INFLUENCE OF CORN MOISTURE, PROTEIN CONCENTRATION AND MONENSIN ON DIGESTION BY FEEDLOT STEERS

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CHAPTER I

INTRODUCTION

Increased cost of production with little increase in return has placed the cattle feeder in a price squeeze. Methods to decrease the cost of production must be investigated. Use of new cattle breeds, growth stimulants, digestive stimulants, feed processing, cheaper feed sources, properly balanced diets, low cost storage facilities and mechanization may help decrease cost of production. Research at Oklahoma State University and cooperating feedlots in the Oklahoma Panhandle have examined some of these methods. This thesis concerns the area of digestive stimulants and feed processing.

In 1976, 192 yearling steers were fed high moisture corn diets with and without monensin in a feedlot study at Goodwell, Oklahoma (Martin et al., 1976). The steers initially weighed 342 kg and were fed either 11 or 12% crude protein diets with or without 0.5% urea. Monensin supplementation was at 27 grams per ton of air dried feed. Protein level had no effect on daily gain or feed efficiency. Urea substitution for soybean meal decreased feed intake and gains. Monensin increased feed efficiency 4.1%, decreased feed intake 5.6% and had no effect on daily gain.

In the following year (Gill et al., 1977a) reported a similar trial with 160 yearling steers fed a whole shelled corn diet with and without monensin at four protein levels (9.5, 10.3, 11.2 and 12.3%). The protein source was soybean meal and monensin supplementation was at 33 ppm. As protein levels increased, daily gain increased 7% and feed efficiency increased 5%. Monensin reduced feed intake 4% and increased feed efficiency 5% with no affect on daily gains. A monensin-protein interaction was apparent. Monensin addition increased feed efficiency most with the lower protein diets. Consequently, a "protein sparing action of monensin" was proposed. Such action has been supported in trials from South Dakota (Gates et al., 1977) and Kentucky (Boling, 1977).

Gill et al. (1978) reported a feeding trial with 187 yearling steers (219 kg) fed a high moisture corn diet with and without monensin at three protein levels (9, 11 and 13%). The protein source was soybean meal with monensin added at 30 ppm. As protein concentration increased, gain and feed efficiency increased. Monensin depressed feed intake and increased feed efficiency by 3%. No "protein sparing effect" was noted in that study as monensin proved more useful in improving feed efficiency with the higher protein levels. Differences between the trials conducted at Goodwell, Oklahoma include corn moisture and forage source.

Response to monensin may depend on feed processing. The 3-5% increase in feed efficiency response to 33 ppm monensin in these three trials is well below the 7-10% improvements reported by Davis and Erhart (1975) with high moisture corn, Sherrod et al. (1975) with steam flaked milo, Wolfe and Matsushina (1975) with whole and steam flaked corn, Raun et al. (1976) with dry corn and Utley et al. (1977) with dry ground corn. Monensin may be more useful with dry corn diets. Thornton et al. (1978a) conducted a digestion trial with 12 Angus steers fed whole shelled corn with and without monensin at two protein levels (9 and 12%) using the protein supplements from the Gill et al. (1977a) trial. Monensin increased dry matter and starch digestibility at the low protein level but not at the higher protein level, suggesting that either monensin or protein enhanced energy availability. Yet, why monensin has shown more benefit with dry corn diets as compared to high moisture corn rations remained unclear.

A digestion trial was therefore conducted to examine the corn moisture by monensin by protein level interaction. Sixteen yearling steers were used in four half plaid 4 by 4 latin squares. Two corn moistures (11 and 23%) and two protein levels (9 and 13%) were fed with and without 33 ppm monensin. Affects on ad libitum nutrient intake, digestibility and nitrogen retention were monitored. The design permitted determination of main effects with full statistical power with 64 observations per mean. The four interactions of corn moisture, protein level and monensin supplementation were confounded in separate latin squares so that the two and three way interactions could be clearly measured in three of the four squares (48 observations per mean).

CHAPTER II

REVIEW OF LITERATURE

Monensin

Chemical Description

Monensin is a polyether antibiotic produced by a strain of *Streptomyces cinnamonensis*. The code of Federal Regulations - Title 21 - Section 138.2, defines monensin as: 2-(5-Ethyltetrahydro-5-(tetrahydro-3-methyl-5-(tetrahydro-6-hydroxy-6-(hydroxymethyl)-3,5-dimethylpyran-2-yl)-2-furyl)-9-hydroxy-β-methoxy-αγ,2,8-tetramethyl-1,6-dioxaspiro(4,5)decane-7-butyric acid (Elanco 1975). During the manufacturing process, monensin is exposed to sodium ions during a pH adjustment, hence, the name monensin sodium. The additive is marketed under the trade name, Rumensin, by Elanco Products Company, a Division of Eli Lilly and Company, Indianapolis, Indiana.

Performance Effects

Feeding trials in the midwestern and southwestern states have established that feeding of monensin improves feed efficiency and decreases feed intake of cattle fed high concentrate diets and improves rate of gain and feed efficiency of cattle fed high roughage rations. Utley (1976) reviewed monensin feeding trials and concluded that:

A. Most grazing trials with young cattle show increases in average daily gain from 27% to 32% when 100 to 200 mg/head/day monensin is fed.

B. High roughage growing diets supplemented with 33 ppm monensin require 6 to 17% less feed per unit of gain and produce average daily gains equal to or better than animals not fed monensin.

C. With high energy finishing diets supplemented at concentrations below 44 ppm monensin, feed intake decreases with increasing monensin concentration with little change on average daily gain. Feed efficiency is improved 5 to 10% with monensin supplementation.

Raun (1976) reported that 11 ppm monensin increased gains by 5% on finishing rations. Wolfe and Matsushima (1975) reported no increase in average daily gain but increased feed efficiency at all levels of monensin.

Biochemical Aspects

Monensin alters *in vitro* metabolism yielding higher propionic acid and lower acetic and butyric acid concentrations (Richardson et al., 1974; Schelling et al., 1978). Alterations of volatile fatty acid proportions occur with substrate of either high concentrate or high roughage composition.

In vivo response to monensin appears similar to the *in vitro* response (Raun et al., 1976; Brown et al., 1974; Potter et al. 1976; Wilson et al., 1975; Davis and Erhart, 1975; Perry et al. 1975). The rate of production as well as level of propionate is increased with monensin feeding (Prange et al., 1978). The increased propionic acid production may be derived via the acrylate pathway (Beede and Farlin, 1975).

The potential energy savings from monensin feeding may be (Raun, 1976):

A. propionic acid used more efficiently at the tissue level

B. lower heat increment for propionic acid

C. less energy loss from propionic acid formation

D. protein sparing action

E. stimulation of protein synthesis in the animal

F. changed composition of digesta reaching the small intestines

G. increased extent of digestion.

These points are discussed individually below.

More propionic acid relative to acetate may increase the efficient use of acetic, propionic and butyric acids for growth and maintenance (Smith, 1971). Lofgreen (1976) reported that monensin addition to barley based rations increased the NE_M by 4% and NE_G by 13%.

Infused propionic acid has a lower heat increment than acetate (Hungate, 1966). Since monensin increases propionic acid production, the animal may have a lower heat increment. Since propionic acid enters the Citric Acid cycle via succinate, it can be used efficiently for gluconeogenesis. But whether propionate is used more efficiently than acetate with normal levels of production remains to be proven.

Reduced energy loss in the rumen during the formation of propionic acid as compared to acetic or butyric acid from glucose is one major metabolic advantage. One glucose molecule contains 672 kilocalories per mole. Of this, 62.5% is conserved in two acetate molecules. The major energetic losses in formation of acetic acid is the loss of carbon as methane and accumulation of hydrogen ion equivalents in the rumen. Seventy-eight percent of the energy from glucose is retained during formation of butyric acid. This is slightly more efficient because hydrogen ions are required in the formation of butyric acid from two acetic acid molecules. When two propionic acid molecules are formed from glucose, hydrogen ions are added, increasing the energetic efficiency to 109% due to the reduced loss of reducing equivalents and methane.

Slyter (1978), using a continuous culture apparatus with forage adapted rumen fluid, reported that increased propionic acid formed from monensin is at the expense of acetate and methane production. Thornton and Owens (1977) observed energy loss as methane was decreased by more than 10% across three roughage levels with monensin supplementation. Methane is the end product of hydrogenation of carbon dioxide. A reduction in methane production would be expected since propionic acid formation is consuming hydrogen ion equivalents. If monensin decreased methane production by 10.7%, this could account for a feed efficiency improvement of only 5.5%. This is approximately half of the 10% improvement reported by some researchers. Therefore monensin may be exhibiting other effects on metabolism explaining the other 5% improvement in feed efficiency.

Altering ruminal pH to an optimum level could increase microbial cell production and digestion of feedstuffs. Dinius et al. (1976)

reported that monensin had no effect on ruminal pH *in vitro* with a forage diet. Richardson et al. (1977) reported monensin increased ruminal pH slightly on both feedlot and pasture rations. Since little ruminal pH effect is evident, it seems reasonable that the uptake of hydrogen equivalents by increased propionic acid formation is compensating for the increase in formation of hydrogen equivalents resulting from decreased methane production.

Protein withdrawal below protein requirements decreased daily gain and feed efficiencies (Boling, 1977). Feed efficiency improved with monensin supplementation to the protein withdrawal feeding regime. Consequently, monensin may be exhibiting a protein sparing effect. Results of several feeding trials (Gill et al., 1977a; Boling, 1977; Harvey, 1977; Gates and Embry, 1977) have suggested that monensin may spare protein.

The protein sparing effect of monensin may be the result of one or more of three possibilities. Propionic acid is a precursor of glucose (Leng et al., 1967) which may spare glucogenic amino acids. Much of the glucose synthesis may come from amino acids (Reilly and Ford, 1971).

Monensin may also increase bypass of dietary feed protein by decreasing proteolysis and protein solubilization of feed protein in the rumen (Owens et al., 1978). Similarly, Poos et al. (1978) reported increased bypass of intact plant protein to the lower gastrointestinal tract with monensin addition. Poos attributed this increased bypass of plant protein to reduced proteolysis. Supporting this concept, Potter et al. (1977) reported that monensin decreased ruminal ammonia concentration on low protein rations. Dinius et al. (1976) also reported lower ruminal ammonia levels in vivo with monensin supplemented forage diets. Tolbert et al. (1977) reported a 9.6% increase in free amino acids and a 25% decrease in free ruminal ammonia in a monensin supplemented in vitro system. Richardson et al. (1975) reported decreased ruminal ammonia concentrations with monensin feeding. In vitro incubations with 50 to 100 ppm monensin decreased amino acid degradation by 25.8 and 16.9% over the control diet (Schelling et al., 1978).

Summarizing, monensin in vitro appears to inhibit deamination and lowers ruminal ammonia concentrations. In vivo, monensin may reduce proteolysis and free amino acids and reduce ruminal ammonia concentration. In any case, monensin is inhibiting proteolysis of feed protein and increasing bypass of plant protein to the lower gastrointestinal tract. If these feed proteins are of high quality, they may improve the balance of amino acids reaching the lower gastrointestinal tract. If useful to the animal, this could increase nitrogen retention and efficiency of growth.

Dinius (1978) observed that monensin decreased ruminal ammonia concentration but did not affect the assimulation of ammonia into microbial protein in an in vitro system. Monensin therefore may not stimulate protein synthesis by rumen microbes.

Effects of monensin at the tissue level, either directly or indirectly through propionate and insulin, have not been investigated to date.

Digestibility. Dinius et al. (1976) reported that monensin had no effect on in vivo digestion of dry matter, crude protein, hemicellulose or cellulose on a forage diet fed ad libutum. Nitrogen digestibility was similar, but nitrogen retention tended to be slightly higher with monensin treatment. Tolbert et al. (1977) reported that monensin increased dry matter digestibility with in vitro incubations on a sorghum substrate.

Hanson and Klopfenstein (1977b) reported that during the first 40 days of monensin feeding, dry matter and acid detergent fiber digestibility was decreased with monensin supplementation. However, digestibility of nutrients approached the control animal values after 40 days. Their ration was a sorghum-corn cob combination. Linn et al. (1975) using a marker system, observed no significant effect on crude protein or dry matter digestibility with addition of monensin to a corn silage ration fed ad libutum, although crude protein digestibility was slightly higher with monensin addition. Tolbert and Lichtenwalner (1978) reported that on an ad libutum feeding regime with monensin supplementation, the apparent digestibility of dry matter, crude protein, ether extract and nitrogen free extract were increased while crude fiber digestibility was decreased. This increase in digestibility was not an intake response in their trial as feed intakes were similar. Nitrogen retention was greater for the control animals. Pond and Ellis (1978) observed an increase in digestibility of forage organic matter with monensin supplementation on Coastal bermuda grass pasture. Utley et al. (1977) reported that monensin addition to dry rolled corn or acid preserved high moisture corn fed ad libutum had no significant affect on apparent digestibility of crude fiber or ether extract. The increase in dry matter and crude protein digestibility approached significance with monensin addition. Elanco (1975) summarized six feeding trials and concluded that monensin significantly increased nitrogen digestibility when fed at levels up to 300 mg/head/day and increased cellulose and dry matter digestibility only at a level of 100 mg/head/day.

The data indicates a trend toward increased crude protein and dry matter digestibility with monensin addition. The effects of monensin on crude fiber and cellulose digestibility are questionable.

Intake. Raun et al. (1974); Embry and Swan (1974); Farlin et al. (1975); Gill et al. (1977a); Sherrod et al. (1975); Burroughs (1975) have observed decreased intakes with monensin feeding. Klopfenstein (1977) reported no affect of monensin on feed intake with corn silage based rations supplemented with urea. Baile et al. (1978) stated that monensin has an offensive flavor which cattle must adjust to. Cattle fed monensin in an alfalfa diet ate as much as control animals the first day, but intakes were reduced in subsequent days whereas cattle fed monensin supplemented concentrate diets showed reduced intakes during the first half hour. When monensin was administered intraruminally, the reduced intake did not follow. It was postulated that with an alfalfa diet, the monensin flavor was a conditioned stimulus for development of a post ingestion aversion associated with gastric malaise. With the concentrate diet, the monensin flavor was sufficient to cause an immediate aversion. Hale et al. (1975) reported that monensin decreased feed intake severely the first few weeks but intake increases to approximately 98% of the control animals by the end of most feeding trials.

Interactions

Monensin by Feed Source. Utley et al. (1977) observed no corn type by monensin interaction when monensin was added to dry corn vs. propionic acid-treated high moisture corn. Monensin addition decreased average daily gain and feed intake but increased feed efficiency with both corn types.

Monensin by Protein Level. Potter et al. (1977) observed no monensin by protein level or source interaction on dry matter intake, average daily gain or feed efficiency using protein levels 10.5 and 12.6 percent with concentrate-alfalfa diets. Gill et al. (1977a) reported a monensin by protein interaction with protein levels of 9.5, 10.3, 11.2 and 12.3 in corn based feedlot rations. Monensin depressed feed intake and rate of gain to a greater extent at the higher protein levels. The feed efficiency advantage from monensin feeding was greater at the low protein concentrations. At the low protein concentrations, monensin had little effect on intake but tended to improve both rate of gain and feed efficiency.

Physical Effects

Carcass Characteristics

Blaxter (1962) indicated that a decline in molar percentage of acetate from 70 to 45% resulted in an increase from 33 to 56% in efficiency of adipose tissue synthesis. Since monensin yields acetate to propionate ratio closer to one, it could improve efficiency of fat deposition.

Brown et al. (1974) reported that addition of monensin to concentrate rations increased the carcass cutability bud did not alter quality grade of the carcass. Potter et al. (1976) summarized carcass data from four feeding studies. There was no effect of monensin on the carcass measurements or the proportions of fat, lean or bone in the edible portion of the carcass. Monensin had no effect upon the moisture, fat or protein of the ribeye muscle. However, Thomas (1976) reported that monensin decreased fat over the twelfth rib. Linn et al. (1975) reported monensin had no effect on carcass characteristics with high forage diets and Davis and Erhart (1975) reported no effect of monensin on carcass characteristics with corn based rations.

Digestive Enzymes

Van Hellen et al. (1977) reported that steers fed monensin across two protein levels had increased pancreatic amylase enzyme activity. In 1976 this same group reported a decreased pancreatic amylase activity with monensin addition to diets of different energy density. Energy density had no influence on amylase activity. Data are inconclusive to the effect of monensin on amylase activity. If monensin increased pancreatic amylase activity, this could increase the digestibility of certain ration components.

Microbial Population

Dinius et al. (1976) reported that protozoal or bacterial population were not altered by the addition of monensin to a forage diet. In contrast, Richardson et al. (1975) reported protozoal numbers may be decreased with monensin feeding.

As an Antibiotic

Monensin is effective in preventing coccidiosis in poultry and has a moderate *in vitro* activity against gram-positive organisms (Richardson et al., 1974). Monensin is effective in preventing severe clinical coccidiosis in ruminants (Fitzgerald and Mansfield, 1973; Bergstrom and Maki, 1976).

NPN Additions

The replacement of protein by urea in monensin supplemented diets has resulted in lower average daily gain (Gill, 1977b; Klopfenstein, 1977). Davis and Erhart (1975) observed that urea addition to a monensin diet increased feed efficiency whereas Gill (1977b) and Klopfenstein (1977) reported lower feed efficiencies. On a whole shell corn diet with .5% urea, Martin et al. (1977) reported that monensin increased intake and average daily gain but has no affect on feed efficiency. Gill et al. (1978) suggested that monensin may benefit high moisture corn only if protein concentration is marginal. Monensin may show more benefit with natural protein supplemented diets.

Corn Moisture

Benefits of High Moisture Corn

High moisture corn (HMC) has become widely accepted in the feedlots of the Oklahoma and Texas Panhandle in recent years. As compared with the dry form, high moisture corn has the following advantages (Goodrich and Meiske, 1976):

A. Earlier harvest

 1) reduced field losses

 2) longer harvest period

 3) adaptive to mechanical feeding

 4) no drying expense

 5) more time to complete fall plowing

 6) increased use of corn stalks by beef cows.

B. Allows the use of higher yielding, later maturing corn varieties

C. Highly palatable

D. Reduced separation of ration ingredients in the bunk

E. Improved feed efficiency.

Disadvantages of high moisture corn include:

A. Loss in market flexibility; must be fed to cattle

B. Storage losses may be high if improperly ensiled

C. Rate of feeding must be sufficient to reduce storage losses

D. Moisture level and harvest time are critical

Under many management systems, advantages of high moisture corn outweigh the disadvantages and HMC is increasing in popularity and use.

Factors Affecting Quality of High Moisture Corn

High moisture corn feeding has resulted in variable cattle performance. Moisture content, particle size, corn maturity and method of storing are important variables which may influence the feeding value of HMC. Moisture content in the range of 26-32 per cent minimizes storage losses and maximizes cattle performance (Goodrich and Meiske, 1976; Perry, 1976; Fox, 1976; Thornton et al., 1978b). If the moisture content is too low, it is difficult to pack and exclude air and air reentry. The presence of air inhibits fermentation and allows mold to flourish. Mold can decrease palatability and may be toxic. High moisture corn which contains excessive moisture may undergo more extensive fermentation and have more dry matter and energy loss. Extended fermentation degrades more protein resulting in a higher soluble nitrogen levels and a lower pH (Goodrich and Meiske, 1976). Ensiling high moisture corn with less than 30% moisture should reduce fermentation loss and lengthen bunk life, but waiting for corn to dry in the field will lower yields due to field loss, cause more feeding loss as dust and result in more oxidation and browning due to more difficult packing (Owens and Thornton, 1976).

Corn maturity is an important factor in determining the feeding value of high moisture corn. The nutrients contained in corn are deposited sequentially with maturity (Thornton et al., 1969). Immature corn has a low gross energy value while corn which is too mature has inadequate moisture for fermentation. Corn grain reaches physiological maturity (defined as full deposition of nutrients in the kernal) between 35-40 per cent moisture. Full yield potential therefore is of little concern as there is little reason to harvest high moisture corn above 30 per cent moisture (Goodrich and Meiske, 1976).

High moisture corn is commonly ground or rolled prior to ensiling to facilitate packing and excluding air. Processing is unnecessary if corn is to be stored in an oxygen-limiting structure. Since the effects of particle size and type of storage are generally confounded, they will be discussed together.

Guyer and Farlin (1976) compared dry shelled corn (14% moisture), with high moisture corn ground and stored at either of two moisture levels (24 and 35%) in separate trench silos and with 24% moisture corn stored whole in an oxygen limiting structure but ground at feeding. Daily gains of cattle were higher for those fed dry shelled corn or whole high moisture corn as compared to those fed high moisture corn ground before ensiling in a trench silo. Intakes were greater for cattle fed dry shelled corn as compared to those fed high moisture corn. The high moisture corn stored whole resulted in higher intakes than the high moisture corn stored ground while the lower moisture corn stored ground had higher intakes than the wetter corn. Lambs in a digestion trial were fed dry shelled corn (14% moisture) and high moisture corn (25% moisture) stored in either the ground form in a trench silo or whole in an oxygen limiting silo. Dry matter digestibility was greater for the whole shelled corn and whole high moisture corn than the high moisture corn stored ground (Guyer and Farlin, 1976). The data indicate that particle size and storage method may be important to maximize efficient use of high moisture corn.

Finer particle size of the high moisture corn stored whole and ground at feeding may benefit animal performance. To examine this, Guyer and Farlin (1976) used high moisture corn stored whole in an oxygen-limiting structure in either the whole or ground form. Grinding decreased rate (5%) and efficiency of gain (3%). Decreasing the particle size of the whole high moisture corn was not beneficial in that study. Galyean et al. (1977) used the nylon bag technique to study dry matter digestibility of high moisture and dry ground corn. Rate of digestion up to 24 hours approximately doubled for each particle size reduction of 50%. This suggested that rate of digestion and possibly site of digestion may be altered by particle size.

Performance

Buchanan-Smith (1976) reviewed a series of comparisons between high moisture corn and dry corn. High moisture corn produced animal gains equal or superior to dry corn in 11 of those 17 studies. Even in the six trials in which high moisture corn slightly reduced rate of gain, feed efficiency was superior for high moisture corn. One must draw conclusions cautiously in feed efficiency measurement, however, as oven drying of high moisture corn volatilizes organic acids. This lowers the measured percentage of dry matter and inflates feed efficiency values.

Corah (1976) reviewed fifteen trials comparing ground high moisture corn stored in trench silos to dry corn. He concluded there was a 5.6% reduction in average daily gain with high moisture corn coupled with a 0.7% decrease in feed efficiency. Ten other trials compared whole high moisture corn stored in an oxygen-limiting structure to dry corn. High moisture corn improved both rate of gain (1.9%) and feed efficiency (5.6%)

Moisture level could influence the relative value of high moisture corn, as well as overall performance. Goodrich and Meiske (1976) summarized several trials and concluded that high moisture corn (less than 29% moisture) as compared to dry corn, produced superior gain (2.57 vs 2.53 lb/day) and feed efficiencies (5.83 vs 6.18 lb DM/lb gain). High moisture corn with greater than 29% moisture produced slower rates of gain (2.46 vs 2.62 lb/day) but slightly improved feed efficiency (7.97 vs 8.14 lb DM/lb gain). It seems evident that high moisture corn has an advantage in feed efficiency but the response in rate of gain is variable.

Intake

If feed efficiency is improved but rate of gain is reduced with HMC, feed intake must be depressed. Indeed high moisture corn as compared to dry corn, decreases feed dry matter intake (Tonroy and Perry, 1976b; Harpster et al., 1975; Goodrich and Meiske, 1976; and Guyer and Farlin, 1976). However, Prigge et al. (1978) noticed no depression in feed intake with 25.3% moisture corn and Thornton et al. (1978b) reported that dry matter intake was 2% higher for 23.4% than 30.3% moisture corn. The data indicate that in most situations, high moisture corn decreases dry matter intake. Owens and Thornton (1976) reviewed 36 comparisons and concluded that dry matter intake of high moisture and dry corn were equivalent when the high moisture corn contained about 24% moisture. However, for every 1% added moisture, intake decreased by about 1%. Clark (1976) attributed the reduced intake to improper storage methods and damaged and poor quality feed. Alternatively, acid stress and increased soluble nitrogen levels could explain the lower feed dry matter intake (Goodrich and Meiske, 1976). Owens and Thornton

(1976) reported that intake decreased with moisture level across all methods of preservation. These should represent high moisture corn containing different levels of soluble nitrogen and acid. Prigge et al. (1978) reported the percentage of nitrogen which is soluble in buffer in high moisture corn can vary from 43.8 to 96.9% compared to about 15% in dry corn.

The factors which affect the amount of soluble nitrogen in high moisture corn include acidity, particle size and moisture content. Lactic acid accumulates with bacterial fermentation of carbohydrate. Organic acids lower the pH and stabilize the silage. Although plant enzymes are responsible for nitrogen solubilization in corn silage (Bergen, 1976), solubilization of nitrogen in high moisture corn continues beyond the few hours that plant enzymes remain active. This suggests that proteolytic enzymes from bacteria or simple acid solubilization are important factors in high moisture corn (Prigge, 1976a). Bacterial fermentation may indirectly affect nitrogen solubilization through acid production.

Particle size is another factor determining the amount of soluble nitrogen. At 56 days after ensiling, high moisture corn in the ground form had 38% of its nitrogen in the soluble form compared to 15% for high moisture corn stored whole (Prigge, 1976a). Mositure level or time of harvesting may also affect soluble nitrogen. The correlation between dry matter content and soluble nitrogen was 0.81 in a survey of 17 high moisture corn trench silos. Furthermore, for each additional percentage unit increase in dry matter content, soluble nitrogen increased by four per cent of total nitrogen (Thornton et al., 1976).

Nutrient Digestibility

Nutrient digestibility is slightly higher with high moisture corn than dry corn. Studies are limited, often with restricted feed intake, and differences appear small and variable (Buchanan-Smith, 1976). As compared to dry corn, high moisture corn had greater digestibility for dry matter, crude protein, energy and organic matter (Clark and Harshbarger, 1972; McKnight et al., 1973; White et al., 1973; Tonroy and Perry, 1974a; Galyean, 1975; Harpster et al., 1975; McLeod et al., 1976; Utley et al., 1977; Prigge et al., 1978). Prigge (1976b) reported similar digestibilities of crude protein and nitrogen from dry and high moisture corn.

Starch digestibility is greater for high moisture than dry corn (McKnight et al., 1973; White et al., 1973; Galyean, 1975). The increase in starch digestion appears to occur before the digesta reaches the small intestine. Galyean (1975) observed increased total tract digestibility of starch for ground high moisture of 2.9% more than for dry rolled corn but intestinal digestion was similar between the two corn types. McKnight et al. (1973) observed a slower rate of ruminal outflow and longer turnover time for digesta with steers fed ground high moisture corn as compared with those fed ground dry rolled corn. A portion of these effects can be explained by the finer particle size of the dry corn. Longer retention time for high moisture corn diets could explain the increased digestibility affects of high moisture corn diets. Ruminal starch digestion was much greater for high moisture corn (54.2%) than for dry corn (25.2%) (McKnight et al., 1973). This observation agrees with that of Galyean (1975) in that increased ruminal fermentation was responsible for the increased starch digestion.

In contrast to the observations of McKnight, Prigge et al. (1978) observed high moisture corn as compared with dry corn, had an increased ruminal dilution rate. This may be a particle size phenomenon as the high moisture corn was gound and the dry corn was rolled.

A review (Buchanan-Smith, 1976) of the mechanism whereby additional moisture content enhances utilization may help explain the high digestibility of dry matter, starch and crude protein of high moisture corn. During reconstitution, water penetration of the grain kernal disrupts the aleurone protein layer releasing starch granules and causing the aleurone layer to secrete an amylolytic enzyme. Increased protein solubility usually accompanies increased starch availability. Preservation in the high moisture form for several weeks may have similar effects.

The metabolizable energy content of high moisture corn increases with increasing moisture content. Based on dry corn-high moisture corn comparisons across moisture levels, the energy value of high moisture corn equalled dry corn at 23% moisture. For every 1% increase in moisture content, the energy value increased 0.3% (Owens and Thornton, 1976). There was a very wide scatter of points, however.

The total volatile fatty acid concentration in the rumen is unaffected by corn preservation but the acetate to propionate ratio may be reduced slightly (Tonroy and Perry, 1974a; Clark, 1976). Therefore, the improvement in energy available for production does not appear to be attributable to altered ruminal endproducts.

High protein digestibility for high moisture corn may be related directly to increased dry matter availability as well as to disruption of the aleurone layer and proteolysis increasing solubility of the protein. Because of higher soluble protein levels, high moisture corn results in higher ruminal ammonia concentrations and increases in ruminal pH (McKnight et al., 1973; Prigge et al., 1978). Guyer and Farlin (1976) reported higher ruminal ammonia concentrations, lower ruminal pH and increased nitrogen digestibility with HMC. A higher rumen pH may also enhance the starch and dry matter digestion in the rumen. The addition of urea to dry and high moisture corn diets produced higher ruminal ammonia levels for dry corn than high moisture corn suggesting that urea may be utilized more efficiently for microbial protein synthesis with high moisture corn despite higher soluble nitrogen levels (Prigge et al., 1976b). The same author in 1978 reported 10% more of the abomasal protein was microbial protein for ground high moisture corn than dry rolled corn. Galyean (1975) also observed a greater precentage of the abomasal nitrogen was of microbial origin with ground high moisture corn. This suggests that the soluble protein from HMC may not readily yield ammonia in the rumen. This observation is in agreement with studies using corn silage. The rate of ammonia release from soluble NPN from ensiled material is lower than from urea (Bergen, 1974).

Thornton et al. (1978b) compared digestibility of two high moisture corns at two moisture levels, 23.4 and 30.3%. The drier corn had lower dry matter and starch digestibility but protein digestibility was similar. The calculated metabolizable energy content was over 5% greater and dry matter digestibility 3% greater for the wetter high moisture corn. The drier high moisture corn produced three times as much fecal starch as the wetter high moisture corn.

Practical Implications

The practical implications of feeding high moisture corn were nicely presented at the High Moisture Grain Symposium by Lake (1976). High moisture corn may not be used as well when it is the only grain in the ration. Steam flaked corn complements high moisture corn, improves ration utilization and extends the bunk life of the feed mixture. Finishing rations containing high moisture corn require a minimum of 13% roughage on a dry matter basis to produce acceptable dry matter intakes. Buchanan-Smith (1976) stated that Guelph University recommends adding more roughage to high moisture corn finishing rations when the grain is ground than when grain is fed in the whole form.

The roughage level fed can greatly influence the value of high moisture corn. Rolled high moisture corn has more advantage over rolled dry corn when fed with corn silage than when fed in an all concentrate ration (Perry, 1976). Clark and Harshbarger (1972) reported that dairy cows ate less forage dry matter when fed high moisture corn than dry corn. This may be attributed to higher TDN content of high moisture corn. As compared to ground dry corn, rolled high moisture corn fed with silage had 6.3% higher TDN.

Protein Concentration

Review of Protein Digestion

Protein and other nitrogenous compounds are required for subsistence of ruminant animals. Nitrogenous compounds are metabolized at two locations in the digestive tract. First, in the rumen bacteria digest protein and form protein during growth. Later, in the small intestine protein which bypasses the rumen as well as microbial protein is enzymatically degraded to polypeptides and amino acids. Secretions of the pancreas and small intestine further hydrolyze much of the polypeptide to free amino acids and short peptides. These endproducts are absorbed across the intestional mucosa while the undigested endproducts are passed on to the colon and large intestine.

Intake

Many feeding trials (Weichental et al., 1963; Elliot, 1964; Kay et al., 1968 and 1969; Broster, 1973; Burns et al., 1974; Jahn and Chandler, 1976; Bird and Leng, 1978; Majdoub et al., 1978) have reported greater feed dry matter intakes by cattle fed rations higher in protein concentration. Several other researchers have observed no change or a reduction in intake with increased protein supplementation (Gardner, 1968; Petersen et al., 1973; Stobo and Roy, 1973; Greathouse et al., 1974; Martin et al., 1976; Bolsen and Oltjen, 1978; Martin et al., 1978; Thornton et al., 1978a). Fontenot and Kelly (1963) observed that feed intake increased with protein up to 14.7% crude protein in the ration and decreased thereafter in feedlot studies. Gill et al. (1977a) reported that intakes increased up to a level of 10.3% crude protein and thereafter declined with 386 kg steers fed a whole shelled corn diet.

The above review of feeding trials portrays a variety of responses of protein level on feed intake. Feed intake response to increased protein concentration may depend upon the fiber content of the ration.

Jahn and Chandler (1976) conducted a trial with six week old Holstein bull calves fed four protein levels and three crude fiber levels. Dry matter intake increased at all fiber levels as protein level increased. Intake also increased with increasing fiber content. As fiber level increased, metabolic fecal nitrogen increased and crude protein digestibility declined. Consequently, the protein requirement for maintenance would increase as the roughage to concentrate ratio increased. Jahn and Chandler (1976) stated that increased metabolic fecal nitrogen reduced crude protein digestibility but could only explain half of the increased protein requirement. Low fiber diets generally have faster energy release and higher protein solubility thereby more efficient ammonia utilization, possibly lowering the dietary protein requirement. Majdoub et al. (1978) observed protein intake increased with protein solubility with dairy cows fed a high protein ration.

Dietary insoluble protein fed in excess of body needs, decreases feed intake (Jahn and Chandler, 1976). If excess protein escapes ruminal degradation, it could theoretically cause an amino acid imbalance in the small intestines. This may explain the decreased intake observed by Gill with 386 kg steers fed rations above 10.3% protein and the decreased intake of rations above 14.7% crude protein in feedlot studies reported by Fontenot and Kelly (1963).

In summary, it appears that the protein effects on intake are related to the solubility of the protein and amount and availability of the energy in the ration. Broster (1973) suggested that maximum efficiency of production requires an optimum protein to energy ratio.

Performance

Increasing the protein concentration (ranges of 9.5-21%) of a ration has been shown to increase gains and efficiency of gain (Fontenot and Kelly, 1963; Haskins et al., 1967; Kay, 1969; Stobo and Roy, 1973; Burris et al., 1974; Gill et al., 1977a; Hagsten et al., 1977; Hanson and Klopfenstein, 1977a; Bolsen and Oltjen, 1978). Conversely, Wiechenthal et al. (1963), Gardner (1968) and Martin et al. (1976) have reported that gains and efficiency of gain were unchanged or decreased as protein concentrations increased from 10.6 to 17% of the ration. Hudson et al. (1969) reported that gains were increased with increased protein levels (10 to 14% CP) but feed efficiency was not increased above 12% crude protein in the ration. The response to increased protein concentration in the ration may occur only at certain stages of the growth curve. Braman et al. (1973) and Martin et al. (1978) observed increased gains and feed efficiency the first 56 days with little affect thereafter. This effect early in the feeding trial may also be an adaptation phenomena to the environmental conditions.

The physiological maturity and size of the cattle will also affect performance due to a difference in dietary protein requirement. Average mature size steers weighing 225 kg gained 9% faster and were 10.2% more efficient in feed efficiency than were larger mature size cattle weighing 250 kg fed a high protein ration (Byers et al., 1977). The reason for this difference was attributed to the fact that the average size cattle consumed 30% more dry matter and gained 10% more rapidly relative to metabolic body size. However, the same laboratory (Coady and Byers, 1978) reported similar results with small versus large mature size cattle but the large size cattle responded more positively to elevated protein concentration and deposited more protein per day.

Since performance is a function of intake and intake may depend on the protein to energy ratio, energy may have an influence on performance. Petersen et al. (1973) observed no response to increased protein concentration for steers fed a high corn silage diet. Gains were significantly increased with increasing protein level as high moisture corn replaced corn silage in the ration. Average daily gain increased linearly with increasing energy level while feed efficiency increased linearly with protein or energy concentrations. Similar responses were reported by Fontenot and Kelly (1969) and Danner and Fox (1978).

It therefore appears that performance response to added protein concentration is influenced by several factors. Energy content, solubility of protein, mature size of cattle, protein source and the age of the cattle all affect the response to dietary protein concentration.

The increased feed efficiency which may result from increased protein concentration in the ration may be due to 1) decreased intake with equivalent gains or 2) higher digestibility of ration components. As increased digestibility of protein is often associated with higher protein intake, the increased intake with elevated protein level favor the latter alternative.

Digestibility

Increasing the crude protein concentration of the ration generally increases protein digestibility (Preston et al., 1965; Kay et al., 1968; Oskov and Fraser, 1969) and nitrogen retention (Head, 1953; Fontenot and Kelly, 1963; Hudson et al., 1969; Greathouse et al., 1974; Jahn and Chandler, 1976; Thornton et al., 1978a). Conversely, Gardner (1968) reported no affect of elevated protein concentration on nitrogen digestibility. Stobo and Roy (1973) also reported that nitrogen retention was not affected by crude protein content of the ration. Orskov and Fraser (1973) reported that increasing increments of soybean meal or fishmeal to sheep rations increased the amount of protein reaching the abomasum. Nitrogen retention also increased with increasing protein level.

Dry matter digestibility was increased by elevated protein concentration in several trials (Kay et al., 1968; Greathouse et al., 1974; Poos et al., 1977; Thornton et al., 1978a). Other authors (Stobo and Roy, 1973; Jahn and Chandler, 1976) have indicated no affect of protein level on dry matter digestion. Head (1953) reported no affect of elevated protein on dry matter or cellulose digestibility on rations fed at 0.5, 1.0 and 1.5 times the requirement for energy. Thornton et al. (1978a) reported an increase in starch digestibility while Orskov and Fraser (1969) noticed no difference in starch digestion with elevated dietary protein. Orskov and Fraser (1969) noted no change in ash digestibility with elevated protein concentration.

Generally, elevated protein concentrations have increased nitrogen and dry matter digestibility. Broster (1973) stated that an increase in readily available carbohydrate in the ration increased total organic matter digestibility while reducing digestibility of fiber; protein increased digestibilities of both organic matter and fiber. Glover et al. (1957) in a review of the early literature concluded that digestibility of crude protein increased rapidly at low ration protein concentration (2 to 9%) and thereafter rose more slowly as the crude protein content increased. Orskov and Fraser (1969) reported a decrease in protein digestibility with increasing amounts of protein in the feed resulting in more dietary crude protein absorption from the small intestine of sheep. Broster et al. (1969) reported that if one holds protein or energy constant and varies the other, a quadratic growth curve results. Increased feed efficiency from elevated protein concentration may be attributable partially to increased feed intake and partially to increased digestibility.

The increased digestibility resulting from elevated protein concentration could occur in the rumen, the lower gastrointestinal tract or both. If increased protein is affecting ruminal digestion, it may alter volatile fatty acid composition. Hudson et al. (1969) and Gill et al. (1977a) reported a decreased acetate to propionate ratios while Hanson et al. (1977a) reported an increase in this ratio with increased protein level. Haskins et al. (1967) reported a decrease in acetate and an increase in butyrate. Gill et al. (1977a) and Roffler et al. (1977) reported an increase in ruminal ammonia with added protein. The literature is inconclusive as to the effects of protein supplementation on ruminal parameters.

Influence of Intake on Digestibility

The affect of intake on ration digestibility appears inconclusive. Brown (1966) reviewed the literature of results between experimental stations as well as between trials at a particular station. He concluded that digestibility may decrease slightly as intake increases. With all forage diets, depression in digestibility is more pronounced when forages are extensively processed (finely ground and pelleted) than when less modified (long or chopped hay). The depression in digestibility of mixed diets is variable and appears dependent on factors other than feeding level. Wiktorsson (1971) stated that choice and form of feedstuff and experimental design are the major reasons for the variability of the reported digestibility. He further stated that there was no reason to assume digestibility is lower with high feed consumption so long as the animals are adapted and fed rations containing long hay and crushed concentrates. However, the method of feed processing modifies the rate of passage of food through the gut and can influence digestibility (Blaxter et al., 1956). Digestibility of mixed rations (forage plus concentrate) is depressed as the level of intake increases (Andersen et al., 1959). Such depression is more pronounced at higher levels of concentrates. These same authors reported that trials in which digestibility was not depressed as intake of a mixed diet increased employed older animals, so animal age may be involved as well.

Dairy cows fed mixed diets exhibited a trend toward higher digestion coefficients as the proportion of grain in the ration increased (Lassiter et al., 1957 and 1958).

The effect of intake on digestibility appears to be the result of several factors. Type and processing of feedstuff, experimental design employed, environmental conditions and age of animal will affect ration digestibility.

CHAPTER III

INFLUENCE OF CORN MOISTURE, PROTEIN CONCENTRATION AND MONENSIN ON DIGESTION BY FEEDLOT STEERS[1,2,3]

Summary

The effect and interactions of corn moisture, protein concentration and monensin on digestibility and nitrogen retention were examined with steers in four half plaid 4x4 latin squares. Sixteen 278 kg growing steers were placed in metabolism stalls and fed <u>ad libutum</u> rations consisting of dry rolled or high moisture corn with two protein levels (9.3 or 12.3%) with or without 33 ppm monensin.

Monensin addition decreased dry matter intake (P<.025) and increased digestibility of dry matter and organic matter (P<.025) and starch and nitrogen (P<.10). Elevated protein level increased nitrogen retention and digestibility of dry matter, organic matter and nitrogen (P<.005), starch and ash (P<.10). The high moisture corn ration, as compared to dry corn produced greater digestibility of dry matter

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[1]Journal Article of the Agricultural Experiment Station, Oklahoma State University, Stillwater.
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and starch ($P<.05$) and organic matter ($P<.025$) and decreased feed intake, nitrogen retention and digestibility, and fecal starch ($P<.05$). A protein by monensin interaction ($P<.10$) existed for nitrogen retained per unit of organic matter digested with monensin decreasing retention at the low protein level while monensin increased nitrogen retention at the higher level of protein. Interactions, indicative of a "protein sparing effect" due to monensin were not detected. Added protein and monensin caused similar increases in digestibility of dry matter, organic matter, starch and nitrogen. The increase in nitrogen digestibility with monensin may be the result of increased starch digestion. With less post ruminal starch to ferment with monensin, metabolic fecal nitrogen would be reduced. The greater benefit of monensin with dry than high moisture corn diets may be attributable to the lower starch digestibility of dry corn than high moisture corn. If monensin lengthened ruminal retention time, starch digestibility with dry corn would improve more than high moisture corn since high moisture corn is already well digested.

Introduction

Monensin and other digestive stimulants have gained wide acceptance in recent years due to the high cost of beef production with limited economic return. Monensin improves feed efficiency with high concentrate diets (Utley, 1976). Benefits from monensin addition to a dry corn ration (Gill et al., 1977a) have been greater than with a high moisture corn ration (Gill et al., 1978). In contrast, Utley et al. (1977) reported no corn type by monensin interaction when monensin was added to dry corn or propionic acid-treated high moisture corn. In Utley's trial, feed intake, average daily gain and feed efficiency were depressed by monensin.

Several authors (Gill et al., 1977a; Boling, 1977; Harvey, 1977; Gates and Embry, 1977) have reported that monensin may exert a "protein sparing action." A protein by monensin interaction was not observed by Potter et al. (1977) with corn-alfalfa diets using protein levels of 10.5 and 12.6% while Gill et al. (1977) observed a protein by monensin interaction with whole shelled corn but not high moisture corn feedlot rations.

The purposes of this study were to evaluate 1) the main effects of corn moisture, protein level and monensin on ration digestibility and nitrogen retention and 2) two and three way interactions of corn moisture, protein level and monensin on ration digestibility and nitrogen retention.

Experimental Procedure

Sixteen steers (278 kg) of Hereford and Angus breeding were randomly allotted to four half plaid 4x4 latin squares. Within each square, the four animals were randomly allotted to ration sequence. The 2x2x2 factorial arrangement of treatments included two corn moisture contents (11 and 23%), two monensin levels (0 and 33 ppm) and two protein levels (9.3 and 12.3%). Within each half-plaid square, one of the two or three way interactions was confounded with animal effects and corn moisture effect was confounded with period effects. The design and analysis of variance are shown in tables 1 and 2. The ration (table 3) consisted of corn grain, corn silage (33% DM) plus a non-pelleted supplement which provided protein, vitamins and minerals (table 4).

TABLE 1. LAYOUT OF EXPERIMENTAL DESIGN

	Animal #							
Period	1	2	3	4	5	6	7	8
	Square 11[a]				Square 12[c]			
1	D9M[b]	D13C	D9C	D13M	H13M	H13C	H9M	H9C
2	D13C	D9M	D13M	D9C	H13C	H13M	H9C	H9M
3	H9C	H13M	H9M	H13C	D9M	D9C	D13M	D13C
4	H13M	H9C	H13C	H9M	D9C	D9M	D13C	D13M
	Animal #							
	9	10	11	12	13	14	15	16
	Square 21[d]				Square 22[e]			
5	D9C	D13M	D9M	D13C	H13M	H9M	H13C	H9C
6	D13M	D9C	D13C	D9M	H9M	H13M	H9C	H13C
7	H9C	H13M	H9M	H13C	D13C	D9C	D13M	D9M
8	H13M	H9C	H13C	H9M	D9C	D13C	D9M	D13M

[a]Corn moisture-monensin-protein level interaction is confounded with animal effects.

[b]Designations as follows: D = dry rolled corn; H = high moisture corn; 9 = 9% crude protein; 13 = 13% crude protein; C = 0 ppm monensin; M = 33 ppm monensin.

[c]Corn moisture-protein level interaction is confounded with animal effects.

[d]Monensin-protein level interaction is confounded with animal effects.

[e]Corn moisture-monensin interaction is confounded with animal effects.

TABLE 2. ANALYSIS OF VARIANCE TABLE

Source	df
Total	63
Square	3
Row in Square	12
Corn	1
Square*Corn	3
Row*Square*Corn	8
Columns in Squares	12
Monensin in Square	4
Monensin	1
Monensin*Square	3
Protein in Square	4
Protein	1
Protein*Square	3
From AB-Clean Squares	
Corn*Monensin	1
Square*Corn*Monensin	2
From AC-Clean Squares	
Corn*Protein	1
Square*Corn*Protein	2
From BC-Clean Squares	
Monensin*Protein	1
Square*Monensin*Protein	2
From ABC-Clean Squares	
Corn*Monensin*Protein	1
Square*Corn*Monensin*Protein	2
Error Square	16
Square 11	4
Square 12	4
Square 21	4
Square 22	4

TABLE 3. COMPLETE RATION COMPOSITION[a]

% Protein	IRN[b]	Dry Rolled Corn (%) 9.3	Dry Rolled Corn (%) 12.3	High Moisture Corn (%) 9.3	High Moisture Corn (%) 12.3
Corn Source	4-02-935	76.91	76.79	77.90	77.78
Corn Silage	3-08-153	12.12	12.10	11.60	11.58
Supplement		10.97	11.11	10.50	10.64

[a]Composition is as a percentage of the total dry matter.

[b]International Reference Number.

TABLE 4. SUPPLEMENT COMPOSITION[a]

Protein Level (%)		9[b]		13	
Monensin Level (ppm)		0	33	0	33
	IRN[c]				
Dehydrated Alfalfa Meal	1-00-023	4.57	4.57	4.65	4.65
Soybean Meal	5-04-604	--	--	82.36	82.18
Dicalcium Phosphate	6-01-080	.71	.71	--	--
Calcium Carbonate	6-01-069	9.15	9.15	9.04	9.04
Potassium Chloride	6-03-756	3.94	3.94	1.36	1.36
Trace Mineralized Salt		2.51	2.51	2.55	2.55
Vitamin A (30,000 IU/gram)	7-05-143	.008	.008	.009	.009
Rumensin 60[d]		--	.17	--	.18
Dry Ground Corn	4-02-935	79.09	78.91	--	--

[a]Ingredients in as a percentage of the dry matter.

[b]Supplements were formulated to contain 9 and 13% crude protein.

[c]International Reference Number.

[d]Rumensin level = 277.5 gms/ton of supplement.

The animals were allowed free access to feed with fresh feed provided daily. Orts were weighed and recorded daily. A 24 day conditioning period was employed to adjust the steers to the corn-corn silage ration. Steers were fed each ration for 14 days with urine and feces collected the final five days. The dry corn was rolled prior to feeding. The high moisture corn was coarsely ground with a tub grinder prior to ensiling in a bunker silo in 1977. The high moisture corn[4] was transported to Stillwater, Oklahoma, bagged in plastic bags and frozen. Bags were removed from storage and allowed to thaw for 24 hours prior to feeding.

Animals were housed in pens with slatted concrete floors the first seven days of each period and moved to metabolism stalls for the final seven days. Weight of each animal was recorded upon entering and leaving the metabolism stalls. Hydrochloric acid (250 ml of 6 N acid/day) was added to the urine collection containers to reduce the urine pH below 3 and thereby reduce ammonia loss. Urine pH was measured with pH paper at time of collection and further reduced with 6 N HCl if necessary. A 10% aliquot of feces was retained from each collection. Aliquots were composited and subsamples frozen for each steer within each period. One percent of the urine was retained and frozen. Feed samples to be analyzed from each period were ground through a Wiley mill with a 1 mm screen. Dry ice was added to the high moisture feeds to facilitate grinding.

[4]Provided by Hatch Feedlot Inc., Guymon, Oklahoma.

Dry matter, starch and ash were determined on the ration and feces. Starch was determined as total alpha-linked glucose polymers by the enzymatic procedure of Macrae and Armstrong (1968). Total nitrogen was determined on non-dried feces, urine and feed samples by the macro-Kjeldahl procedure. Fecal pH was measured with a combination electrode when fecal samples were thawed for laboratory analysis.

The data were analyzed by analysis of variance using Least Squares Analysis (1972) and regression analysis using General Linear Model subroutine (1976) of Statistical Analysis System (SAS). Significance differences between treatments was determined by the F-test procedure (Steel and Torrie, 1960).

The corn effect was tested with the square by corn interaction mean square. The protein, monensin and interaction effects were tested using pooled error mean squares.

Results and Discussion

The chemical composition of each ration is presented in table 5 with individual ingredient analysis in table 6. The dry corn had higher dry and organic matter content which is the result of lower moisture content. The higher protein rations contained less starch which is attributable to soybean meal dilution of the corn. Ash content was similar for all rations.

Monensin

Monensin supplementation decreased dry matter intake by 12.3%

TABLE 5. RATION ANALYSIS[a]

	Dry Corn				Wet Corn			
Ration[b]	9C	9M	13C	13M	9C	9M	13C	13M
Dry Matter (%)	73.99	74.10	74.21	74.21	67.59	67.61	67.69	67.71
Organic Matter (%)	93.55	93.71	93.85	93.74	93.49	93.63	93.78	93.66
Starch (%)	67.54	68.07	62.18	61.86	68.20	68.80	62.84	62.84
Crude Protein (%)	9.35	9.27	12.23	12.55	9.24	9.17	12.01	12.33
Ash (%)	4.77	4.66	4.56	4.64	4.40	4.30	4.21	4.29

[a]Composition as a percentage of total dry matter

[b]C = control (no monensin)
M = monensin added (33 ppm)
9 or 13 = predicted protein level (%)

TABLE 6. ANALYSIS OF RATION INGREDIENTS

IRN[a]			Dry Matter	Starch	Ash Crude	Protein	Soluble Nitrogen[c]
4-02-935	High Moisture Corn[b]	(%)	76.97	80.75	1.65	9.34	50.2
4-02-935	Dry Rolled Corn	(%)	89.11	76.00	1.96	9.66	23.6
3-08-153	Corn Silage	(%)	32.91	22.90	7.44	7.11	72.9

[a] International Reference Number

[b] Ingredient analyses on a dry matter basis

[c] Percentage of total nitrogen

(P<.025) as shown in table 7. Many researchers have observed depressions in feed intake with monensin feeding. This has been suggested as a conditioned response to a malaise produced by monensin and associated by the animal with the odor or flavor of impurities in Rumensin but not found in the pure drug (Baile et al., 1978). Fecal starch, urine volume and nitrogen retention tended to be lower with monensin feeding. The decrease in fecal starch may be partially if not entirely explained by more complete digestion resulting from longer ruminal or intestinal retention time and reduced intake (Lemenager, 1977). The decrease in nitrogen retention (g/day) with monensin feeding may partially be explained by reduced energy and protein intake. Monensin addition increased the digestibility of dry matter (P<.025), organic matter (P<.025), starch (P<.10) and nitrogen (P<.10) by 2.8, 2.9, 1.3 and 3.4% respectively. Tolbert and Lichtenwalner (1978) reported increased digestibility of dry matter and nitrogen and Thornton et al. (1978a) reported trends toward enhanced dry matter, nitrogen and starch digestibility with monensin feeding. In this study, the increased dry matter and organic matter digestibility can be explained by the increased starch digestibility resulting from longer retention time in the rumen. Fecal pH was higher (P<.05) with monensin feeding. This may reflect less fermentation and lactate production in the colon if starch is more completely digested before this point is reached.

TABLE 7. INFLUENCE OF MONENSIN ON METABOLISM

	Monensin Concentration (ppm)		
	0	33	SE[a]
Dry Matter Intake (g/day)	4994[bc]	4381[d]	149
Digestibility (%)			
Dry Matter	81.20[c]	83.54[d]	.64
Organic Matter	82.21[c]	84.55[d]	.65
Starch	96.49[g]	97.72[h]	.45
Nitrogen	70.25[g]	72.65[h]	.87
Ash	59.58	61.89	1.47
Nitrogen Retention (g/day)	32.56	29.56	2.06
Nitrogen Retention/Organic Matter Digested (mg/g)	8.086	7.641	.45
Fecal			
pH	5.51[e]	5.77[f]	.076
Starch (%)	10.52	8.65	.082
Ash (%)	9.98	10.54	.33
Urine Output (g/day)	4860	4293	339

[a]Standard error of the mean

[b]Each figure is the mean of 64 observations

[cd]Means in a row with different superscripts differ statistically ($P<.025$)

[ef]Means in a row with different superscripts differ statistically ($P<.05$)

[gh]Means in a row with different superscripts differ statistically ($P<.10$)

Corn Moisture Content

Results summarized by corn moisture are presented in table 8. High moisture corn was associated with decreased dry matter intake ($P<.05$). Several workers have reported decreased dry matter intake with high moisture corn (Harpster et al., 1975; Tonroy et al., 1974b; Goodrich and Meiske, 1976; Guyer and Farlin, 1976). Owens and Thorton (1976) reviewed 36 comparisons of high moisture corn and dry corn. Using regression analysis, they concluded that dry matter intakes were approximately equal for the two corn types when higher moisture corn was 24% moisture. For every 1% increase in corn moisture above 24%, feed intake decreased by 1%. Elevated soluble nitrogen levels may be responsible for the intake depression (Prigge, 1976a).

Nitrogen retention was lower ($P<.025$) when steers were fed the high moisture corn. McKnight et al. (1973) also observed decreased nitrogen retention with high moisture corn as compared to dry corn. Nitrogen digestibility was similar for both corn types. Contrary to this observation, Galyean (1975), McKnight et al. (1973) and Prigge et al. (1978) all reported increased nitrogen digestibility for high moisture corn compared to dry corn. These studies used corn higher in moisture and probably higher nitrogen solubility which may explain some of the increased digestibility. Nitrogen retained per unit of organic matter digested appeared to decrease as corn moisture increased.

Dry matter ($P<.05$), organic matter ($P<.025$) and starch ($P<.05$) digestibilities were greater by 2.9, 3.2 and 3.4 percentage points

TABLE 8. INFLUENCE OF CORN MOISTURE ON METABOLISM

	Corn Moisture (%)		
	11	23	SE[a]
Dry Matter Intake (g/day)	5143[bc]	4232[d]	202
Digestibility (%)			
Dry Matter	81.18[c]	83.56[d]	.47
Organic Matter	82.01[e]	84.75[f]	.46
Starch	95.48[c]	98.72[d]	.67
Nitrogen	71.83	71.06	.55
Ash	64.19[c]	57.28[d]	1.29
Nitrogen Retention (g/day)	34.20[c]	27.91[d]	1.43
Nitrogen Retention/Organic Matter Digested (mg/g)	8.185	7.543	.29
Fecal			
pH	5.48[c]	5.80[f]	.06
Starch (%)	14.31[c]	4.86[d]	1.74
Ash (%)	9.22[g]	11.29[h]	.20
Urine Output (g/day)	4786	4367	207

[a]Standard error of the mean

[b]Each figure is the mean of 64 observations

[cd]Means in a row with different superscripts differ statistically ($P<.05$)

[ef]Means in a row with different superscripts differ statistically ($P<.025$)

[gh]Means in a row with different superscripts differ statistically ($P<.005$)

respectively for high moisture corn over dry corn. The increased digestibility of dry matter and organic matter is due to the increased digestibility of starch with high moisture corn over dry corn. Galyean (1975) observed similar results for high moisture corn and further concluded that more of the starch digestion occurs in the rumen with high moisture corn than with dry corn. This correlates with the decreased fecal starch observed with the wetter corn diet in this trial. Fecal pH ($P<.025$) and ash content ($P<.05$) were increased for the wetter corn. Ash digestibility was decreased by 7 percentage units with high moisture corn over dry corn. The reason for the decreased ash digestibility is unclear but may suggest that additional mineral supplementation may be beneficial with high moisture corn diets.

Protein Concentration

Results for the two protein concentrations are shown in table 9. Increasing the crude protein content to 12.3% increased digestibility of dry matter, organic matter and nitrogen ($P<.005$), starch and ash ($P<.10$) and nitrogen retention ($P<.005$). In this study, the supplemental protein came from soybean meal which is more digestible than corn protein in the basal 9.3% protein ration. This may explain part of the increased nitrogen digestibility at the higher protein level. The low protein ration may have provided insufficient ruminal ammonia to maximize the rate of digestion.

TABLE 9. INFLUENCE OF PROTEIN LEVEL ON METABOLISM

	Protein Level (%)		
	9.3	12.3	SE[a]
Dry Matter Intake (g/day)	4523[b]	4852	149
Digestibility (%)			
Dry Matter	80.39[e]	84.35[f]	.64
Organic Matter	81.41[e]	85.34[f]	.65
Starch	96.49[c]	97.71[d]	.45
Nitrogen	66.35[e]	76.55[f]	.87
Ash	58.74[c]	62.74[d]	1.47
Nitrogen Retention (g/day)	22.55[e]	39.57[f]	2.06
Nitrogen Retention/Organic Matter Digested (mg/g)	5.927	9.800	.45
Fecal			
pH	5.69	5.59	.076
Starch (%)	10.30	8.87	.82
Ash (%)	9.86	10.65	.33
Urine Output (g/day)	4329	4824	339

[a]Standard error of the mean

[b]Each figure is the mean of 64 observations

[cd]Means in a row with different superscripts differ statistically ($P<.10$)

[ef]Means in a row with different superscripts differ statistically ($P<.005$)

Thornton et al (1978a) also reported increased dry matter, nitrogen and starch digestibilities with increasing protein level of whole shell corn diets. Similar results have been reported (Jahn and Chandler, 1976) for nitrogen digestibility and retention with increasing protein concentration with high moisture and dry corn diets. A trend toward higher dry matter intake and more urine output existed for the higher protein level. The fecal pH and starch content tended to decrease at the higher protein level. Fecal ash content tended to increase with increasing protein concentration.

Corn Moisture-Protein Interaction

Combined effects of corn moisture and protein level are presented in table 10. The high moisture corn diet at 9.3% crude protein level produced the lowest nitrogen retention expressed as grams per day or per unit of organic matter digested however, additional protein increased nitrogen retention across both corn types. Increasing the protein level reduced the effect of corn moisture on intake but even at the higher protein level, dry matter intake of high moisture corn was 10.7% below that of dry corn. The stimulation of consumption of high moisture corn by increased protein concentration suggest that form or availability of the nitrogen in high moisture corn may be inadequate. Additional protein had no effect on dry matter intake of the dry corn diet. The soluble nitrogen of high moisture corn is primarily non-protein nitrogen. This may have limited availability to microorganisms in the rumen (Bergen, 1976) and thereby limit microbial growth. Consequently, addition of a high quality protein as soybean meal may stimulate intake.

TABLE 10. INFLUENCE OF CORN MOISTURE AND PROTEIN LEVEL ON METABOLISM

Corn Mositure (%)	11		23		
Protein Level (%)	9.3	12.3	9.3	12.3	SE[a]
Dry Matter Intake (g/day)	5160[b]	5127	3888	4577	210
Digestibility (%)					
Dry Matter	77.70	84.66	83.08	84.04	.91
Organic Matter	79.41	84.61	83.42	86.08	.91
Starch	94.07	96.90	98.93	98.52	.63
Nitrogen	66.63	77.34	66.37	75.76	1.22
Ash	62.36	66.03	55.13	59.45	2.08
Nitrogen Retention (g/day)	27.34	41.07	17.76	38.07	2.11
Nitrogen Retention/Organic Matter Digested (mg/g)	6.67	9.71	5.20	9.89	.63
Fecal					
pH	5.44	5.53	5.95	5.66	.11
Starch (%)	16.20	12.42	4.90	5.32	1.16
Ash (%)	9.19	9.26	10.54	12.04	.47
Urine Output (g/day)	4579	4992	4079	4656	479

[a]Standard error of the mean
[b]Each figure is the mean of 16 observations

The higher protein concentration increased digestibility of dry matter, organic matter and nitrogen within both corn types while increasing starch digestibility and decreasing fecal starch content with dry corn. Additional protein had no effect on fecal starch with high moisture corn, primarily because of the high basal digestibility.

Corn Moisture-Monensin Interaction

The addition of monensin at both corn moisture contents increased fecal pH (table 11). Digestibility of dry matter, organic matter, starch, nitrogen and ash were increased with monensin addition more with the dry corn than with the high moisture corn ration. The reason monensin addition increased nitrogen digestibility more with dry corn than high moisture corn may be associated with cecal starch availability. Orskov et al. (1971) has reported fecal nitrogen is correlated with carbohydrate disappearance in the large intestine . If monensin reduces the amount of starch reaching the lower gut, it should thereby reduce metabolic fecal nitrogen and increase apparent nitrogen digestibility. Monensin supplementation to the dry corn diet decreased fecal starch content. Nitrogen retention in grams per day and per unit of organic matter digested was decreased with monensin addition to the high moisture corn ration.

Protein-Monensin Interaction

The addition of monensin to both protein levels increased the digestibility of dry matter, organic matter and starch (table 12). Monensin addition decreased fecal starch content much more with the

TABLE 11. INFLUENCE OF CORN MOISTURE AND MONENSIN ON METABOLISM

Corn Mositure (%)	11		23		
Monensin (ppm)	0	33	0	33	SE[a]
Dry Matter Intake (g/day)	5354[b]	4933	4636	3829	210
Digestibility (%)					
Dry Matter	79.35	83.02	83.06	84.07	.91
Organic Matter	80.19	83.83	84.23	85.27	.91
Starch	94.30	96.67	98.68	98.77	.63
Nitrogen	69.81	73.86	70.69	71.44	1.22
Ash	62.14	66.25	57.04	57.54	2.08
Nitrogen Retention (g/day)	33.83	34.58	31.29	24.53	2.11
Nitrogen Retention/Organic Matter Digested (mg/g)	8.03	8.35	8.15	6.94	.63
Fecal					
pH	5.37	5.59	5.66	5.95	.11
Starch (%)	16.33	12.30	4.70	5.02	1.16
Ash (%)	9.03	9.41	10.92	11.66	.47
Urine Output (g/day)	5004	4568	4716	4019	479

[a]Standard error of the mean

[b]Each figure is the mean of 16 observations

TABLE 12. INFLUENCE OF PROTEIN LEVEL AND MONENSIN ON METABOLISM

Protein Level (%)	9.3		12.3		
Monensin (ppm)	0	33	0	33	SE[a]
Dry Matter Intake (g/day)	4828[b]	4220	5162	4542	210
Digestibility (%)					
Dry Matter	78.99	81.80	83.42	85.50	.91
Organic Matter	79.98	82.05	82.86	86.25	.91
Starch	95.59	97.41	97.39	98.03	.63
Nitrogen	65.85	66.85	74.65	78.45	1.22
Ash	58.14	59.34	61.03	64.45	2.08
Nitrogen Retention (g/day)	27.31	17.79	37.81	41.32	2.11
Nitrogen Retention/Organic Matter Digested (mg/g)	6.89[c]	4.97[d]	9.28[e]	10.32[e]	.63
Fecal					
pH	5.60	5.78	5.43	5.75	.11
Starch (%)	11.41	9.14	9.62	8.13	1.16
Ash (%)	9.63	10.09	10.32	10.98	.47
Urine Output (g/day)	4830	4890	3834	4758	479

[a] Standard error of the mean

[b] Each figure is the mean of 16 observations

[cde] Means in a row with different subscripts differ statistically ($P<.10$)

9.3% than with 12.3% protein ration. A protein by monensin interaction (P<.10) existed for nitrogen retained per unit of organic matter digested. When monensin was added, nitrogen retained per unit of organic matter digested decreased at the low protein level but increased at the higher protein level. Nitrogen retention followed a similar trend. Performance results reported previously by Gill et al. (1977a), Boling (1977), Harvey (1977), and Gates and Embry (1977) had suggested that monensin has a "protein sparing effect". No monensin by protein interaction on nitrogen parameters were evident in this trial.

Previously, Owens et al. (1978) reported increased bypass of dietary protein but no corresponding increase in microbial protein with monensin supplementation of a 17% crude protein diet. Bypassed feed nitrogen may explain the increased nitrogen retention at the high protein level with both corn types. The supplemental protein was soybean meal which has a high biological value and could increase nitrogen retention. The reason for depressed nitrogen retention with monensin supplementation at the low protein level is unclear.

Corn Moisture-Protein-Monensin Interaction

Least square means for all treatments are presented in table 13. There were no statistically significant three-way interactions.

Regression Analysis

Simple regression equations were calculated for the various dependent variables to detect interrelationships not readily apparent from visual inspection of the tables of results.

TABLE 13. INFLUENCE OF CORN MOISTURE, PROTEIN LEVEL AND MONENSIN ON METABOLISM

Corn Moisture (%)	11				23				
Protein Level (%)	9.3		12.3		9.3		12.3		
Monensin (ppm)	0	33	0	33	0	33	0	33	SE[a]
Dry Matter Intake (g/day)	5407[b]	4913	5301	4953	4248	3527	5023	4130	297
Digestibility (%)									
Dry Matter	75.86	79.54	82.83	86.49	82.11	84.05	84.00	84.08	1.29
Organic Matter	76.89	81.93	83.49	85.73	83.06	83.78	85.40	86.76	1.29
Starch	92.43	95.71	96.17	97.62	98.74	99.11	98.61	98.43	.89
Nitrogen	64.44	68.21	75.17	79.51	67.26	65.48	74.12	77.39	1.73
Ash	59.94	64.77	64.33	67.73	56.34	53.91	57.73	61.16	2.15
Nitrogen Retention (g/day)	30.30	24.38	37.33	44.78	24.31	11.20	38.27	37.86	4.12
Nitrogen Retention/ Organic Matter Digested (mg/g)	7.17	6.16	8.88	10.53	6.61	3.78	9.68	10.10	.90
Fecal									
pH	5.41	5.45	5.32	5.73	5.78	6.12	5.55	5.76	.15
Starch (%)	18.65	13.75	14.00	10.84	4.17	4.63	5.23	5.41	1.64

TABLE 13 (Continued)

Corn Moisture (%)	11				23				
Protein Level (%)	9.3		12.3		9.3		12.3		
Monensin (ppm)	0	33	0	33	0	33	0	33	SE[a]
Ash (%)	9.30	8.77	9.07	9.75	9.97	11.87	11.11	12.22	.66
Urine Output (g/day)	4891	4267	5116	4868	4768	3390	4664	4647	678

[a]Standard error of the mean

[b]Each figure is the mean of 8 observations

Effects of dry matter intake on nutrient digestibility is shown in table 14. Digestibility of dry matter, organic matter and starch decreased whereas digestibility of nitrogen and ash increased as feed intake increased. More of the variation in starch digestibility was associated with intake than of the other nutrients. The inadequacy of intake explaining the digestibility effects is in agreement with results reported by Brown (1966) and Wiktorsson (1971). Monensin decreased intake by a mean of 613 grams per day. Based on the regression equations, this could increase dry matter, organic matter and starch digestion by .12, .13 and .19 percentage points respectively. As monensin addition increased digestibility of these nutrients by 2.3, 2.3, and 1.2% respectively, only a small portion of the increased digestibility of nutrients can be explained by the reduced feed intake when monensin was fed. The affect of intake of an individual nutrient on its own digestibility is given in table 18 in the Appendix A.

Nitrogen retention tended to increase with organic matter intake. For every kilogram of organic matter intake, 12.6 more grams of nitrogen were retained per day (table 14; figure 1). This value is not corrected for maintenance nitrogen requirements so would be expected to be curvilinear. Nitrogen retention is also linearly associated with nitrogen intake. For every ten gram increase in nitrogen intake, nitrogen retention increased 6.37 grams (figure 2).

Nitrogen retention was influenced by energy and nitrogen content and digestibility. Figures 3 and 4 indicate that nitrogen retention increased linearly with digestible organic and nitrogen intake. The regression equations for nitrogen retention from several ration

TABLE 14. INTAKE AFFECTS ON DIGESTIBILITY

Parameter	Regression Equation	r^2
Digestibility of:		
Feed dry matter intake = x, in kg.		
Dry Matter	Y = 86.863 - (.192)X	.05
Organic Matter	Y = 88.540 - (.220)X	.07
Starch	Y = 104.660 - (.322)X	.26
Nitrogen	Y = 66.401 + (.215)X	.03
Ash	Y = 49.423 + (.483)X	.10

Figure 1. Nitrogen retention versus daily organic matter intake Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn; 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn, 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.

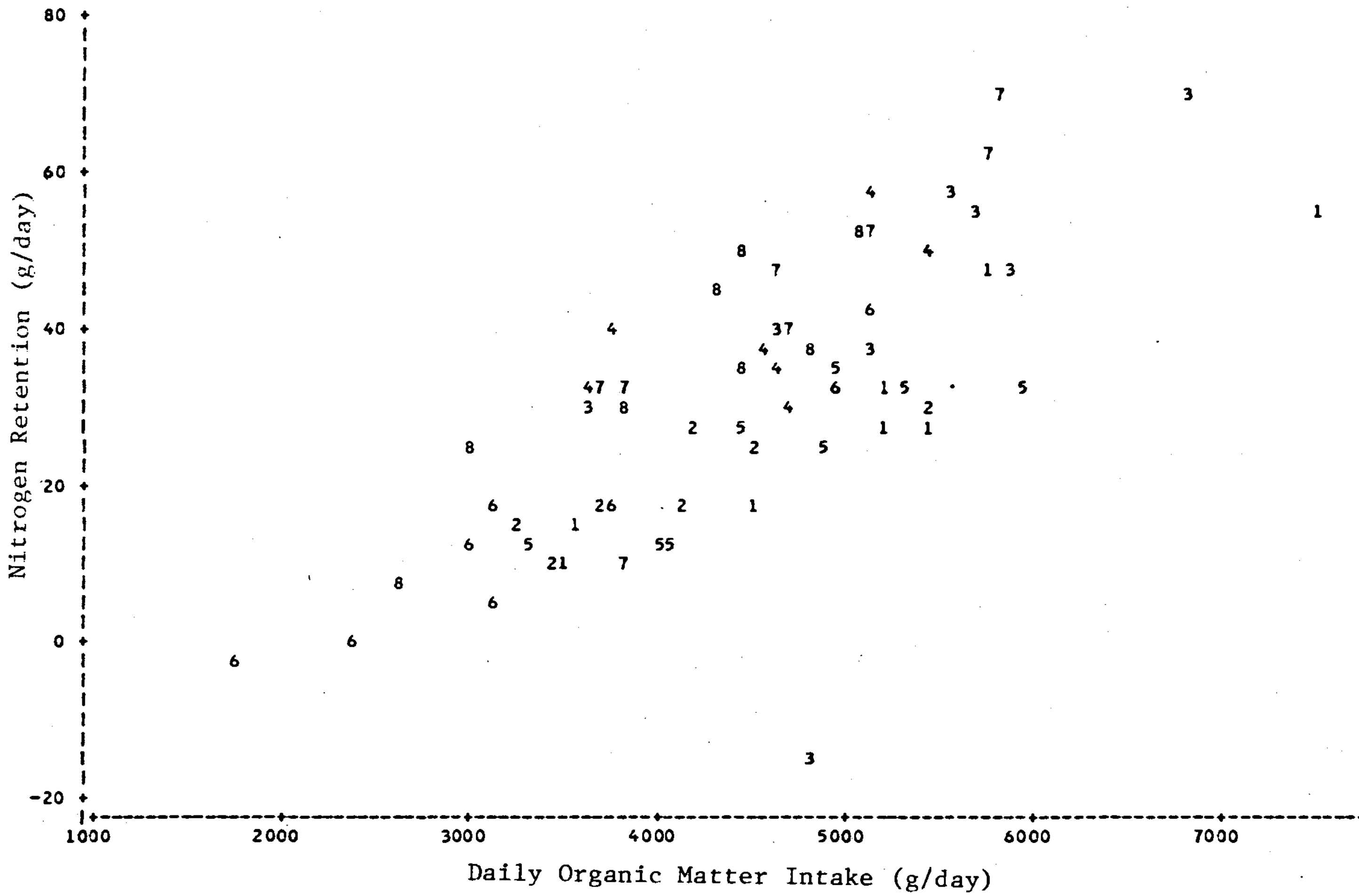

80
60
40
20
0
-20
Nitrogen Retention (g/day)
1000
2000
3000
4000
5000
6000
7000
Daily Organic Matter Intake (g/day)

Figure 2. Nitrogen retention versus daily nitrogen intake
Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn, 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn, 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.

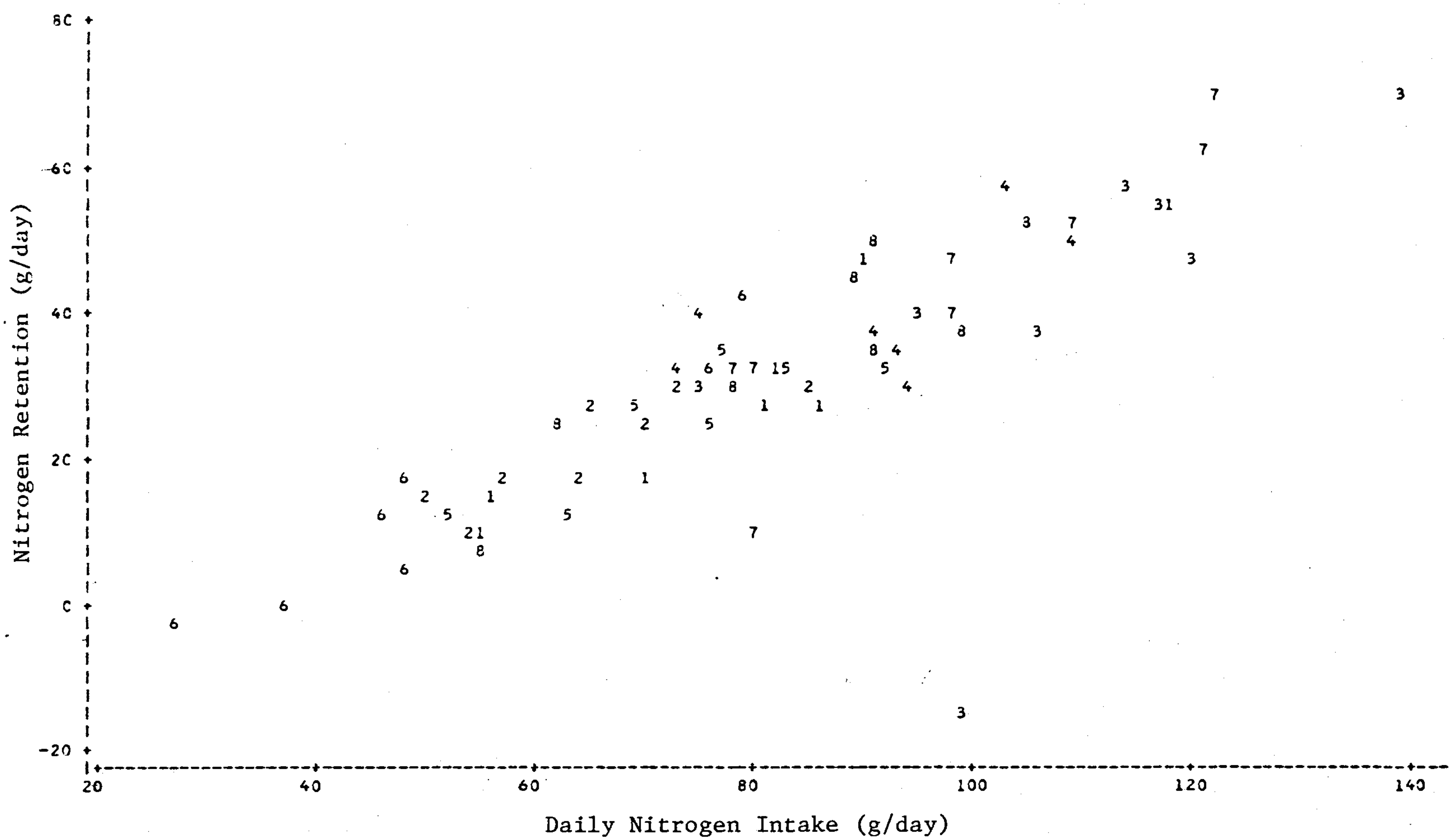
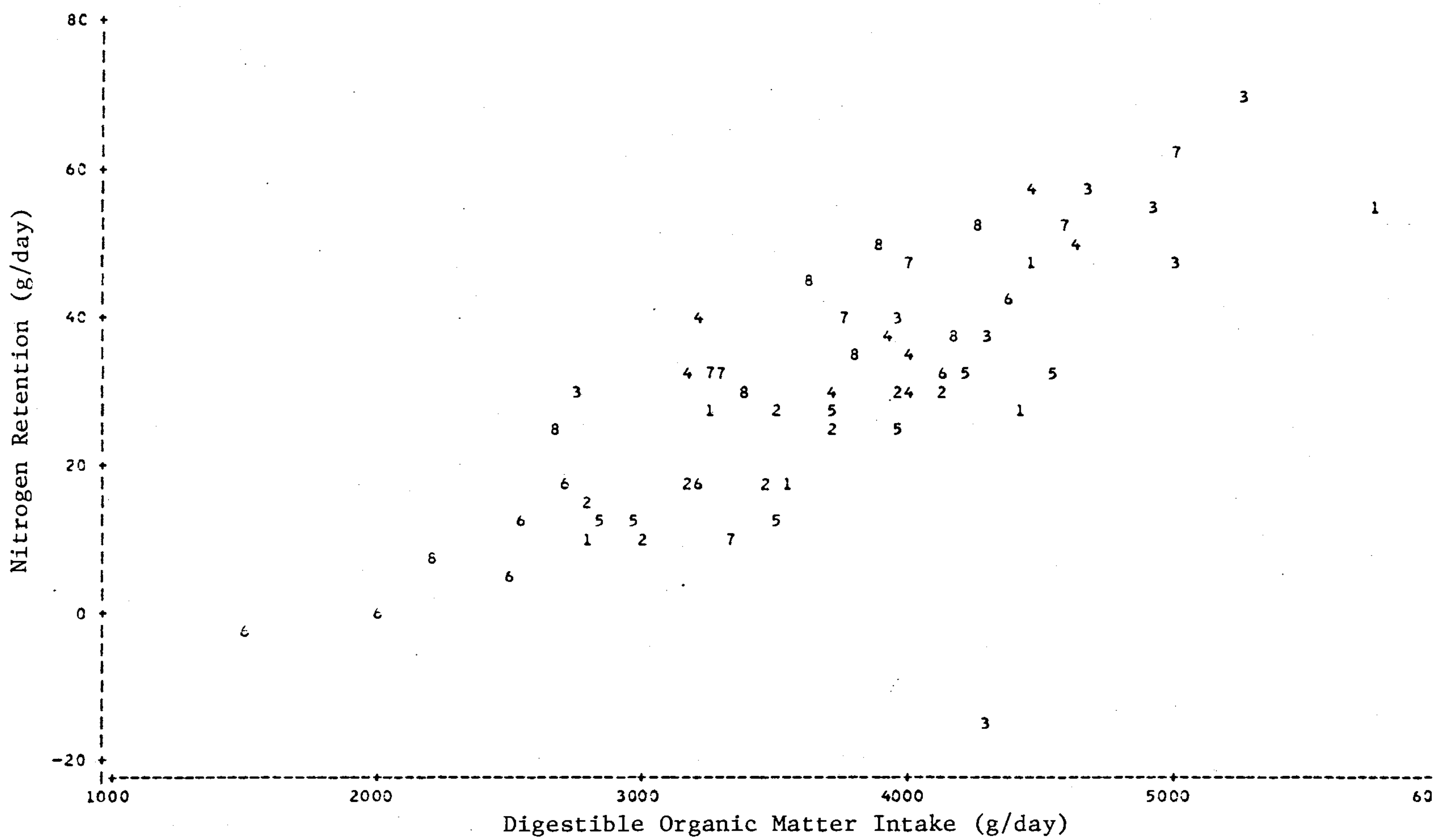
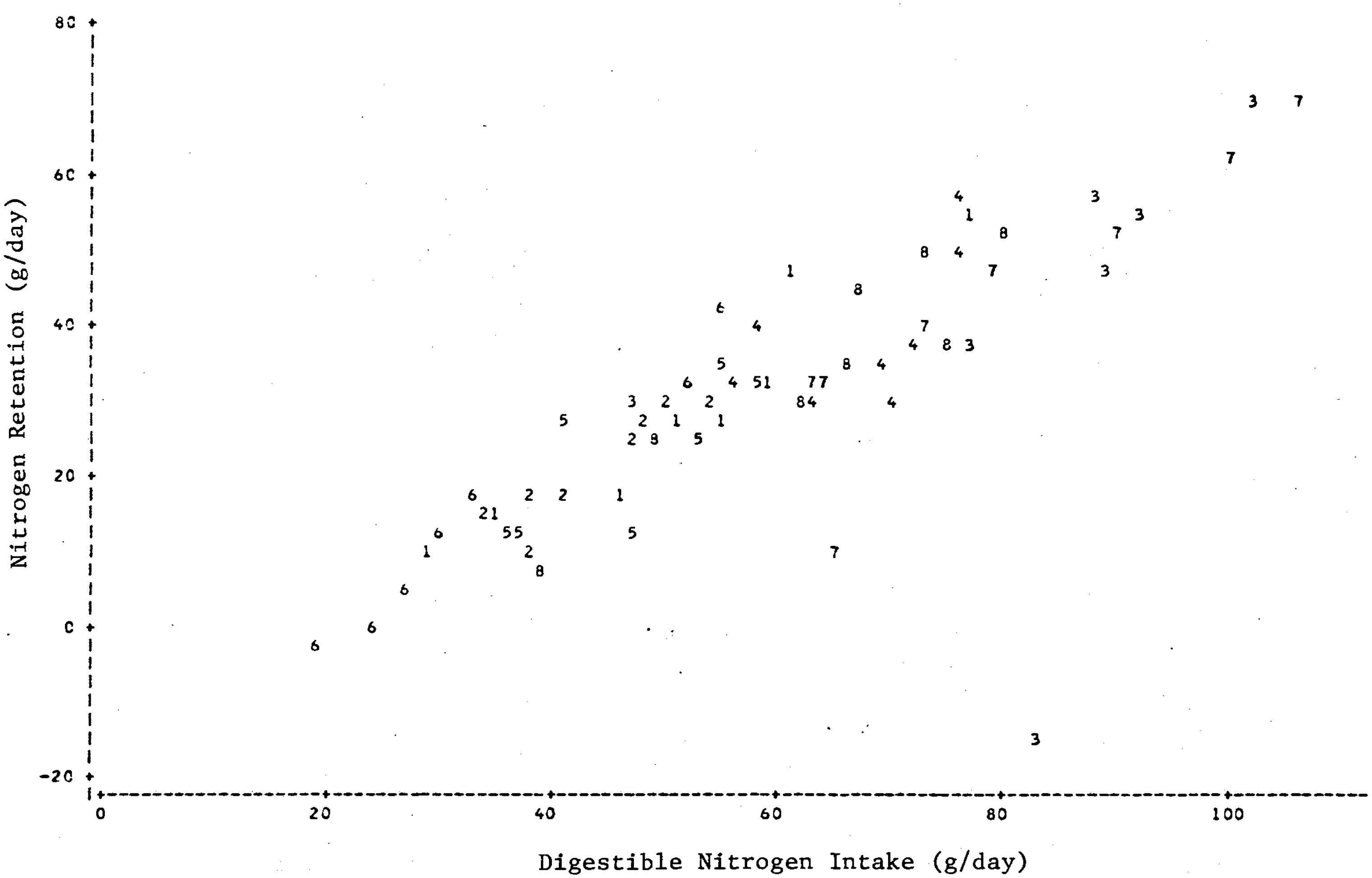

Nitrogen Retention (g/day)
80
60
40
20
0
-20
20
40
60
80
100
120
140
Daily Nitrogen Intake (g/day)

Figure 3. Nitrogen retention versus digestible organic matter intake Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn; 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn, 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.



Nitrogen Retention (g/day)
80
60
40
20
0
-20
1000
2000
3000
4000
5000
60
Digestible Organic Matter Intake (g/day)

Figure 4. Nitrogen retention versus digestible nitrogen intake Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn, 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn, 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.



Nitrogen Retention (g/day)
80
60
40
20
0
-20
0
20
40
60
80
100
Digestible Nitrogen Intake (g/day)

nutrients are presented in Appendix A, table 16. Regression equations for nitrogen retained per unit of organic matter digested are presented in Appendix A, table 17.

Fecal pH tended to increase with starch digestibility (figure 5), but a large amount of variation exists in the scatter plot (table 15). Consequently, fecal pH may be less than an ideal indicator of starch digestion, contrary to results of Wheeler and Noller (1977).

Fecal starch content was an excellent indicator of starch digestibility (table 15). For a 1 percentage unit increase in starch as a percentage of fecal dry matter, starch digestibility decreased by .41% (figure 6).

In conclusion, monensin did not appear to "spare protein" in this study. Monensin did increase nitrogen digestibility but this may be the result of decreased metabolic fecal nitrogen (Owens et al., 1978). Monensin addition to the dry corn diet markedly increased nitrogen digestibility but with the high moisture corn diet nitrogen digestibility remained unchanged and nitrogen retention as a percentage of intake decreased with added monensin. This reduced nitrogen retention may be the result of reduced feed intake with monensin feeding. Alternatively, if monensin decreases ruminal proteolysis and the soluble nitrogen of high moisture corn is of low biological value, monensin could reduce the nutritive value of protein leaving the rumen.

Monensin or protein addition increased digestion of starch from dry corn with no affect on the wetter corn. The increased digestibility

Figure 5. Starch digestibility versus Fecal pH
Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn, 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn; 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.

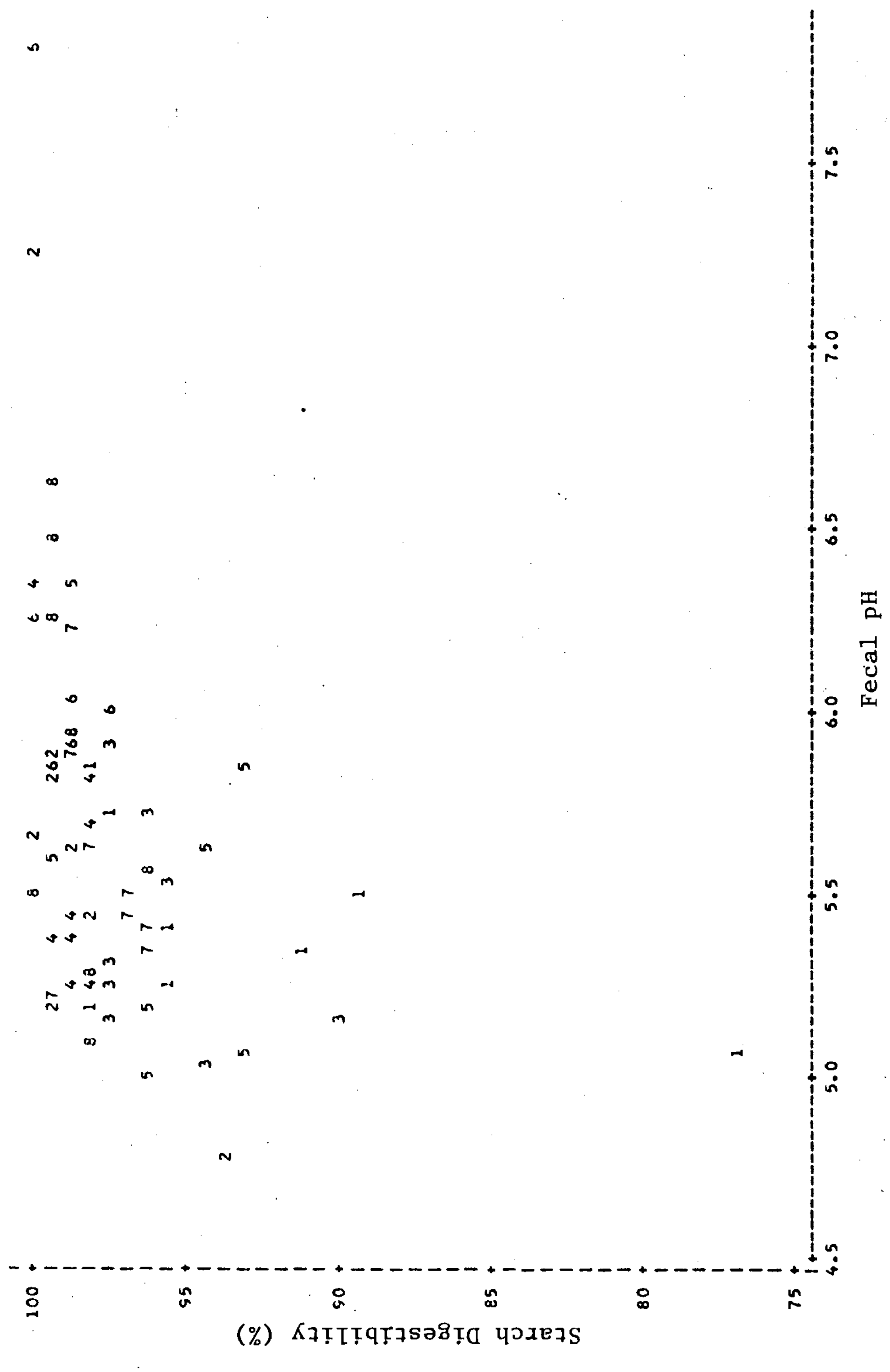
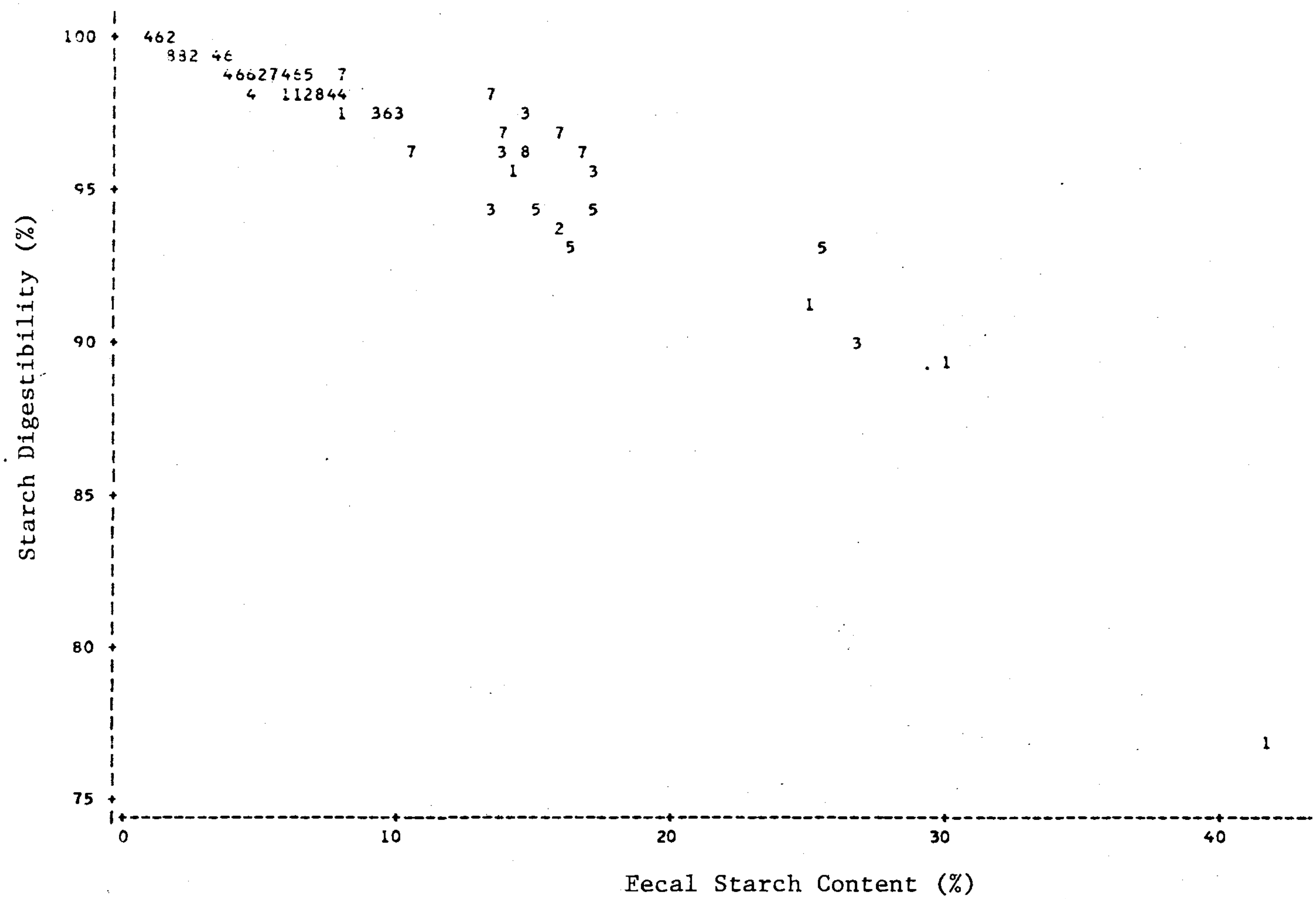

Starch Digestibility (%)
100
95
90
85
80
75
Fecal pH
4.5
5.0
5.5
6.0
6.5
7.0
7.5

TABLE 15. STARCH DIGESTIBILITY REGRESSION EQUATIONS

Independent Variable	Regression Equation	r^2
FECAL		
pH	Y = 82.62124 + (2.56781)X	.15
Starch	Y = 101.03352 - (.410042)X	.87

Figure 6. Starch digestibility versus Fecal starch content 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn; 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn, 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.


Starch Digestibility (%)
100
95
90
85
80
75
0
10
20
30
40
Fecal Starch Content (%)

of dry matter, organic matter, starch, nitrogen and ash due to monensin may be the result of a longer retention time in the rumen (Lemenager, 1977) especially with the dry corn diets. Since added monensin increases energy availability from dry corn similar to protein supplementation, monensin benefit in the feedlot would be expected to be greater with low protein rations.

Benefits from monensin or added protein on starch and organic matter digestibility with high moisture corn were minimal as compared with dry corn. This, plus the reduction in high moisture corn intake with monensin supplementation, may explain why feed efficiency in a feedlot may be improved more by adding monensin to dry corn diets than to high moisture corn diets (Gill et al., 1977a and 1978).

Of the three apparent monensin actions, reduced methane loss, increased retention time and (potentially) increased bypass of feed protein, a dry corn low protein ration should benefit from all three. Higher protein rations may benefit from the reduced methanogensis and increased retention time. But with rations for which increased gut retention time is not of considerable benefit, such as with steam flaked, high mositure corn or barley based rations, monensin benefit may be restricted to inhibited methanogensis alone.

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APPENDIX A

TABLES

TABLE 16. NITROGEN RETENTION REGRESSION EQUATIONS

Independent Variable	Regression Equation	r^2
Feed Dry Matter Intake	Y = -24.876 + (.002386)X	.55
Organic Matter Intake	Y = -25.193 + (.012565)X	.55
Starch Intake	Y = -18.753 + (.016310)X	.43
Nitrogen Intake	Y = -20.730 + (.637595)X	.70
Ash Intake	Y = -17.360 + (.229570)X	.48
Digestible Organic Matter Intake	Y = -30.453 + (.016533)X	.62
Digestible Starch Intake	Y = -24.364 + (.018772)X	.45
Digestible Nitrogen Intake	Y = -10.751 + (.710431)X	.66

TABLE 17. NITROGEN RETAINED PER UNIT OF ORGANIC MATTER DIGESTED REGRESSION EQUATIONS

Independent Variable	Regression Equation	r^2
Digestible Nitrogen Intake	Y = .51420 + (.124889)X	.48
Digestible Organic Matter Intake	Y = -1.87776 + (.002618)X	.36
Digestible Starch Intake	Y = -.433536 + (.002810)X	.23
Nitrogen Intake	Y = -1.12855 + (.110713)X	.50
Feed Dry Matter Intake	Y = -.93309 + (.000375)X	.32
Organic Matter	Y = -.99592 + (.001979)X	.32
Starch Intake	Y = .41291 + (.002440)X	.22

TABLE 18. INDIVIDUAL NUTRIENT INTAKE AFFECTS ON DIGESTIBILITY

Parameter	Regression Equation	r^2
Nitrogen Digestibility	$Y = 58.892 + (.15460)X^a$	.25
Organic Matter Digestibility	$Y = 88.499 - (.00114)X^b$	.06
Ash Digestibility	$Y = 49.321 + (.05413)X^c$	.12
Starch Digestibility	$Y = 105.2852 - (.002697)X^d$	.30

[a]X = nitrogen intake

[b]X = organic matter intake

[c]X = ash intake

[d]X = starch intake

TABLE 19. AOV FOR DRY MATTER, ORGANIC MATTER, STARCH, NITROGEN AND ASH DIGESTIBILITIES

Source	df	MS				
		DM	OM	Starch	Nitrogen	Ash
Total	63	21.37	21.95	12.02	51.19	69.41
Square	3	1.23	1.31	9.29	22.73	100.70
Row in Square	12					
Corn	1	90.92	119.68	168.33	9.50	763.13
Square*Corn	3	7.06	6.78	14.53	9.62	53.18
Row*Square*Corn	8	9.06	8.48	2.33	30.42	37.31
Columns in Squares	12	33.34	34.14	16.49	41.12	67.99
Monensin in Square	4					
Monensin	1	87.93	87.64	24.20	92.35	85.70
Monensin*Square	3	17.14	17.16	5.48	6.72	45.27
Protein in Square	4					
Protein	1	250.35	247.25	23.61	1666.14	255.54
Protein*Square	3	12.85	12.45	9.64	19.87	40.89
Corn*Monensin	1	21.29	0.64	15.39	32.99	112.31
Square*Corn*Monensin	2	12.63	32.08	14.93	18.30	10.24
Corn*Protein	1	17.31	10.83	2.63	8.06	20.51
Square*Corn*Protein	2	0.88	16.92	0.68	10.53	47.83
Monensin*Protein	1	2.93	3.11	6.63	23.64	6.86
Square*Monensin*Protein	2	5.99	30.40	7.02	4.52	29.18
Corn*Monensin*Protein	1	9.66	8.88	8.54	15.14	39.86
Square*Corn*Monensin*Protein	2	13.48	12.81	13.75	6.49	52.06

TABLE 19 (Continued)

Source	df	MS				
		DM	OM	Starch	Nitrogen	Ash
Error	16	13.30	13.38	6.35	24.00	69.54
Square 11	4	4.58	4.79	0.39	12.94	11.09
Square 12	4	12.00	13.14	13.74	36.71	48.11
Square 21	4	16.57	15.90	1.91	39.51	46.22
Square 22	4	20.05	19.70	9.35	6.82	172.73

TABLE 20. AOV FOR FEED DRY MATTER INTAKE, NITROGEN RETENTION AND NITROGEN RETENTION PER UNIT ORGANIC MATTER DIGESTED

Source	df	MS		
		FDDMI	NBAL	NBAL/OM
Total	63	29912083	310.54	13.27
Square	3	15496661	151.71	14.33
Row in Square	12			
Corn	1	332455478	633.87	6.60
Square*Corn	3	32482535	65.87	2.74
Row*Square*Corn	8	25743610	280.49	8.79
Columns in Squares	12	28400024	340.59	12.65
Monensin in Square	4			
Monensin	1	150599793	143.58	3.18
Monensin*Square	3	35495477	439.62	11.94
Protein in Square	4			
Protein	1	43138908	4636.61	239.99
Protein*Square	3	24524880	334.62	19.17
Corn*Monensin	1	11180903	73.70	7.00
Square*Corn*Monensin	2	1014345	453.48	0.46
Corn*Protein	1	46985470	27.19	8.21
Square*Corn*Protein	2	32564395	238.93	8.18
Monensin*Protein	1	8965891	377.42	26.23
Square*Monensin*Protein	2	1380274	144.11	17.64
Corn*Monensin*Protein	1	16236036	0.30	0.24

TABLE 20 (Continued)

Source	df	MS		
		FDDMI	NBAL	NBAL/OM
Square*Corn*Monensin*Protein	2	25684058	421.17	16.39
Error	16	17679057	135.52	6.50
Square 11	4	18343865	100.31	4.71
Square 12	4	7926043	223.49	12.85
Square 21	4	19146284	114.49	5.22
Square 22	4	25300034	103.78	3.22

TABLE 21. AOV FOR URINE VOLUME, FECAL ASH PERCENTAGE, FECAL STARCH AND FECAL pH

Source	df	MS			
		URWW	FECASPC	FECST	FECpH
Total	63	127309116	4.05	62.40	0.27
Square	3	263757858	4.51	59.41	0.41
Row in Square	12				
Corn	1	69956496	68.62	1427.90	1.67
Square*Corn	3	34150791	1.25	97.44	0.10
Row*Square*Corn	8	28691273	1.65	17.80	0.23
Column in Square	12	336913223	4.79	80.17	0.41
Monensin in Square	4				
Monensin	1	128453889	5.06	55.32	1.02
Monensin*Square	3	104904256	1.18	10.98	0.07
Protein in Square	4				
Protein	1	97851664	9.91	32.63	0.15
Protein*Square	3	33916990	0.47	34.05	0.34
Corn*Monensin	1	340240876	0.02	56.77	0.01
Square*Corn*Monensin	2	13160586	5.54	49.09	0.04
Corn*Protein	1	40401195	6.05	16.92	0.13
Square*Corn*Protein	2	159217089	0.78	5.49	0.25
Monensin*Protein	1	71482245	0.08	19.76	0.36
Square*Monensin*Protein	2	175796395	2.09	8.72	0.02
Corn*Monensin*Protein	1	18196644	0.01	33.33	0.09
Square*Corn*Monensin*Protein	2	125188073	0.27	54.70	0.31

TABLE 21 (Continued)

Source	df	MS			
		URWW	FECASPC	FECST	FECpH
Error	16	91866134	3.46	21.40	0.18
Square 11	4	22948997	1.17	2.67	0.14
Square 12	4	42883953	2.94	19.54	0.03
Square 21	4	134200958	1.57	11.98	0.14
Square 22	4	167430628	8.16	51.40	0.42

APPENDIX B

FIGURES

Figure 7. Nitrogen retention versus daily starch intake
Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn, 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn; 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.

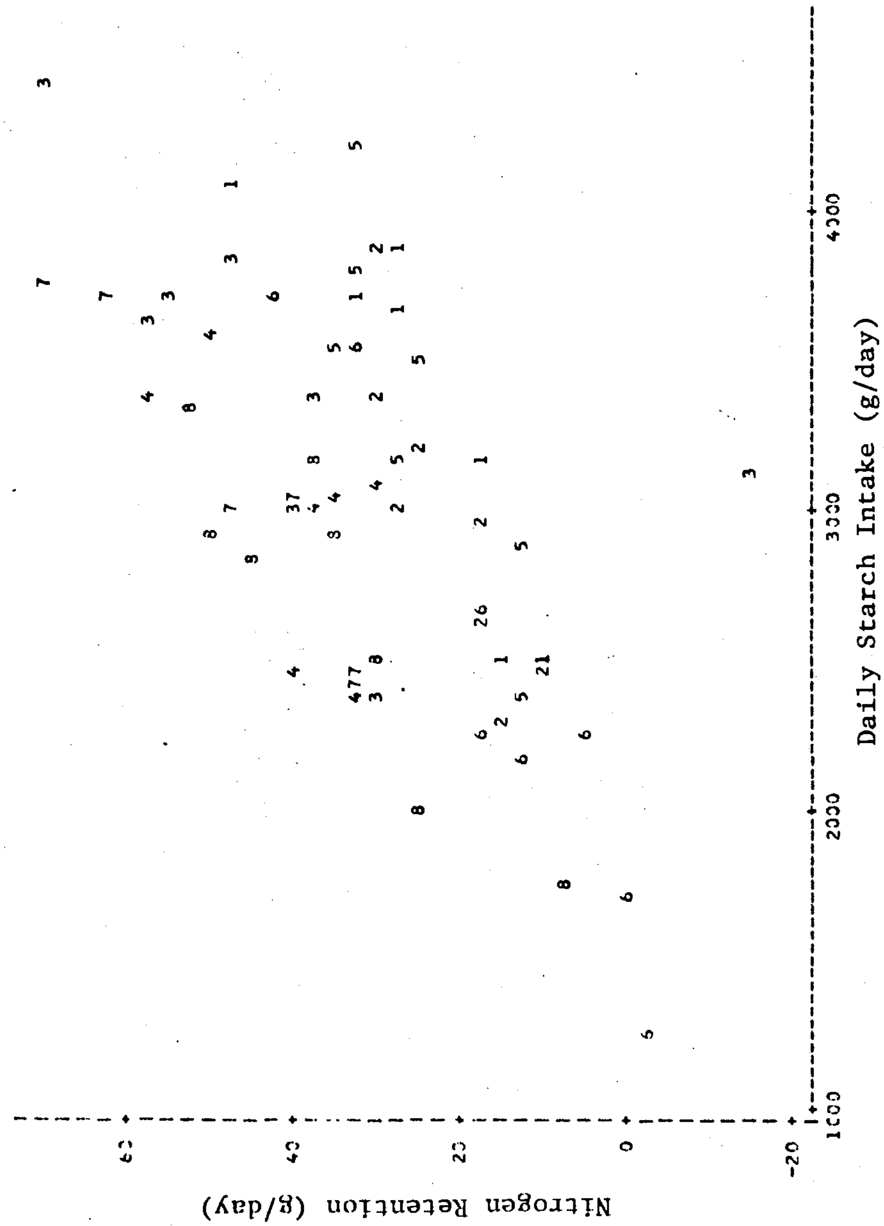

Nitrogen Retention (g/day)
-20
0
20
40
60
1000
2000
3000
4000
Daily Starch Intake (g/day)

Figure 8. Nitrogen retained per unit of organic matter digested versus digestible organic matter intake; Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn, 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn; 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.

Nitrogen Retained Per Unit of Organic Matter Digested
Versus Digestible Organic Matter Intake (mg/g)

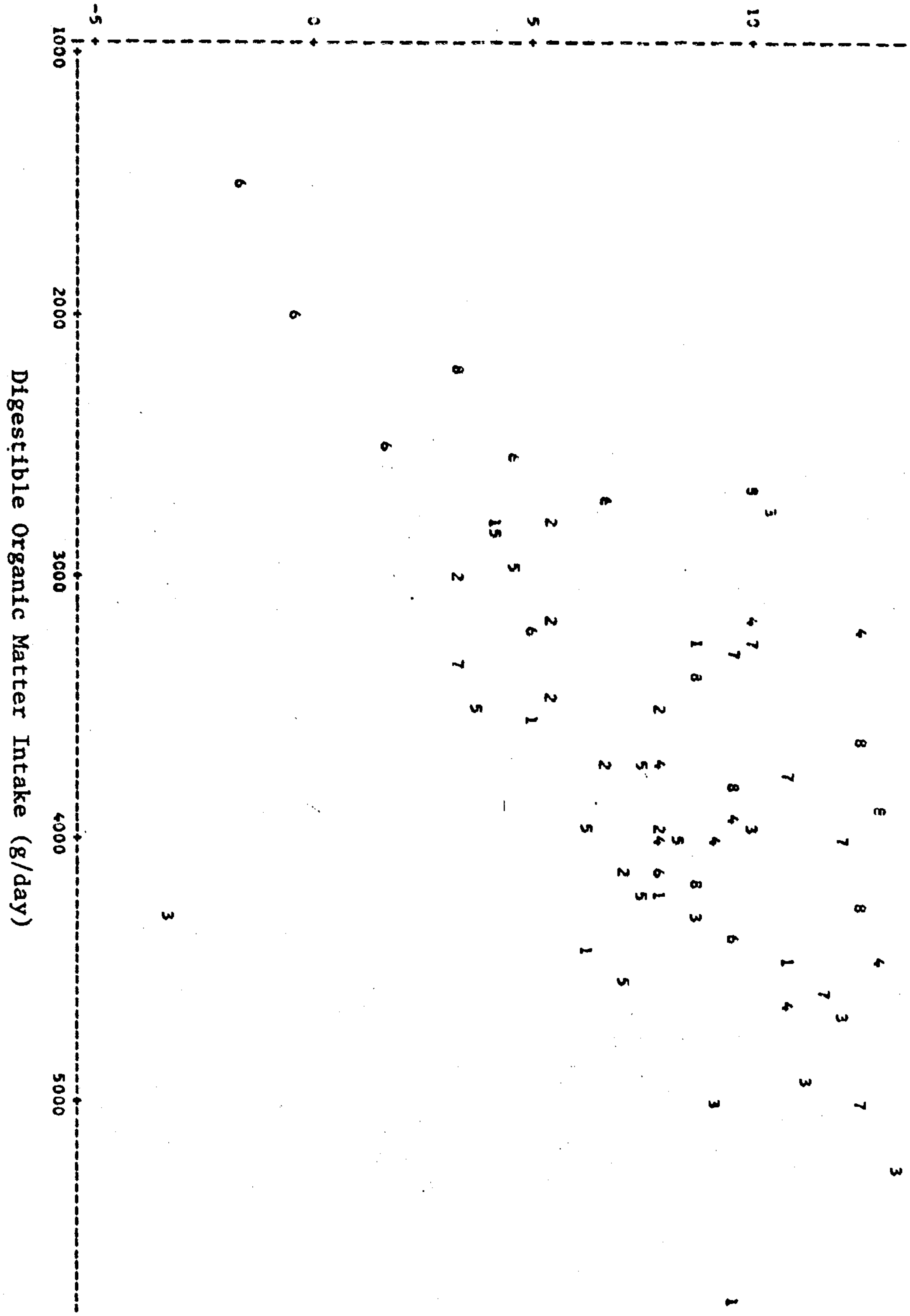


Figure 9. Nitrogen digestibility versus daily nitrogen intake Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn, 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP 33 ppm monensin; 7 = dry corn; 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.

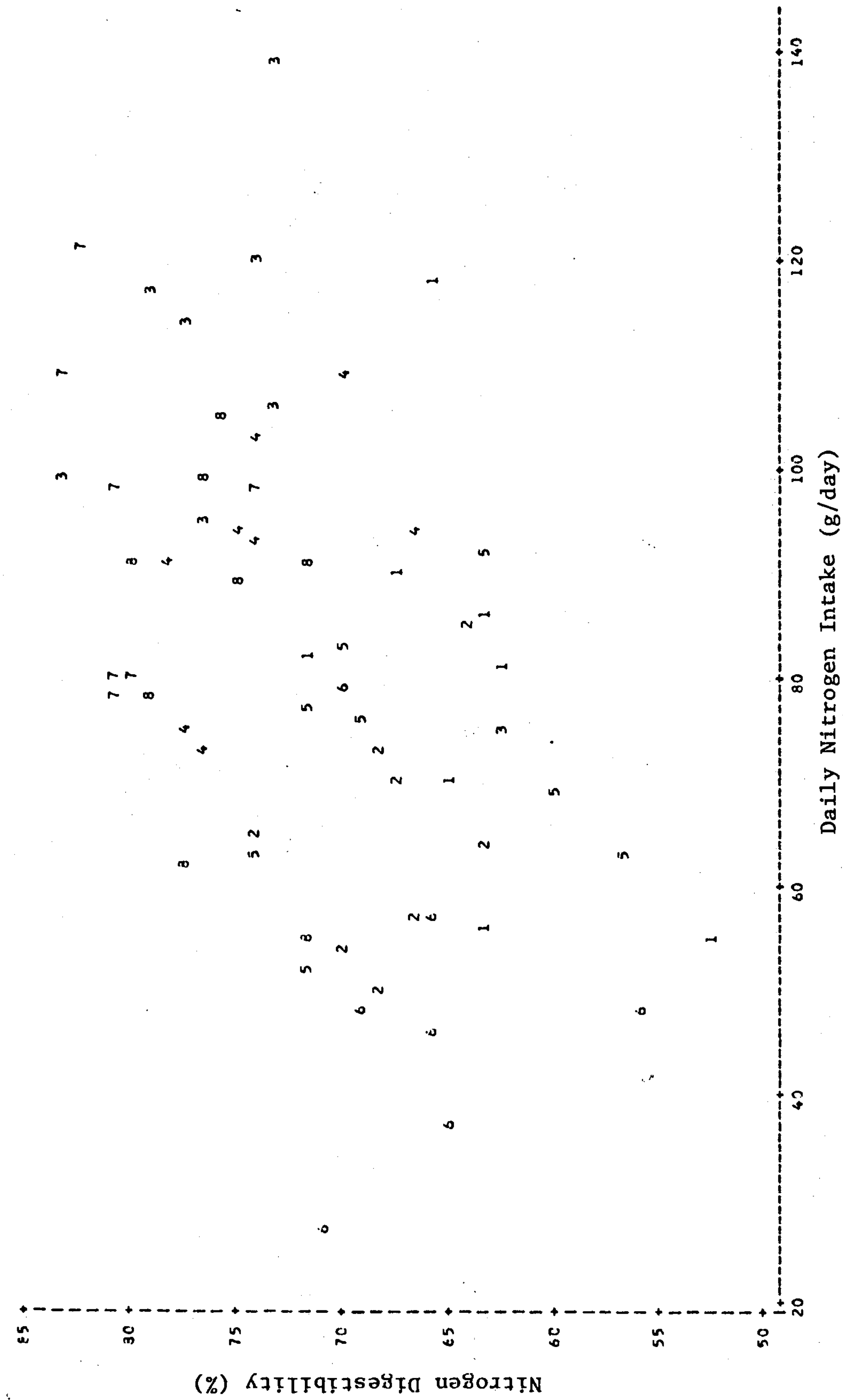

Nitrogen Digestibility (%)
Daily Nitrogen Intake (g/day)
50
55
60
65
70
75
80
85
20
40
60
80
100
120
140

Figure 10. Starch digestibility versus daily starch intake 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn, 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn, 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.

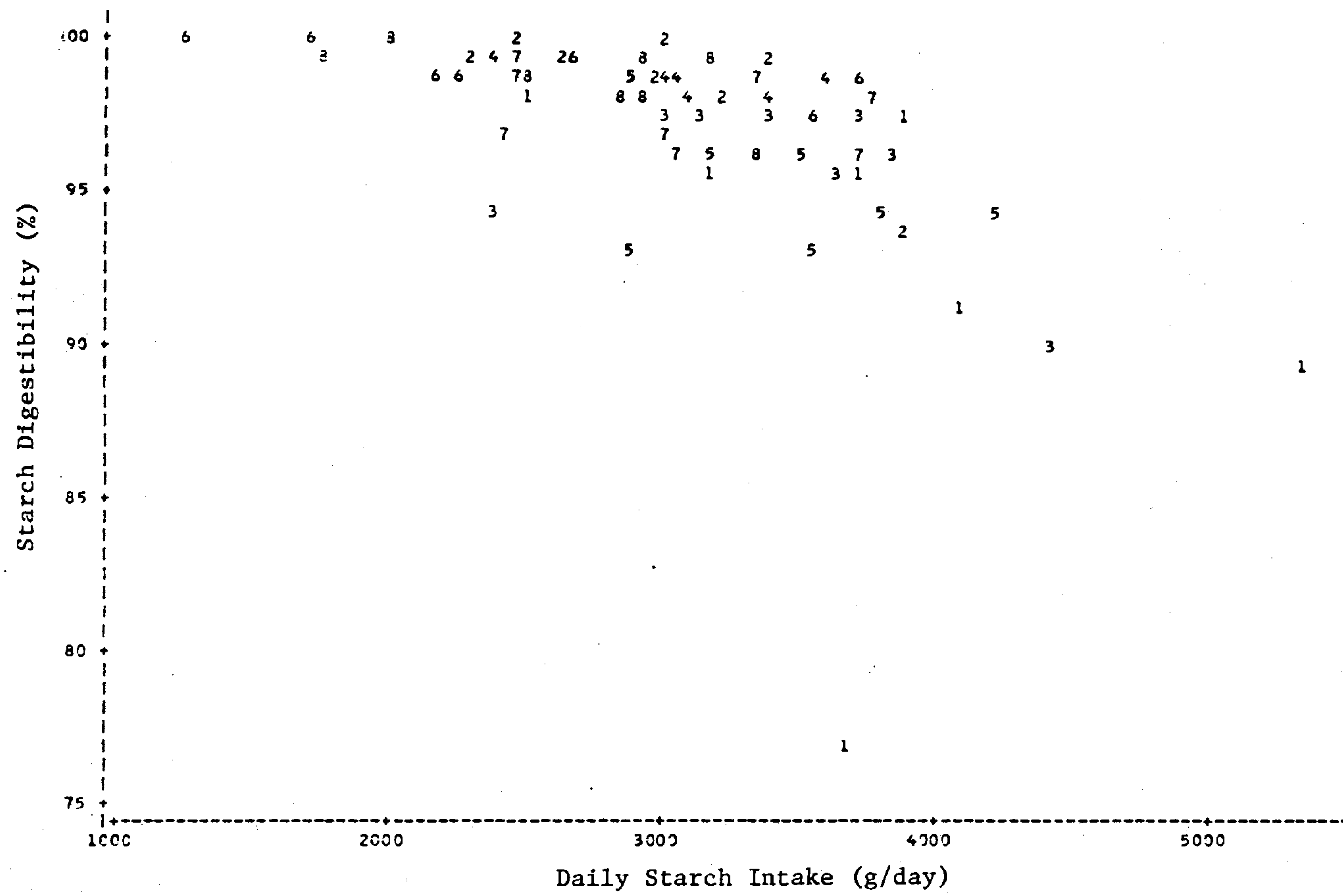

Starch Digestibility (%)
100
95
90
85
80
75
1000
2000
3000
4000
5000
Daily Starch Intake (g/day)

Figure 11. Fecal starch content versus daily starch intake
Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn, 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn, 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.

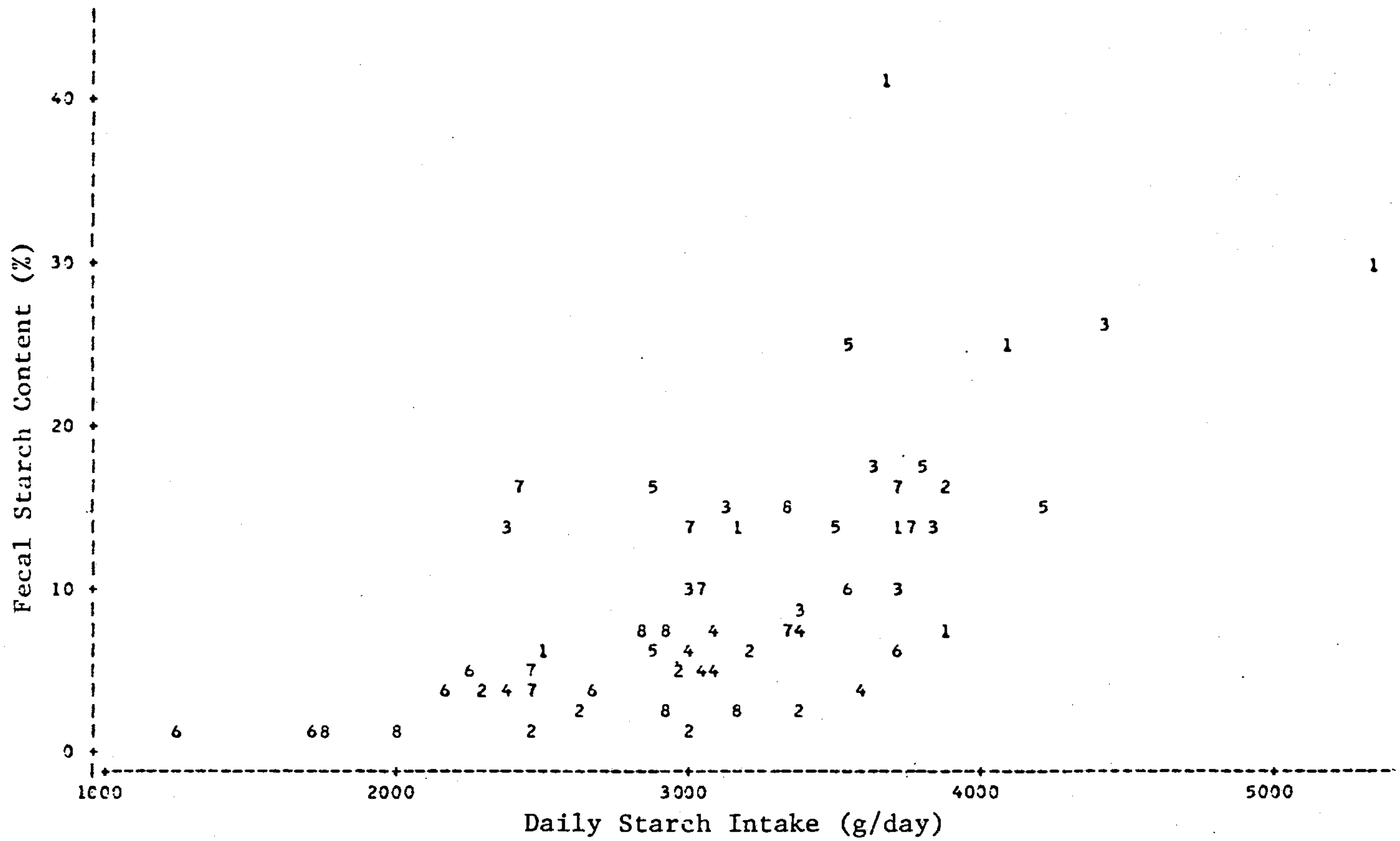
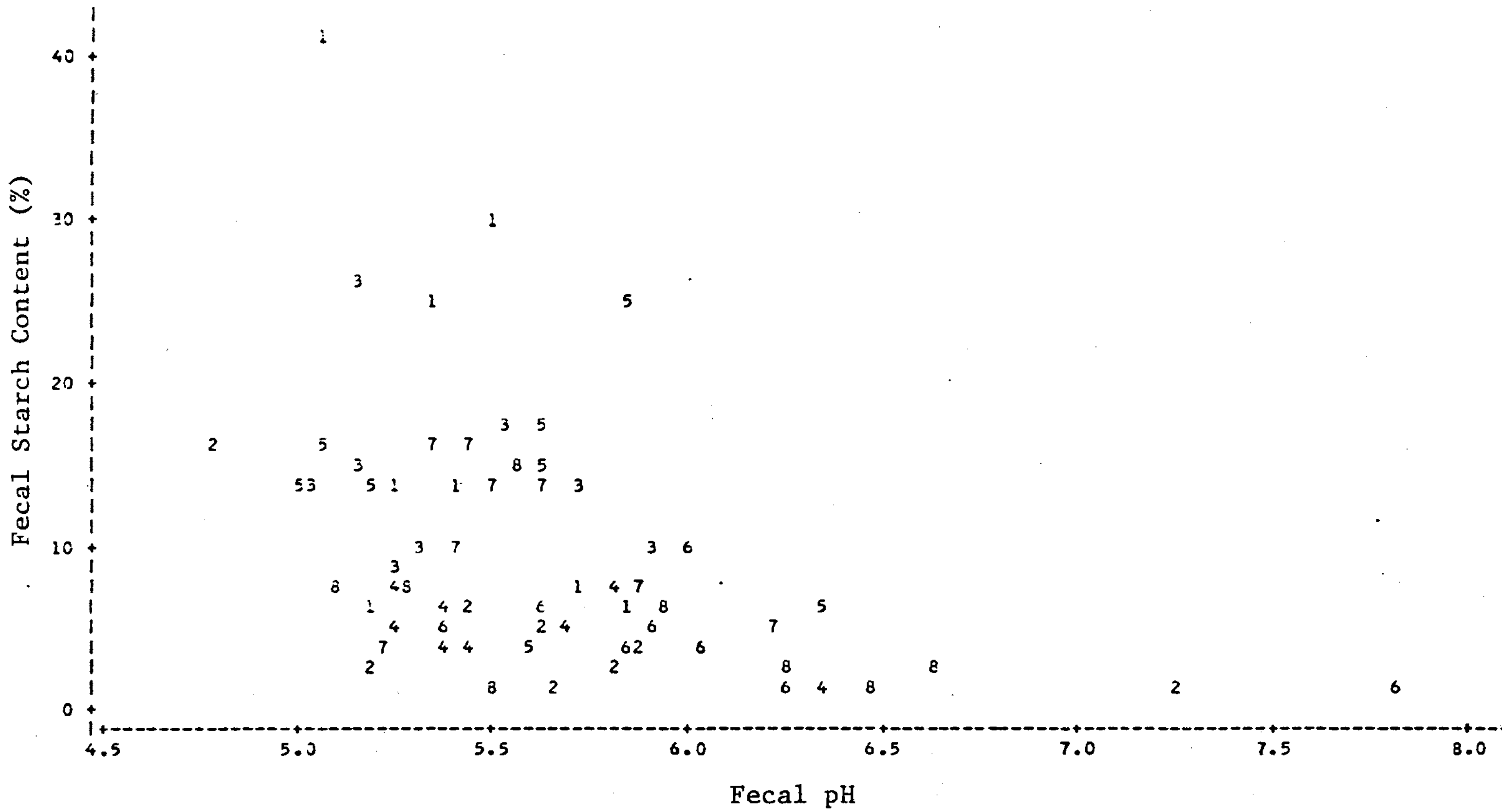

Fecal Starch Content (%)
40
30
20
10
0
1000
2000
3000
4000
5000
Daily Starch Intake (g/day)

Figure 12. Fecal starch content versus Fecal pH
Legend: 1 = dry corn, 9.3% CP, 0 ppm monensin; 2 = high moisture corn, 9.3% CP, 0 ppm monensin; 3 = dry corn, 12.3% CP, 0 ppm monensin; 4 = high moisture corn, 12.3% CP, 0 ppm monensin; 5 = dry corn, 9.3% CP, 33 ppm monensin; 6 = high moisture corn, 9.3% CP, 33 ppm monensin; 7 = dry corn, 12.3% CP, 33 ppm monensin; 8 = high moisture corn, 12.3% CP, 33 ppm monensin.


Fecal Starch Content (%)
0
10
20
30
40
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
Fecal pH

VITA

Steven Ronald Rust

Candidate for the Degree of

Master of Science

Thesis: INFLUENCE OF CORN MOISTURE, PROTEIN CONCENTRATION AND MONENSIN ON DIGESTION BY FEEDLOT STEERS

Major Field: Animal Science

Biographical:

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