, since concentrates were fed at a constant amount and corn silage was fed ad libitum throughout the experiment. Therefore, there was some confounding in the experiment since higher percent silage rations tended to be fed more to the heavier animals toward the end of the experiment. This resulted in more highly positive correlation coefficients between VI per animal and percentage of silage in the ration than would have been expected if a range of percent silage would have been fed to animals regardless of weight.

When VI (either DM or DE) was expressed as a percentage of body weight, the correlation coefficients with percent silage in the ration were still positive but much lower than with VI per animal. The aforementioned confounding does not exist with this expression of VI. The positive relationship between percent forage in the ration and VI per body weight is in agreement with results by Montgomery and Baumgardt (1965a) and Cowsert and Montgomery (1969).

Expressing VI as a function of metabolic weight (as compared to percentage of body weight) increased the correlation with percent silage in the ration. This result was expected, since not only basal metabolism, but also several other physiological phenomena in the animal are more closely related to metabolic size than they are to body weight. Thus Conrad et al. (1964), working with dairy cattle, reported that intake was directly related to the 0.73 power of body weight. Also, Clark and Barth (1970), studying the relationship of VI of growing-finishing beef cattle with other measures of nutritive value of rations, reported that VI per unit of metabolic size was more closely related to ration digestibility than to VI per unit of body weight. A positive but nonsignificant relationship between increasing proportions of forage in the ration and voluntary digestible energy intake by animals was evident from the results of Montgomery and Baumgardt (1965a).

II. Simple Correlations Between Voluntary Intake and Animal Performance

There were highly positive correlation coefficients between VI (both DM and DE) per animal per day and body weight. The heavier animals had a higher total VI per day. This would be expected since body weight changes are the results of dietary input.

Negative correlation coefficients were observed between body weight and VI per body weight. Therefore, body weight per se is not useful as a basis to express feed intake of animals of different sizes. Crampton et al. (1960) attempted to remove the influence of weight on feed intake of sheep. They reported figures that were not correlated with the actual weights of the test animals. When their observed feed intakes were correlated with intake per 100 lb weight, and with intake per unit of metabolic size ($W_{kg}^{.75}$) correlation coefficients of 0.21 and 0.076, respectively, were obtained. These coefficients were compared to the correlation coefficient of 0.75 between observed feed intake and the body weight of the sheep. It is biologically reasonable to assume that body weight to some extent affects feed intake. Thus, the use of r^2 (coefficient of determination) makes it possible to account for the amount of variability explained by the independent variable, body weight. This procedure gives figures suggesting that actual body weight determined feed intake to the extent of 56% (i.e., 0.75^2). In contrast, in the values representing feed intake per 100 lb of sheep, differences in body weight of sheep influenced the figures only about 4.4% (i.e., 0.21^2). However, when intake was expressed per unit of metabolic size ($W_{kg}^{.75}$) the effective importance of body weight of sheep was reduced to about half of 1% (i.e., $.076^2$).

In the present experiment, actual body weight determined feed intake to the extent of 44% (0.66^2). When intake was expressed per unit of metabolic size, the remaining influence of body weight was reduced to approximately 7% (-0.27^2) for DM intake and to 1% (-0.09^2) for DE intake.

The correlation coefficient across all periods between ADG and VI (both DM and DE) per animal per day was negative. This is erroneous, since increased feed consumption does not result in decreased gains. This negative correlation coefficient is the result of confounding between ADG and periods (ADG decreased as the experiment progressed). Other explanations of this negative correlation between VI and ADG are 1.) as the experiment progressed, an increasing proportion of the feed consumed was used for the synthesis of body fat rather than lean body tissue and 2.) as the experiment progressed, greater proportions of the feed consumed were contributed by corn silage which might limit their intake to less than the animal's physiological demand. However, the same correlation coefficients within periods resulted in a more correct relationship between intake and daily gains. Correlations with either DM or DE intake per animal per day, respectively, with ADG within the four experimental periods were as follows: period 1: 0.41, 0.38; period 2: -.27, -.40; period 3: 0.58, 0.42; and period 4: 0.18, -.20. As expected, the relationship was positive in periods 1 and 3. There was essentially no relationship in period 4. The unexpected negative correlation in period 2 was caused by lower than expected ADG in this period (ADG in periods 1-4: 104, 0.87, 0.89, 0.72), while there was a steady increase in VI per period (VI-DM: 493, 554, 568, 586 kg/day; VI-DE: 16.1, 18.3, 18.3, 20.6 Mcal/day). The low ADG in the second period also affected its relationship with other measures of VI adversely.

Feed efficiency (DM intake per gain) was positively correlated with VI-DM and VI-DE across all periods (Table 2). Since higher numbers represent decreased efficiency, this positive correlation denotes a decrease in feed efficiency at increasing levels of intake. This relationship was also evident on a within-period basis in periods 1 and 2 and remained of similar magnitude in other expressions of VI (VI per body weight, VI per metabolic size, VI-DE above maintenance).

In the classical work by Forbes et al. (1928), the relationship of plane of nutrition with several expressions of feed and energetic efficiency was established. Efficiency was highest at a maintenance level and steadily decreased with increasing feed intake. This correlation between VI and feed efficiency was positive when VI was expressed on an animal or body weight basis. Forbes et al. (1928) explained that the decrease in efficiency was based on the "principle of diminishing increments," since digestibility decreases and heat increment increases with successive increments of food intake.

III. Simple Correlations Between Voluntary Intake and Body Characteristics

There was a high positive correlation between estimated fat percentage of the carcass and VI-DM and VI-DE (Table 2). Almost all coefficients within periods were also positive (VI-DM, periods 1-4: .60, .62, .31 and .46; VI-DE, periods 1-4: .59, .64, .20 and -.05). The fatter animals consumed more DM and more DE even within a period probably because they were also the heavier animals. When VI-DM and VI-DE was expressed as a function of body weight, percent fat was negatively correlated with VI-DM (r = -0.48) and with VI-DE (r = -.34) when analyzed across periods (Table 2), however, there was essentially no relationship with estimated fat content of the carcass when expressed on a period basis. Percent carcass fat also was not related to VI-DM and VI-DE when expressed per metabolic size either on a within or an across-period basis.

DE intake above maintenance was highly positively correlated with estimated carcass fat percentage (Table 2). However, this same strong positive relationship only was evident in periods 1 and 2. In periods 3 and 4 there was essentially no relationship. The causative relationship between these two variables is that those animals consuming higher amounts of DE above their requirements become fatter. Correlation coefficients between various measures of VI and estimated mid-period lean percentage of the carcass will not be discussed since percent fat was calculated from percent lean.

IV. Multiple Regression Equations with VI as the Dependent Variable

From all the variables related to VI, several of them which were easily obtained, biologically more meaningful and more highly correlated were chosen to develop multiple regression equations predicting various expressions of VI-DM and VI-DE. Coefficients of determination (R^2) from the various regression models are presented in Table 3 and components of selected equations are shown in Table 4.

For all expressions of VI in models containing percent of DE from silage as one of the independent variables, slightly more of the variability was accounted for than in models which contained DM from silage (Table 3). Also, a better estimate of any expression of VI-DM (than

TABLE 3

R^2 VALUES FOR CERTAIN EXPRESSIONS OF VOLUNTARY INTAKE USED AS DEPENDENT VARIABLES[a]

Independent variables	Dependent variable						
	Voluntary DM intake per day	Voluntary DE intake per day	Voluntary DM intake per day per kg body weight	Voluntary DE intake per day per kg body weight	Voluntary DM intake per day per metab. size	Voluntary DE intake per day per metab. size	Voluntary DE intake per day above maint.
Percent DM from silage; mid-period weight; elapsed day	0.789	0.775	0.729	0.670	0.639	0.607	0.707
Percent DE from silage; mid-period weight; elapsed day	0.803	0.784	0.746	0.685	0.660	0.624	0.719

[a]The reduction in sum of squares due to fitting each of the models was statistically significant ($P<.0001$).

TABLE 4

PARTIAL REGRESSION COEFFICIENTS, MEAN INTERCEPT AND R^2 VALUES FOR CERTAIN EXPRESSIONS OF VOLUNTARY INTAKE USED AS THE DEPENDENT VARIABLES

	Dependent Variables							
	Voluntary DM intake per day		Voluntary DE intake per day		Voluntary DM intake/day per kg body weight		Voluntary DE intake/day per kg body weight	
Mean intercept	-1.73	-0.905	-4829	-1321	0.0141	0.0170	49.2	61.7
Percent DM from silage	0.0806		339		0.000290		1.20	
Percent DE from silage		0.0784		327		0.000282		1.16
Mid-period weight	0.00902	0.00861	4.35	3.04	-0.0000404	-0.0000419	-0.219	-0.223
Elapsed day	-0.00274	-0.00239	22.8	24.1	-0.00000821	0.00000694	0.0811	0.0854
R^2	0.789[a]	0.803[a]	0.775[a]	0.784[a]	0.729[a]	0.746[a]	0.670[a]	0.685[a]

[a]The reduction in sum of squares due to fitting each of the models was statistically significant (P<.0001.).

of VI-DE) was obtained in every case, regardless of the independent variables used. R^2s were very high and ranged from 0.607 to 0.803. The equation models in which more of the variability in VI was explained (Table 4) were VI per animal and VI per body weight.

In the first model in Table 4, VI-DM was predicted from the three independent variables percentage of DM from silage, animal weight during the middle of the experimental period and elapsed days. These variables explained 79% of the variability in VI-DM. In Appendix Tables 7-9 the means of the variables have been listed by period and treatment. Ranges (high and low values) for the variables have been selected from these means to duscuss the individual effects of the independent variables used in equation models in Table 4. However, it is recognized that there was a much wider range in variability in individual (per lot) observations. Thus, the range in percentage of DM from silage was from 56 to 63 in means by period and treatment, while the range was 49 to 70 in individual pen observation.

Results of equation model 1 indicated that each increase of 1% dry matter from silage in the ration resulted in an increase of 0.08 kg of VI-DM. Using the range of values per period and treatment observed in the ration and period means of this study (56-63% DM from silage), when 56% of the DM came from silage the result was a VI-DM of 5.14 kg/animal/day. However, if 63% of the ration DM came from silage the VI-DM increased to 5.71 kg/animal/day.

Within the limits of this experiment, body weight had the largest influence on VI-DM. Heifers weighing 229 kg voluntarily consumed 5.06 kg of DM/day while heifers weighing 317 kg consumed 5.85 kg/day. When percentage of DM coming from silage and body weight of animals were held constant, VI-DM decreased during the course of the experiment. On day 1 of the experiment, VI-DM was 5.67 kg/animal/day, while it was 5.37 kg/animal/day on elapsed day 110.

In model 4 (Table 4), 78% of the variability in voluntary digestible energy intake (VI-DE) was explained by the independent variables % DE from silage, mid-period weight and elapsed day. VI-DE was 17.3 Mcal/animal/day when 50% of the ration DE came from corn silage; when 57% of DE came from silage VI-DE was 19.6 Mcal/animal/day. When heifers weighed 229 kg, their VI-DE was 19.6 Mcal/animal/day and at a body weight of 317 kg, it was 18.6 Mcal/animal/day (when % DE from silage and elapsed days were held constant). At the beginning of the trial they consumed 18.4 Mcal/animal/day and while they consumed 19.7 Mcal/animal/day at the end.

V. Multiple Regression Equations with VI as the Independent Variable

Multiple regression equations were developed in which the animal performance variables ADG and DM efficiency (DM intake, kg per weight gain, kg) were the dependent variables predicted from one of the VI expressions and several other meaningful variables. From models predicting ADG, coefficients of determination (R^2) resulted which explained from 36 to 47% of the variability (Table 5). R^2s from models predicting DM efficiency were somewhat higher (.48 to .60). R^2 was always higher when percent DE from silage, rather than percent DM from

TABLE 5

R^2 VALUES FOR CERTAIN EXPRESSIONS OF ANIMAL PERFORMANCE USED AS DEPENDENT VARIABLES[a]

Independent variables	Dependent variable ADG	Dependent variable DM efficiency
Percent DM from silage; vol. DM intake/day; elapsed day; mid-period weight	0.361	0.480
Percent DE from silage; vol. DE intake/day; elapsed day; mid-period weight	0.468	0.601
Percent DM from silage; vol. DM intake/day/kg body weight; elapsed day; mid-period weight	0.361	0.475
Percent DE from silage; vol. DE intake/day/kg body weight; elapsed day; mid-period weight	0.448	0.586
Percent DM from silage; vol. DM intake/day/metab. size; elapsed day; mid-period weight	0.361	0.476
Percent DE from silage; vol. DE intake/day/metab. size; elapsed day; mid-period weight	0.454	0.591
Percent DM from silage; percent DE from silage; vol. DE intake/day above maint.; elapsed day; mid-period weight	0.473	0.601

[a]The reduction in sum of squares due to fitting each of the models was statistically significant ($P<.0001$).

silage, was one of the dependent variables. This was the case both in the prediction of ADG and DM efficiency.

The individual equation components for predicting ADG and DM efficiency are presented in Table 6. Model number 2 containing the two DE variables (% DE from silage and VI-DE) will be discussed further because more of the variability in ADG was explained.

When 50% of the DE came from silage, ADG was 0.85 kg/day. This increased to 0.97 kg/day when the percentage of DE from silage was increased to 57%. Voluntary DE intake had a marked effect on ADG. At a 15,000 kcal/day intake of DE, ADG was 1.07 kg/day. When the daily DE intake increased to 21,000 kcal the predicted ADG decreased to 0.75 kg/day. These results do not agree with common knowledge in animal nutrition and cannot be explained. They may be caused by some remaining confounding not removed when percent of DE from silage, elapsed day and mid-period weight were held constant. With the other variables held constant, heifers gained 1.07 kg/day at the beginning of the experiment and 0.77 kg/day at the end, and lighter animals (279 kg) gained 0.84 kg/day while the predicted ADG for heavier heifers (317 kg) was 0.96 kg/day.

Model number 3 will be used to explain the effect of percent DM silage, VI-DM, elapsed days and mid-period weight on the dependent variable DM efficiency. Less of the variability in DM efficiency was explained by this equation (R^2 = 0.601) but model 3 was considered more meaningful since it contained all the DM variables.

Overall means for DM efficiency for the experiment was 6.57 kg of DM intake per kg of body weight gain, with a standard error of 1.88

TABLE 6

PARTIAL REGRESSION COEFFICIENTS, MEAN INTERCEPT AND R^2 VALUES FOR CERTAIN EXPRESSIONS OF ANIMAL PERFORMANCE USED AS THE DEPENDENT VARIABLE

	Dependent variables			
	ADG		DM efficiency	
Mean intercept	0.828	0.756	-1.06	-0.467
Percent DM from silage	-0.000412		0.0608	
Percent DE from silage		0.0167		-0.0770
Voluntary DM intake/day	-0.00398		1.01	
Voluntary DE intake/day		-0.0000530		0.000653
Elapsed day	-0.00406	-0.00278	0.0338	0.0159
Mid-period weight	0.00124	0.00136	-0.0130	-0.00648
R^2	0.361[a]	0.468[a]	0.480[a]	0.601[a]

[a]The reduction in sum of squares due to fitting each of the models was statistically significant ($P<.0001$).

(Appendix Table 8). This DM efficiency was similar to the one for Good heifers (7.7) and Medium heifers (8.0) calculated from the data of Anderson, High and Chapman (1971) who fed primarily corn silage rations for 140 days.

Percentage of the ration DM coming from silage influenced DM efficiency greatly. When 56% of the ration DM came from silage, DM efficiency was 6.1. DM efficiency decreased to 6.6 (larger number denotes lower efficiency) when the ration DM contributed by silage increased to 63%. When % DM from silage, elapsed days and body weight were held constant, a 4.6 kg/animal/day DM intake resulted in DM efficiency of 5.7 while an increase in the plane of nutrition (6.07 kg VI-DM) decreased feed efficiency to 7.2 kg of DM per kg of body weight gain. Within the limits of this experiment, elapsed days had the greatest effect on DM efficiency. At the start of the experiment (day 1) heifers were most efficient in converting DM intake to body weight gains (4.4 kg of DM intake per kg of gain). Toward the end, heifers were least efficient because 5.7 kg of DM intake were required for them to gain 1 kg of body weight. The influence of body weight on DM efficiency was less than that of the two aforementioned variables. Heifers weighing 229 kg required 7.1 kg of DM intake to make 1 kg gain while heifers weighing 317 kg required 8.0 kg.

VI. Conclusion

In the present study, the individual and combined effects of some of the commonly-measured or easily-calculated variables on voluntary intake of dry matter or digestible energy have been determined.

It has previously been recognized that the type of ration (proportion of concentrates to forages) has a great effect on voluntary DM intake. In the present study, there were no great differences between forage: concentrate ratios, i.e. percent of DM coming from corn silage varied only from 50 to 70%, in extreme situations. Yet a pronounced effect of a changing forage:concentrate ratio on VI by beef heifers was still observed. The forage-to-concentrate ratio had a greater effect on the voluntary intake of digestible energy than on the voluntary intake of dry matter. The marked effect of voluntary ration intake of beef heifers fed a high corn-silage ration on the rate of body weight gains and feed efficiency was also demonstrated and quantified. This effect was in addition to effects of body weight, forage:concentrate ratio and length of the experiment.

CHAPTER V

SUMMARY

The objectives of this study were to determine the influence of ration characteristics and body characteristics on voluntary feed intake of beef heifers and to determine the influence of voluntary ration intake on animal gains and feed efficiency when corn silage was fed as the primary ration constituent.

Corn silage ad libitum and 2.72 kg of various concentrates per animal per day were fed to 432 beef heifers, initially weighing 204-227 kg, during three one-year periods. The experiments were from 110 to 140 days in length and each experiment was divided into four periods of approximately one month each. Body weights and sonaray measurements of fat thickness were determined initially and at monthly intervals throughout the experiment. These measurements provided the basis of the body characteristic variables (percent fat and percent lean) and for the calculation of average daily gain (ADG) for each experimental period. Daily amounts of feed offered, refused and consumed by each pen of animals provided the basis of the voluntary intake variables and for the feed efficiency variables for each experimental period.

Factors known or suspected to affect voluntary intake (VI) were used, and their effects on voluntary intake were determined using simple correlation coefficients with period measurements used as repeat observations.

The independent variables, percent dry matter (DM) from silage, percent digestible energy (DE) from silage, mid-period weight and elapsed days, were utilized to establish useful multiple regression equations to predict voluntary feed intake.

Simple correlation coefficients between various voluntary intake measurements and other factors known or suspected to influence either ADG or feed efficiency (DM intake, kg per body weight gain, kg) were calculated.

Multiple regression equations were also developed to determine the influence of voluntary intake and other variables (percent DM from silage, percent DE from silage, voluntary DM intake per day, voluntary DE intake per day, elapsed days and mid-period weight) on animal performance (ADG and feed efficiency) with period measurements used as repeat observations.

Voluntary intake of dry matter (VI-DM) and of digestible energy (VI-DE) was highly correlated with either variable which characterizes the ration, namely percent of either DM or DE from silage (r = approximately 0.8). Therefore, VI increased as the proportion of silage in the ration increased. The other expressions of VI (VI per body weight, VI per metabolic size and VI above maintenance) were also positively correlated with percentage of either DM or DE contributed by silage.

There were highly positive correlation coefficients between VI and body weight. When VI was expressed per body weight, it was negatively correlated with body weight. Expressing VI per metabolic body size reduced the influence of body weight to approximately 7% of the total influence of body weight.

ADG was positively correlated with VI in some experimental periods only. This was due to lower than expected gains in one period while

VI was as high as expected. Feed efficiency (higher numbers represent lower efficiency) was positively correlated with VI, VI per body weight, VI per metabolic size and VI-DE above maintenance.

There was a high positive correlation between estimated fat percentage of the carcass and VI-DM and VI-DE. Almost all coefficients within periods were also positive (VI-DM, period 1-4: .60, .62, .31, and .46; VI-DE, periods 1-4: .59, .64, .20, and -.05). The fatter animals consumed more DM and more DE even within a period probably because they were also the heavier animals.

The more meaningful prediction equations for VI were as follows: VI-DM, kg/day = -1.73 + 0.0806 (%DM from silage) + 0.00902 (mid-period weight, kg) - 0.00274 (elapsed days); VI-DE, kcal/day = -1321 + 327 (%DE from silage) + 3.04 (mid-period weight, kg) + 24.1 (elapsed days). The more meaningful prediction equations for animal performance were as follows: ADG, kg = 0.756 + 0.0167 (%DE from silage) - 0.0000530 (VI-DE, kcal/day) - 0.00278 (elapsed days) + 0.00136 (mid-period weight, kg); DM efficiency = -1.06 + 0.0608 (%DM from silage) + 1.01 (VI-DM, kg/day) + 0.0338 (elapsed days) - 0.0130 (weight, kg).

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LITERATURE CITED

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APPENDIX

TABLE 7

SUMMARY OF VOLUNTARY DM AND DE INTAKE

Ration Treatment			Voluntary DM intake per day			Voluntary DE intake per day			
No.	Supplement[a]	Period	kg	Per kg body weight, kg	Per metab. size, kg	Mcal	Per body weight, kcal	Per metab. size, Mcal	Above maint., Mcal
1	---	1	4.93	.0209	.0818	16.1	68.3	.268	11.6
		2	5.58	.0212	.0853	18.6	70.5	.284	13.6
		3	5.62	.0186	.0774	18.3	60.2	.251	12.7
		4	5.77	.0184	.0774	20.3	64.9	.273	14.6
		mean	5.47	.0198	.0805	18.3	66.0	.269	13.1
2	0.6% CSM	1	5.14	.0218	.0853	16.6	70.5	.276	12.0
		2	5.70	.0214	.0866	18.9	70.8	.286	13.8
		3	5.80	.0188	.0788	18.6	60.5	.253	13.0
		4	5.99	.0189	.0797	20.9	66.1	.278	15.2
		mean	5.66	.0202	.0826	18.8	67.0	.274	13.5
3	0.1% Urea	1	5.16	.0219	.0857	16.5	70.2	.275	12.0
		2	5.76	.0217	.0875	18.9	70.9	.286	13.9
		3	5.96	.0194	.0812	19.0	6.17	.258	13.4
		4	6.07	.0192	.0809	21.0	66.5	.280	15.3
		mean	5.74	.0205	.0838	18.9	67.3	.275	13.6
4	1.2% CSM	1	4.85	.0206	.0805	15.8	67.2	.263	11.3
		2	5.42	.0206	.0829	18.1	68.5	.275	13.1
		3	5.45	.0181	.0754	17.7	58.7	.244	12.2
		4	5.76	.0185	.0778	20.2	65.1	.273	14.6
		mean	5.37	.0194	.0791	17.9	64.9	.264	12.8
5	0.2% Urea	1	4.60	.0201	.0782	15.0	65.7	.255	10.6
		2	5.15	.0199	.0798	17.1	66.3	.266	12.2
		3	5.51	.0184	.0764	18.1	60.3	.251	12.6
		4	5.66	.0183	.0767	20.3	65.7	.275	14.7
		mean	5.23	.0192	.0778	17.6	64.5	.262	12.5

[a]Supplement to the corn silage-cracked shelled corn ration.

TABLE 8

SUMMARY OF VARIOUS RATION AND ANIMAL PERFORMANCE CHARACTERISTICS

Ration treatment			Ration characteristics		Animal performance per day		
No.	Supplement[a]	Period	DE from silage, %	DE from silage, %	Mid-period weight, kg	ADG, kg	DM intake per gain kg/kg
1	---	1	58.0	50.1	236	0.99	5.02
		2	59.6	51.7	264	0.83	7.03
		3	60.6	52.8	303	0.94	6.06
		4	62.5	54.8	314	0.72	8.42
		mean	60.2	52.4	279	0.87	6.63
2	0.6% CSM	1	59.6	52.1	236	1.07	4.82
		2	60.2	52.8	266	0.91	6.44
		3	61.5	54.1	308	0.90	6.56
		4	63.6	56.3	317	0.73	8.50
		mean	61.2	53.8	282	0.90	6.58
3	0.1% Urea	1	59.5	52.4	236	1.10	4.72
		2	60.4	53.4	266	0.88	6.77
		3	62.3	55.4	308	0.93	6.45
		4	63.8	57.0	317	0.71	8.85
		mean	61.5	54.5	282	0.90	6.70
4	1.2% CSM	1	58.7	50.8	235	1.03	4.74
		2	59.5	51.7	263	0.82	6.87
		3	60.6	52.8	301	0.82	6.89
		4	63.6	55.9	311	0.74	8.08
		mean	60.6	52.8	277	0.85	6.65
5	0.2% Urea	1	56.3	48.4	229	1.01	4.60
		2	56.4	48.4	259	0.90	5.78
		3	60.4	52.5	301	0.87	6.44
		4	62.5	54.8	309	0.73	8.15
		mean	58.9	51.0	275	0.88	6.23

[a]Supplement to the corn silage-cracked shelled corn ration.

TABLE 9

SUMMARY OF BODY CHARACTERISTICS

Ration treatment			Body characteristics		
No.	Supplement[a]	Period	Initial fat, mm	Mid-period fat, %	Mid-period lean, %
1	---	1	3.62	17.5	68.5
		2	3.62	21.1	64.9
		3	3.62	24.4	61.6
		4	3.62	25.6	60.4
		mean	3.62	22.1	63.9
2	0.6% CSM	1	3.54	17.6	68.4
		2	3.54	21.3	64.7
		3	3.54	24.8	61.2
		4	3.54	26.0	60.0
		mean	3.54	22.4	63.6
3	0.1% Urea	1	3.41	17.4	68.6
		2	3.41	21.1	64.9
		3	3.41	24.5	61.5
		4	3.41	25.8	60.2
		mean	3.41	22.2	63.8
4	1.2% CSM	1	3.37	17.1	68.8
		2	3.37	20.7	65.3
		3	3.37	24.0	62.0
		4	3.37	25.3	60.7
		mean	3.37	21.8	64.2
5	0.2% Urea	1	3.18	16.4	69.6
		2	3.18	20.1	65.9
		3	3.18	23.7	62.3
		4	3.18	25.0	61.0
		mean	3.18	21.3	64.7

[a]Supplement to the corn silage-cracked shelled corn ration.

TABLE 10

OVERALL MEANS AND STANDARD DEVIATIONS OF VOLUNTARY INTAKE AND VARIOUS RATION, ANIMAL PERFORMANCE AND BODY CHARACTERISTICS

Variable	Mean	Standard deviation
Voluntary DM intake per day		
total, kg	5.51	0.584
per kg body weight, kg	0.0199	0.00191
per metabolic size, kg	0.0809	0.00671
Voluntary DE intake per day		
total, Mcal	18.3	2307
per body weight, kcal	66.0	6.56
per metabolic size, Mcal	0.269	24.9
above maintenance, Mcal	13.1	2017
DM from silage, %	60.5	4.57
DE from silage, %	53.0	4.82
Mid-period weight, kg	279	34.4
ADG, kg	0.881	0.173
DM intake, kg per gain, kg	6.57	1.88
Initial fat, mm	3.44	1.08
Mid-period fat, %	22.0	0.0370
Mid-period lean, %	64.0	3.70

VITA

Jerry Wright Williams, son of Harry Edward Williams and Maxine (Wright) Williams was born in Nashville, Davidson County, Tennessee on May 5, 1934. He attended elementary school in Davidson and Dickson County and graduated from Dickson High School in 1952. He was employed by the Tennessee State Highway Department from 1952 until 1956. From July 1956 until July 1960 he served in the United States Air Force. In September 1961, he entered East Taxas State University at Commerce where he received the Bachelor of Science degree in Agriculture in 1965 and the Master of Science degree in Agriculture in 1966.

In August 1966 he was employed by Middle Tennessee State University at Murfreesboro as a member of the Department of Agriculture in charge of the horse science program.

In June 1968 he began graduate study in the Department of Animal Husbandry-Veterinary Science at the University of Tennessee, Knoxville. He received the Doctor of Philosophy degree with a major in Animal Science in December 1975.

He is a member of the American Society of Animal Science, the Equine Nutrition and Physiology Society and is a Master Mason.

He is married to the former Glenda Jane Moore of Van Buren, Crawford County, Arkansas.