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COMPOSITION AND NUTRITIONAL QUALITY OF
MICHIGAN LOW TEST WEIGHT CORN (1992) WHEN
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presented by

PETER PAUL CIZMARIK

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of the requirements for

 M.S. degree in ANIMAL SCIENCE

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**COMPOSITION AND NUTRITIONAL QUALITY OF MICHIGAN LOW TEST
WEIGHT CORN (1992) WHEN FED TO PIGS**

By

Peter Paul Cizmarik

A THESIS

**Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of**

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ABSTRACT

COMPOSITION AND NUTRITIONAL QUALITY OF MICHIGAN LOW TEST WEIGHT CORN (1992) WHEN FED TO PIGS

By

Peter Paul Cizmarik

A cold growing season resulted in wet, low-test weight corn at harvest in Michigan in 1992. The nutritional quality of this corn was evaluated. Forty-six corn samples were obtained from different locations within the State of Michigan and analyzed for dry matter, crude protein, lysine, minerals and protein fractions. Secondly, corns of four test weight (54 to 76 kg/hl) were fed to pigs in an energy and nitrogen balance study.

Calcium, phosphorus, iron, zinc and selenium were all within ranges for typical Michigan corn, while lysine (% DM) varied from 0.2 to 0.27 and was positively related to crude protein ($P=0.03$). Protein quality differed among corns ($P<.05$) and was lowest ($P<.01$) for corn 62.

Metabolizable energy values increased linearly with test weight (54-76 kg/hl); corns 62, 66 and 76 all had higher ($P<.01$) metabolizable energy than corn 54. Apparent nitrogen and dry matter digestibilities were highest for corn 76. Both, protein quality and energy content was somewhat higher for the highest test weight corn. Nutritional quality of corn was not markedly lowered until test weight fell below 55 kg/hl.

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1.0 INTRODUCTION

Livestock production is the single largest agricultural sector in the United States. Sales of livestock and livestock products in the US make up approximately 50% of cash receipts of agricultural product sales (Agricultural Outlook 1985). The importance of livestock production in the United States agricultural economy, as well as in the overall economy, is apparent. In this connection, it must be recognized that roughly three-fourths of the costs of producing livestock are feed costs. A high percentage of our nation's grain production is normally used for livestock feeding purposes. Of all the grains commonly used in livestock and poultry diets in the United States, corn is by far the most important crop, because it is produced in a quantity substantially over that needed for human food. The United States is the world's leader in corn production; annual production approaches 50% of the world total. Corn generally accounts for about 80% of the total quantity of grain fed to livestock and poultry in the United States (AACCH, 1987). Corn is palatable, readily digested by humans and by

monogastric and ruminant animals, and is one of the best sources of metabolizable energy (ME) among the grains. The availability of corn and soybean meal, as economical sources of energy and protein, has played a most important role in the initial rapid growth and the sustained development of US livestock and poultry production. Initially, these livestock production enterprises used primarily by-product materials from the grain milling and beverage industries. As the nutritional needs of farm animals became better known and the demand for high available energy balanced diets increased, ground corn became a major feed ingredient. Although corn is low in protein content, the high proportion of corn in livestock diet makes corn a major source of protein for the livestock industry. Corn may thus provide 20-50% of the total protein present in many livestock diets. However, the nutritional quality of corn protein is low, because of a low lysine content coupled with marginal tryptophan and threonine and a high leucine content.

The corn harvested in Michigan after the 1992 growing season was not typical. The growing conditions were cold and wet, particularly during the later part of the season. Moisture concentrations in corn at typical harvest times were higher than normal, suggesting that the maturity of corn was not as advanced and requiring more artificial

drying of the crop. Another widespread observation was that the test weight of 1992 Michigan corn was often well below bench values. If the test weight is down, is the overall nutritional value also reduced?

Two studies were developed to: (1)determine with growing pigs dry matter, nitrogen and energy digestibilities of four corn samples ranging in test weight from 54, 62, 66 to 76 kg/hl; (2)determine nitrogen and energy balance, protein quality and ME values of four corn samples; (3)determine lysine content of 46 corn samples; (4)determine minerals content of 46 corn samples with emphasis on Ca, P, Zn, Fe and Se; (5)determine correlation between lysine and test weight, crude protein and test weight, crude protein and lysine of 46 test weight corns; (6)determine protein fractions of four test weight corns with emphasis on prolamines (Zein), albumins-globulins and glutelins.

2.0 LITERATURE REVIEW

2.1 Amino Acids Composition and Protein Quality of Corn

It has been well established that when swine are fed diets that are deficient in protein they do not grow or reproduce normally (Pond, 1973; Baker and Speer, 1983). It is now clearly recognized, however, that it is not proteins *per se* but their building blocks, amino acids (AA), that are the essential nutrients. The quality of dietary protein is determined by its amino acid content, by its digestibility and availability of amino acids and the essential amino acids profile in relationship to the essential amino acids requirement profile; eg. the AA balance required by the animal (Wang and Fuller, 1989). Cantor and Young (1982) showed, that quite likely most of the relatively high "protein requirements" of humans and other animals may simply be a requirement for one or more of the essential amino acids and that when all of the essential amino acids are present in the diet at optimum levels, the actual protein requirement may be considerably lower than previously indicated. Young pigs gain weight at nearly normal rates when fed diets containing no intact protein, but containing appropriate mixtures of free amino acids (Shelton et al., 1950; Beeson et al., 1951; Mertz et

al., 1952; Eggert et al., 1955). Furthermore, sows are able to maintain a normal pregnancy during the last 84 days of gestation when fed a diet that contains crystalline amino acids as the sole source of nitrogen (Easter and Baker, 1976).

Some amino acids are essential dietary components in certain situations, but not in others. Arginine is required for the growth of young pigs (Southern and Baker, 1983), but sows are able to synthesize arginine via the urea cycle at a rate sufficient to meet their needs for postpubertal growth and pregnancy (Easter et al., 1974; Easter and Baker, 1976). Histidine is required during pregnancy (Easter and Baker, 1977), but does not seem to be a dietary requirement for maintenance of adult swine (Baker et al., 1966). Proline (non essential amino acid) is not a dietary requirement for swine for most stages of their life cycle, but very young pigs (1 to 5 kg) are apparently unable to synthesize proline rapidly enough to meet their requirements (Ball et al., 1986).

The requirement for the two sulfur amino acids (methionine and cystine) is usually met by a mixture of these amino acids. Cystine can be synthesized from methionine (but not vice versa), and therefore, methionine can meet the total need for sulfur amino acids. Cystine can satisfy at least 50% of the sulfur amino acid requirement

(Shelton et al., 1951b; Becker et al., 1955; Mitchell et al., 1968; Baker et al., 1969b).

Phenylalanine can be converted to tyrosine, but not vice versa. Tyrosine can satisfy at least 50% of the total aromatic amino acid requirement (sum of tyrosine and phenylalanine), (Robbins and Baker, 1977).

It has been established that the nutritional value (quality) of a protein is primarily dependent on its amino acid composition, especially the content and balance of essential amino acids. With more knowledge about the amino acid composition of proteins and the amino acid requirements of swine, the emphasis has moved toward assessing how well proteins and mixtures of proteins meet amino acid requirements. A protein that contains a perfect balance of amino acids, both among the essential amino acids and between essential and nonessential amino acids, has been defined as an ideal protein (Cole, 1979; ARC, 1981).

Cereal grains, mostly corn or barley, form the basis of most swine diets throughout the world and generally supply 40% to 50% of the protein in the diets of growing-finishing pigs. The amino acids in corn have generally been found to be more available than in other grains (Eggum, 1973a). This grain, however, contains a relatively low protein level, which also has an unbalanced pattern of essential amino acids. Several experiments with swine at various stages of growth have demonstrated that lysine

(1st) and tryptophan (2nd) are about equally limiting in corn for growing pigs (Clawson and Matrone, 1963; Cromwell et al., 1967; Gallo and Pond, 1968; Baker et al., 1969; Ilori and Conrad, 1977; Lewis et al., 1979). Bressani et al.(1962) stated that tryptophan and lysine showed varietal differences at each of the four localities where corn was grown. Usually, the nutritional value of corn and its protein can be related directly to the lysine content of the kernel and is governed by its digestibility, balance and content of indispensable amino acids. According to Arnold et al. (1977), lysine content on dry weight basis increases as the total nitrogen content increases. Paerz et al.(1969) found a significant correlation between N (varying from 1.6 to 2.6%) and lysine in grain of 48 selected strains of corn. Davis et al.(1970) analyzed 114 samples of inbred corns that contained the same N range and found significant relationships among AA concentrations (as percent of dry matter or as percent of protein). Keeney (1970) investigated corn AA content in lower N corns (from 1.04 to 1.57%). He confirmed that the level of almost all essential AAs was highest in the grain having the highest N. Also, Miller et al.(1950) observed high correlations between protein content, lysine and tryptophan, but were unable to detect any differences in the distribution of these amino acids between high- and low-protein corn. In experiments with rats, Lewis et al.(1982) found that threonine and isoleucine were the third and fourth limiting amino acids in corn. In terms of supporting nitrogen

retention in young gravid gilts, corn is first-limiting in lysine and second-limiting in tryptophan (Allee and Baker, 1970). After lysine and tryptophan, threonine is next in importance, and is third-limiting in corn (Grosbach et al., 1985). Several authors reported similar sequence of lysine, tryptophan and threonine in corn. Asche et al.(1985), Cromwell et al. (1967), and Burgoon et al.(1992) reported 0.28%, 0.24% and 0.31% of lysine, 0.09%, 0.09% and 0.05% of tryptophan and 0.33%, 0.32% and 0.35% of threonine respectively. On the other hand, the proteins in corn have a relatively high percentage of methionine and cystine. However, Adeola et al.(1986) state that the digestibility of protein is meaningful only if all the associated amino acids are similarly available. Interestingly, there are data that suggest that a decrease in dietary protein may reduce the lysine requirement of swine for maintenance when all other amino acids are adequate, however, pigs grow much slower (Klay, 1964a,b; Baker et al., 1975; Lunchick et al., 1978; Easter and Baker, 1980).

The current National Research Council recommends that feed for growing pigs(20.4-49.8kg)contains at least 0.48% threonine. However, Friesen et al.(1992) found that the threonine requirement is higher and concluded that the growing pig requires a dietary threonine concentration of approximately 0.50%-0.60% (10-11g per day) to optimize growth performance. In another study Friesen et al.(1992) demonstrated that high lean growth gilts require at least 21-22g per day of total lysine for optimal average daily

gain, feed efficiency, and protein accretion rate. Tanksley et al.(1987) showed that the contribution of corn in meeting requirements for lysine was 27%, for tryptophan 33% and for threonine 49%.

Rivera et al.(1978) demonstrated that none of the differences in protein quality for rats or pigs, or in availability of Amino Acids(AA) and True Nitrogen Digestibility(TND) for pigs due to stage of maturity or drying temperature, were significant for corn. However, a trend for better gains and feed conversion by pigs fed the immature corn compared to those fed mature corn was observed. Also, drying high-moisture corn at 40°C resulted in higher AA availabilities and TND than drying at 60°C. The reverse was true for low-moisture corn which showed higher AA availabilities and TND from drying at 60°C vs. at 40°C. It appeared that high-moisture corn is more susceptible to protein damage due to heat treatment than low-moisture corn.

The protein content of corn grain is relatively high during early maturation and decreases as full maturity is reached (Sayre, 1948; Kiesselbach, 1950; Chandler, 1960). Not only is the protein content of corn higher at early stages of maturity, but also its amino acid profile seems to be of higher quality.

Bressani and Conde (1961) followed the changes of several amino acids in the corn kernel at nine stages of maturity and found appreciable reductions in the content of

lysine, methionine, tyrosine and tryptophan in contrast to increases in leucine as corn approached maturity.

Corn protein composition, and its amino acid ratios, may vary widely due to genetic manipulation by plant breeders, and to a lesser degree, by crop year (Earle, 1977), soil fertility, crop management (nitrogen fertilization), and climatic conditions (Hamilton et al., 1951; Bird and Olson, 1972; Pierre et al., 1977; Asghari and Hanson, 1984). Application of fertilizer to normal dent corn can increase the total protein content to about 11.5%, but growing corn depleted of nitrogen can produce kernels with as low as 6% protein (Pierre et al., 1977). According to Hamilton et al. (1951), Schneider et al. (1953), Pierre et al. (1977), protein content is influenced by the available soil nitrogen and by genetics of the plant (Alexander and Creech, 1977; Pollner et al., 1979). Dudley et al. (1974) have shown that the total protein content of corn can vary from 4.4 to 26.6% by selection for protein content without regard to grain yield. Differences in kernel protein and yield response to soil nitrogen levels may also be influenced by genetic differences in the capacity of genotypes to take up nitrogen from the soil and translocate the N as protein in kernels (Pollner et al., 1979). Nitrogen availability to the plant can also be reduced by competition from weeds and by drought. Most changes in protein content of corn are due to changes in the amount of endosperm proteins, mainly zein (Hamilton et al., 1951), relative to the total protein present in the kernel.

2.2 Nitrogen and Energy Balance, Test Weight and Nutritional Values of Corn, DM, N and Energy Digestibility

Increasing grain moisture content (MC) affects test weight values and energy density of corn negatively. Nelson (1980) showed that test weight of corn at 10% MC was 74 kg/hl, while at 25% MC it was 69 kg/hl. As for trading practices, Hill (1982b) proposed a more accurate practice that reflects the actual dry matter in a lot of grain. He proposed to retain 15.5% MC as the basis for trading. At this moisture level, dry matter content is 84.5% and one 56 lb (25.4 kg) bushel of corn contains 47.32 lb (21.5 kg) of dry matter. This is defined as a "standard bushel".

The most widely used measure of density in the commercial US grain market is the so called test weight, a measure of bulk density obtained by weighing a specific volume of the grain. Measurement of test weight is important in storing and transporting corn because it determines the size of container required for a given lot of corn. In the United States, test weight is measured in pounds per bushel, but in the metric system, it is measured in kilograms per hectoliter. The minimum test weight for US Grade No.1 corn is 56 lb/bu (1 bu=0.3524 hl), which is 72.08 kg/hl. According to Hall and Hill (1974), test weight changes during drying. These authors state that the amount of increase in test weight during drying is affected by: (a) initial moisture content of corn, (b) amount of kernel

damage, (c)drying temperature, (d)final moisture content, and (e)variety. Most users of corn have commonly assumed that test weight is a measure of the maturity or plumpness of kernels, but the data of Hall and Hill (1973, 1974) bring this assumption into question. Dorsey-Redding et al. (1991) found a low positive correlation between test weight and protein (0.15-0.20) and a medium positive correlation between density and protein (0.33-0.39). This observation supports the conclusion that test weight is a poor indicator of grain quality (Feeman, 1973).

It is true that corn harvested before maturity is low in test weight. Maturity in corn is defined as the cessation of dry weight accumulation by the kernels and is identified as attainment of maximum moisture-free weight per thousand kernels and, therefore, maximum yield (Frey, 1981). Maturation is also associated with gradual loss of moisture (Hallauer and Russell, 1966; Schmidt and Hallauer, 1966) and with changes in density and test weight (Hill, 1975; Nelson, 1980). As Shaw (1977) pointed out, the proper maturation of corn is affected more by temperature in the last two weeks of August and most of September, than by rainfall, except in very dry weeks. Prolonged periods of cloudiness, alone or combined with abnormally low temperatures, can slow the corn maturation process; this occurred in some parts of the North American Corn Belt in 1967, 1972, 1974, and also in 1992. At the other extreme, moisture stress and high temperatures during the grain-filling period can reduce the maturation rate.

Earle (1977) summarized the data on influence of temperature and rainfall on protein and yield levels from 1907 to 1972. There is a negative correlation between yields and protein content. Data show clearly that increased yields, which started in early nineteen-thirties, resulted in relatively lower grain protein; however, increased fertilizer usage on corn has apparently been enough to maintain protein levels as yields kept increasing. Temperature and rainfall had generally positive correlations to protein content and yields, but only moderate increase of temperature and rather lower rainfall, especially in July, favored higher protein levels and yields (Earle, 1977).

Hicks (1975) reported that corn with a test weight of 40 lb/bu (51.4 kg/hl) has only 93% of the total digestible nutrients of corn with 56 lb/bu (72.0 kg/hl) test weight. He showed that a standard discount schedule of one cent (1975 \$ value) per bushel fairly discounts this loss in value. But graduated discount schedules that deduct five cents per bushel for test weights under 50 lb/bu (64.3 kg/hl) depart widely from the loss in actual value. Hill (1975) reported that three sets of compositional and feeding data show that corn with a test weight of 59.0-76.0 kg/hl (46-59 lb/bu) was satisfactory for swine. For sheep, similar feeding results were obtained by Thornton et al. (1969). Corn of 45 kg/hl (35 lb/bu) had a lower feeding value, but even the standard discount schedule overpenalized the low test weight corn (Hill, 1975). Leeson

and Summers (1975) reported that test weight of immature corn showed a positive correlation with metabolizable energy for poultry (broilers) but a negative correlation with protein and sugar content. Studies on metabolizable energy (ME) of corn harvested from 53% to 31% moisture also showed that ME values of immature corn decrease by some 12 kcal/kg for each 1% increase in moisture at harvest when fed to poultry (Leeson and Summers, 1976; Leeson et al., 1977). Relationships between test weight and animal feeding results are not consistent, probably because of the influence of other contributing factors relating to the causes of the test weight reduction and the differences in corn composition.

Early studies of energy metabolism of swine were reported by Capstick and Wood (1922), Deighton (1923, 1929), Brierem (1936, 1939) and Brody (1945). NRC (1964) and ARC (1967) adopted the expression of energy requirements of swine in terms of digestible or metabolizable energy. Digestible energy (DE) is the energy of the food consumed less the gross energy of the feces. Digestible energy for pigs is correlated with the presence of fiber in feed ingredients because of the limited ability of the pig to digest cellulose and related compounds. Metabolizable energy (ME) is the digestible energy consumed less the energy lost in urine and combustible gases. The energy lost in urine is the energy from nonutilized absorbed compounds and end products of metabolic processes associated with protein metabolism (i.e., urea).

Table 1 Comparison of Energy Values and Digestibilities from Several Sources

Author	GE (Kcal/g)	DE (Kcal/g)	ME (Kcal/g)	Digestibility (%)			NPU (%)	BV (%)
Adesola et al. (1986)	4.37	4.08	3.66	92.7	86.9-88.9	93.4	34.3-36.3	39.8-41.1
Allee and Baker (1970)				93.5	80.4			
Asche et al. (1986)		3.69-3.75	3.57-3.66	86.0	78.8-80.9			52.2-63.2
Baird (1971, 1974)	4.05	3.83-3.95	3.59-3.86		86.9-87.2			
Bayley et al. (1974)		3.84	3.63					
Crowell et al. (1969)				86.9				
De Goey and Ewan (1975)	3.96	3.43	3.32					
Diggs et al. (1965)	4.49	4.00	3.89					56.4
Dobbins et al. (1950)			3.66					
Garrigus and Mitchell (1935)								
Gipp and Cline (1972)	4.04							
Gupta et al. (1979)		3.32-3.39		86.5			50.9	58.8
Lawrence (1968)				83.3-88.9	78.3-85.3	83.1-86.9		
Lin et al. (1987)		3.91	3.75-3.83	90.5		91.4		
Mitchell et al. (1952)				88.3				49.2
Morgan et al. (1975)	4.51	4.02	3.94					
Nordstrom et al. (1972)	3.99							
Robinson et al. (1950)		3.43	3.25					
Scarbieri et al. (1977)			73.5					51.9
Seerley et al. (1972)		3.95	3.86	88.1	82.0-85.9	86.9-87.2		
Sullivan et al. (1989)		3.93	3.80	89.0	85.0	89.0		
Wiseman et al. (1982)	4.45	3.84	3.77					

Combustible gases are generally less than 2% of Gross Energy intake in swine (Bowland et al., 1970; Just, 1982) and are frequently not measured or considered in ME evaluations. Recovered energy (RE), net energy for gain (NEg) or energy balance is the feed energy retained as part of the body or voided as a useful product, and in growing animals is equivalent to tissue energy gain. Digestible energy values are easily determined and have been reported for a variety of feed ingredients. However, metabolizable energy provides more constant estimate than DE of the energy value of feeds. The ratio of ME to DE ranges from 0.90 to 0.98 and ME decreases with increasing protein level in corn (Asplund and Harris, 1969; May and Bell, 1971; Morgan et al., 1975).

Energy values of corn were investigated in numerous balance experiments in the past and are summarized in the Table 1. along with dry matter, nitrogen and energy digestibility, net protein utilization and biological values.

2.3 Minerals in Corn

Corn germ is rich in mineral elements (ash); it contains 78% of the kernel minerals, probably because they are essential for early growth of the embryo. Corn, like other cereal grains, is very low in calcium. The phosphorus content of corn is also low but is about equal to that in the other common cereals and represents the most abundant inorganic component in corn. It is largely present as the potassium-magnesium salt of phytic acid, the hexaphosphate ester of inositol. Phytin is an important storage form of phosphorus (Hamilton et al., 1951; O'Dell et al., 1972), which is liberated by phytase enzymes to initiate embryo development. The germ of corn contains nearly 90% of the phytate present in whole corn. For monogastric animals, it is reasonable to assume that only 30% of the total available phosphorus present is utilizable by this class of animals. The presence of phytic acid interferes with the availability of certain minerals, especially calcium, zinc, and iron (Underwood, 1962; Momcilovic and Stahl, 1976).

The trace mineral content of corn is low compared to that in small grains. In addition to supplying supplemental sources of the macrominerals in a corn-soymeal diet, it is advisable to include supplemental sources of the trace

minerals, including zinc, selenium, iron, manganese, copper, and iodine, to prevent deficiencies (NRC, 1988).

Wolnik et al.(1983) showed in their work that values of most major elements such as Ca and P fall within a fairly narrow range, while trace element compositions are much more variable in corn. Although the absolute concentrations of the elements may vary from sample to sample, crop cultivars display distinct patterns of relative elemental abundance even when grown over wide geographical areas. The general pattern for the major elements was $P > Ca$. Levels of Ca and P are deficient and the bioavailability of P is low in corn, therefore, they must be supplemented to grain-soybean meal diets for pigs to perform at an optimal level. Studies by Bethke et al.(1929) and by Wilgus (1931) showed that the diet must contain not only minimum levels but also an optimum ratio of calcium to phosphorus. A ratio of 1:1 to 1.5:1 is generally considered to be within an acceptable range (NRC, 1988).

While minor elements display more variation, certain predominant patterns are still apparent. The general pattern for minor elements was $Zn > Fe > Se$. However, corn grown in North Dakota is an important source of the essential element selenium (0.01-1.00ppm) for animal rations with biological availability of 83% (Scott, 1973),

Table 2 Comparison of Minerals Values from Several Sources

Author	Ca (%)	P (%)	Fe (ppm)	Zn (ppm)	Se (ppm)
Adeola et al. (1986)	0.80	0.73			
Anonymous (1969, 1982)	0.01-0.10	0.26-0.75			
Combs (1980)					0.038
Cullison and Lowrey (1987)	0.03	0.26-0.29	30.0	14.0	0.08
NRC (1988)	0.03	0.28	33.0	19.0	0.07
Patrias and Olson (1969)			1 - 100	13 - 30	0.01-1.00**
Scott (1986)	0.62	0.30	35.0	10.0	
Seerley (1991)	0.05-0.10	0.25	33.0	10.5	0.05
Requirement (25kg pig)*	0.60	0.50	60.0	60.0	0.15

* NRC (1988)

** North Dakota corn

unlike Michigan corn, which is deficient in selenium (Watson and Ramstad, 1987).

The elements that often showed the most normal distribution were generally those with a relatively narrow range between minimum and maximum values. This limited normal distribution indicates that crop genetic factors are more important than fertility, soil, and environment (Chaney, 1983). Minerals values from several sources are presented in Table 2.

2.4 Protein Fractions of Corn

Corn is often considered only as a major source of calories, mostly derived from its high starch content. Yet the sheer bulk of corn consumed as animal feed or human food makes it essential to consider the protein supplied with the calories. However, corn protein is made up of several different types of subfractions which show significant differences in protein and lysine content (Figure 1. and Figure 2.). The original protein classes are albumins (water-soluble), globulins (salt-soluble), zein or prolamins (aqueous alcohol-soluble), glutelins, and residue (not soluble in water, saline solutions or aqueous alcohol), with the glutelins being the proteins extracted by dilute alkali or acid (Osborne, 1907). A comparison of corn protein fractions from several sources are reported in Table 3.

As early as eighty years ago, Osborne and Mendel (1914) were able to conclude that zein was the protein that limited the ability of corn to supply nutritionally essential amino acids and that substitution of other corn proteins for zein would improve the nutritional value of corn, in other words, replacement of zein by other corn kernel proteins or decreasing the amount of prolamins would result in an improvement in the ability of corn to support

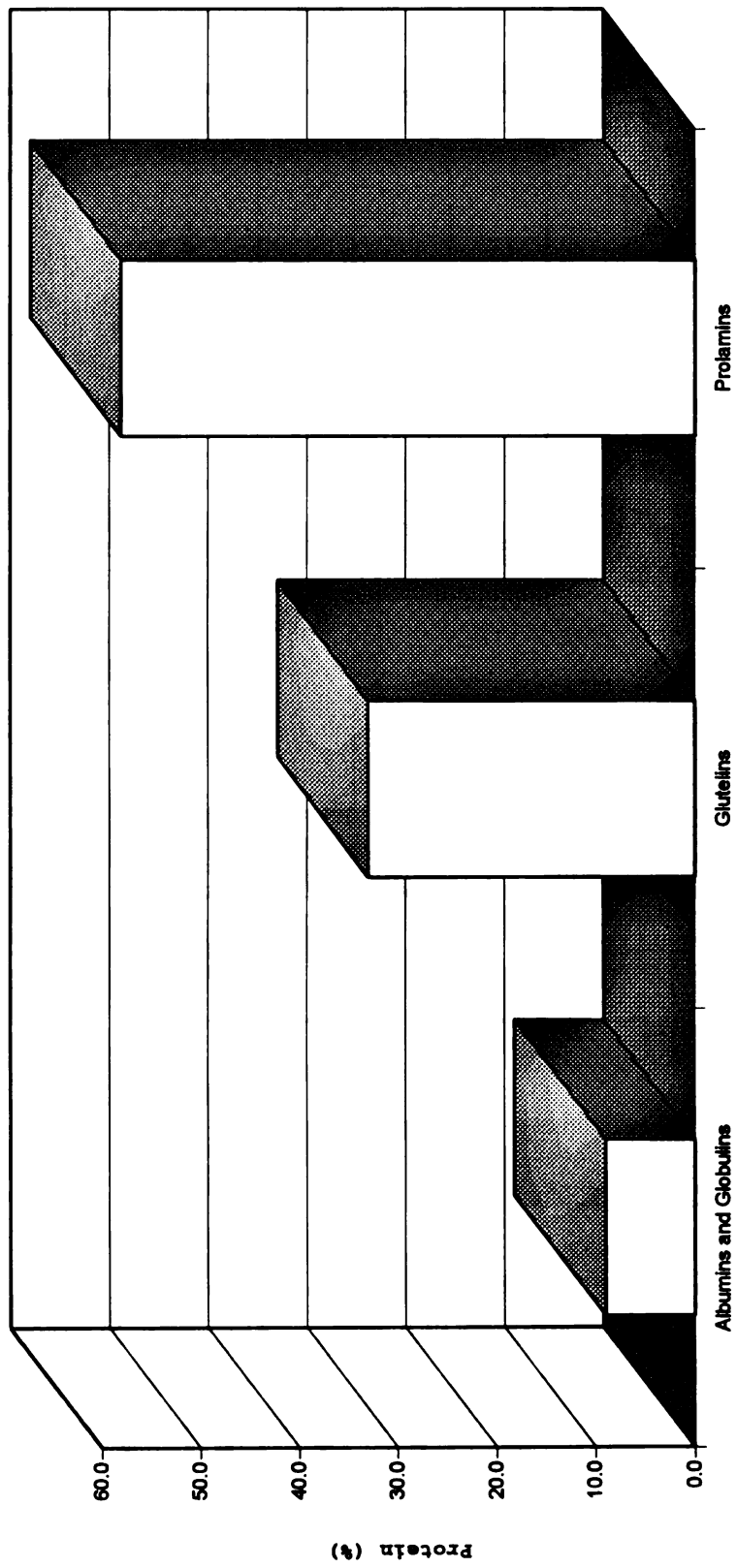


Figure 1 Corn Protein Fractions (NRC, 1988)

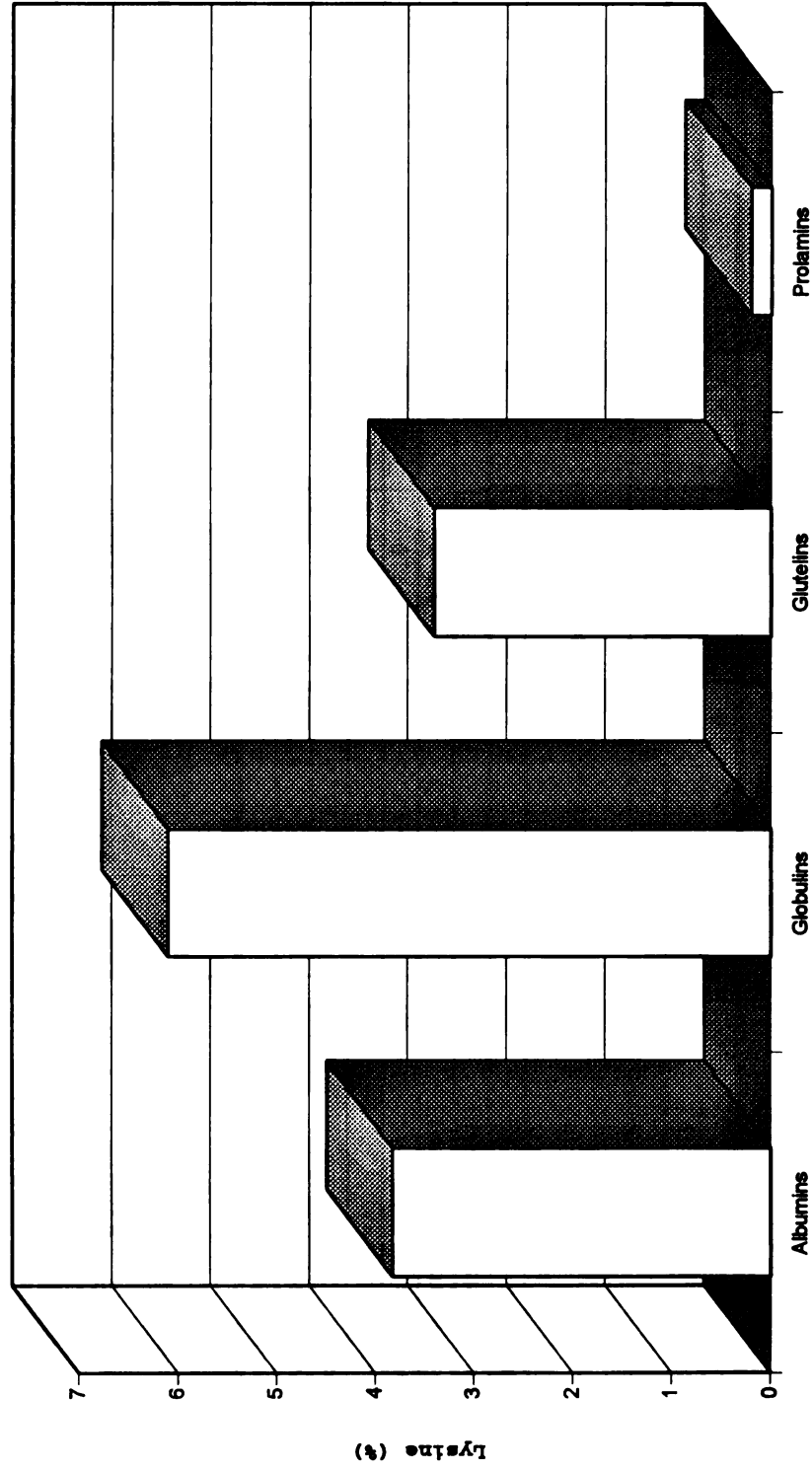


Figure 2 Lysine Content in Corn Protein Fractions (NRC, 1988)

Table 3 Comparison of Protein Fractions from Several Sources

Author	Albumins (%)	Globulins (%)	Glutelins (%)	Prolamins (%)	Undissolved (%)	Residue (%)
Bundy et al. (1967)	10.9	6.6		22.6		
Gupta et al. (1979)	3.56	4.75	43.04	43.33		5.32
Mertz (1957)	21.0-23.0		24.0	47.0	6.0	
Mosse (1966)	13.4-14.2		31.2-34.5	43.0-48.4		
Osborne and Mendel (1914)	11.8-12.0		37.0	34.0	17.0	
Paiva et al. (1991)	5.9-6.3		27.3	66.3		9.5
Tello et al. (1965)			29.0	37.0		
Wolf et al. (1975)		5.8		39.2		51.6
Lysine in Protein Fractions (%)						
Concon (1966)	6.4	4.4	3.7	0.1		
Dimler (1966)		5.5	2.5	0.1		
Wilson (1983)	5.9	5.0	5.4	0.2		

the growth of nonruminant animals. The observations of Frey (1951) are in harmony with this well-established fact in that high protein corn contains a greater proportion of zein in its total protein than low protein corn.

Corn prolamins, zeins, constitute a family of the alcohol-soluble corn endosperm storage proteins that are located within protein bodies (Lending and Larkins, 1989). They are the major type of protein in the corn kernel, accounting for 50-60% of the total seed protein (Wilson, 1983) and are almost exclusively located in seeds of the botanical family Gramineae. Their only known physiologic role in the plant is as a source of nourishment for the developing embryo. Zeins have unusual amino acid compositions: Their high glutamine, proline, and hydrophobic amino acid contents give them unique solubility (insoluble in water or aqueous salt solutions, but soluble in aqueous alcohol), and their deficiency in the animal essential amino acids, lysine, and tryptophan causes traditional corn varieties to be poor in protein quality. Salamini and Baldi (1969) observed a correlation coefficient of -0.81 when total corn lysine, in several varieties of corn, was related to the amount of the alcohol-soluble fraction (zein) in their meals. Tsai et al. (1983) concluded on basis of similar experiments that:

1. Lysine content as percent of protein decreases when zein

as percent of protein increases; 2. Zein as percent of dry weight increases as the total protein content increases; 3. Lysine as percent of protein is inversely proportional to the ratio of zein to total protein; and lysine as percent of dry weight is proportional to the content of nonzein protein.

Distribution of zein in immature corn was investigated by Zeleny (1935). He found that zein was nearly absent in very immature corn but was synthesized rapidly as the corn approached maturity. The rapid increase in the ratio of zein to total nitrogen was almost exactly paralleled by the decrease in water-soluble nonprotein nitrogen.

The nonprolamin proteins traditionally have been divided into albumins, globulins, and glutelins. Albumins are defined as water-soluble proteins (Osborne, 1924), but in too many cases the actual practice has been to define them as water-extractable proteins. Osborne's original procedure (1924) separates albumins from globulins on the basis that, after an extraction with a salt solution, the albumins remain soluble after dialysis against water, whereas the globulins are precipitated. The lysine levels are substantial, thus, the albumins are a good dietary source of essential amino acids. The globulin proteins are potential storage proteins and have also a high lysine content (4.4-5.0%). The glutelin fraction in corn

represents a significant proportion of the total protein,
as stated by *Dimler (1966)*, as much as 40 or 50%.

3.0 MATERIALS AND METHODS

3.1 Design

Forty-two corn samples (grab sampled) from different locations within the State of Michigan and four test weight corns of 54, 62, 66 and 76 kg/hl (dry matter of all four test weight corns was 87%) were analyzed for lysine and minerals. The latter were also analyzed for protein fractions and tested in the balance experiment. All corns were from a Michigan State University Extension survey. Test weights measurements were done by one person. There were no agronomic details (soil type, fertilization or variety of corn). In this study, a metabolic trial (Schneider and Platt, 1975) concerning nitrogen retention and energy utilization in swine was performed with four test weight corns which came from St. Joseph County. Four test weights corns were ground and mixed to obtain sufficient amounts of each corn for the complete balance trial. Twelve weaned, crossbreed Yorkshire x Hampshire pigs averaging 9.3 kg were randomly divided into four groups and placed individually in metabolism cages, resulting in three pigs per treatment. All cages had wire mesh floors suitable for separated urine and feces collection. The balance trial

Table 4 Experimental Design of Metabolism Trial

Period	A*	B*	C*	D*
Feed intake				
I.	Control BS**	Control BS**	Control BS**	Control BS**
II.	Prot.adapt. BS** Corn 54***	Prot.adapt. BS** Corn 62***	Prot.adapt. BS** Corn 66***	Prot.Adapt. BS** Corn 76***
III.	Test Corn 54****	Test Corn 62****	Test Corn 66****	Test Corn 76****
IV.	Test Corn 54****	Test Corn 62****	Test Corn 66****	Test Corn 76****

* Pig groups (3pigs/group)

** Basal supplement (200 grams)

*** 200 grams

**** 400 grams

Table 5 Composition of Experimental Diets

	BS*	54**	62**	66**	76**
Ingredients	% Dry matter				
Corn	0	100	100	100	100
Soybean meal	93.25	0	0	0	0
Defluorinated Phosphate	5.00	0	0	0	0
Salt	0.50	0	0	0	0
MSU VTM Premix	0.50	0	0	0	0
Vitamin E-Se Premix	0.50	0	0	0	0
ASP-250	0.25	0	0	0	0
* Basal supplement					
** Test corn(refers to kg/hl)					

was divided into four periods of five days each. Pigs were allowed two days between each period of the balance trial to adjust to the succeeding diet. Pigs were fed twice daily, and water was given with the meal at a two to one ratio. The balance trial was conducted as outlined in Table 4 and the diets fed are given in Table 5. Pigs were fed only corn during periods III and IV. The results obtained reflect solely the nutrients available in the corns. Period IV was a replicate of period III, thus, there are 6 independent sets of observations per corn for statistical assessment purposes. Final average weight of pigs was 23 kg. The purpose of the trial was to determine the nitrogen and energy balances in respect to each test weight corn.

3.2 Collection of Samples

Urine collections were made on a 5-day fixed time basis. Urine output was recorded and subsamples of 50 ml were taken, securely sealed and stored until analyses were performed. Fecal collections were also made on a 5-day fixed time basis, allowed to dry at ambient temperature, weighted and later redried for DM determinations. The dried feces were ground twice through a 2 mm diameter screen in a Wiley Mill.

3.3 Determination of Percent Protein and Nitrogen

All urine and fecal samples were tested for nitrogen and protein contents by the standard Auto-Kjeldahl method using the Technicon Auto-Kjeldahl Analyser. Percent of nitrogen was converted to percent of crude protein by the coefficient of 6.25 (AOAC, 1992).

3.4 Determination of Gross Energy

Corn, urinary and fecal energies were determined by the Paar Adiabatic Oxygen Bomb Calorimetric method (AOAC, 1992).

3.5 Determination of Lysine Composition

All of the forty-six corn samples were analyzed for lysine composition. The corns were dried and approximately 100 mg were hydrolyzed in 20 ml of 6N hydrochloric acid under a N atmosphere at 121 °C in an autoclave for 24 hours. The hydrolyzates were filtered and the volume adjusted to 40 ml. Twenty µl of hydrolysates were prepared and derivatized with phenylisothiocyanate (PITC). The PITC

derivatives were diluted to 200 μ l (Waters Manual, 1986) and 15 μ l were injected onto a 15 cm Pico Tag AA column (Waters) and eluted with a binary gradient (Waters Manual, 1986). Column temperature was set a 38 °C, flow rate was 1 ml/min., detector UV at 254 nm. Chromotopography was accomplished on a Waters HPLC system with a 712 WISP Injector, 2,510 Pumps, 720 Controller, 730 Data Module and 440 Spectrometer.

3.6 Determination of Minerals

Minerals analyses were performed only with corn samples. Analyses included a Spectro-Fluorometric analyses of Se which had to be carried out separately from Ca, Zn, P and Fe. Ca, Zn and Fe were quantitated by atomic absorption spectroscopy after nitric acid-perchloric acid digestion. Phosphorus was determined in the nitric-perchloric digest using the Fiske-Subbarow procedure (AOAC, 1992).

3.7 Determination of Protein Fractions

Only test corn samples were analyzed for protein fractions. Albumins and globulins were extracted by 0.5M

sodium chloride. Prolamins (Zein) were extracted by 70% ethanol. After extraction, each residue (for prolamins determination) was washed with water to remove salt. The glutelins were present in the residue (Osborne, 1907). First set of the salt/water extraction residues (Residue A) were analyzed for N. Second set of the salt/water and ethanol extraction residues (Residue B) were also analyzed for N. Calculations were made as follows:

- a) Total corn(N) - Residue A(N) = Albumins and Globulins
- b) Total corn(N) - Residue B(N) = Albumins, Globulins and Zein
- c) (b) - (a) = Zein
- d) Residue B = Glutelins

3.8 Calculations and Statistical Analyses

Upon obtaining the data from the N balance study and gross energy determinations of the corn, fecal and urinary samples, treatment differences in regards to percent apparent dry matter digestibility, percent apparent protein (N) digestibility, percent apparent gross energy digestibility, percent digestible energy, percent metabolizable energy, percent absorbed N, percent net protein utilization, percent N retention and percent biological value were determined by Anova: Single-Factor

(SAS, 1989). When a significant treatment difference existed, Tukey's Studentized Range (HSD) Test for variable (Tukey, 1989) was used to determine significant differences among treatments. Basis for these statistical analyses were nitrogen and energy balance values calculated for each corn using routine procedures (Adeola et al., 1986).

4.0 RESULTS AND DISCUSSION

4.1 Lysine, Crude Protein and Test Weight Distribution

Distribution of crude protein and lysine content in forty-six corns by counties and in relation to test weight are presented in Tables 6 and 7, respectively. Distribution of test weight by counties and locations of corns within the State of Michigan are presented in Figures 3 and 4, respectively. Samples number 89 and 90 were excluded from the observation since they were complete feeds. Corn test weights varied substantially - i.e. 54 kilogram per hectoliter to 75 kilogram per hectoliter. The crude protein content of the corn samples averaged 8.72% compared to a NRC, 1988 value of 8.50%. Wide variations in protein content were observed with test weight. For the test weight corns in range 54-61 kg/hl, the average protein content was 8.70% with a range of 7.3-10.2%, in range 62-65 kg/hl, the average protein content was 8.85% with a range of 8.1-10.2%, and finally in range 66-75 kg/hl, the average protein content was 8.65% with a range of 7.6-9.6%. As shown, similar data appeared to be the norm for all corn test weight categories. Apparently the variation in protein content within a given corn test weight category is about the same as the variation among test weight categories, suggesting that significant differences do not exist

**Table 6 Distribution of Crude Protein, Lysine and
Test Weight of Corn by Counties**

Corn (#)	County	Dry Matter (%)	Crude Protein (%)*	Lysine (%)**	Lysine (%***)	Test Weight (kg/hl)
5	Allegan	85.6	8.8	0.21	2.38	66
6	Allegan	85.3	8.3	0.20	2.41	63
7	Allegan	84.7	8.1	0.23	2.84	66
8	Allegan	87.3	8.7	0.23	2.64	67
9	Ogemaw	87.2	9.6	0.24	2.50	66
10	Ogemaw	88.2	9.8	0.23	2.35	57
12	Ogemaw	85.8	9.6	0.23	2.40	55
22	Branch	79.4	8.1	0.23	2.84	63
23	Branch	90.1	8.7	0.22	2.53	55
25	Mecosta	85.7	10.2	0.25	2.45	59
26	Mecosta	89.5	8.9	0.22	2.47	64
27	Huron	77.3	8.7	0.23	2.64	59
28	Huron	73.7	8.8	0.24	2.73	54
30	St. Joseph	85.7	7.8	0.25	3.21	55
31	St. Joseph	89.8	7.6	0.24	3.16	56
32	Branch	86.6	8.9	0.24	2.70	73
33	St. Joseph	88.8	7.3	0.24	3.29	54
34	St. Joseph	86.1	8.5	0.24	2.82	58
35	Cass	86.8	8.8	0.24	2.73	71
36	Cass	89.7	7.5	0.20	2.67	60
37	Cass	85.2	8.5	0.22	2.59	66
38	Cass	86.1	8.5	0.22	2.59	64
71	Cass	90.1	8.9	0.27	3.03	68

* Crude protein data obtained from Tom Pilbeam

** Of whole sample

*** Of protein

Table 6 (cont'd).

Corn (#)	County	Dry Matter (%)	Crude Protein (%)*	Lysine (%)**	Lysine (%***)	Test Weight (kg/hl)
72	Branch	77.0	7.6	0.24	3.16	69
73	Eaton	86.1	8.6	0.25	2.91	75
74	Ingham	90.5	8.6	0.26	3.02	63
75	Eaton	87.5	9.1	0.26	2.86	63
76	Gratiot	86.1	8.7	0.25	2.87	61
77	Kalamazoo	86.4	9.3	0.26	2.79	69
78	Kalamazoo	87.0	9.3	0.25	2.69	62
79	Gratiot	88.1	8.6	0.24	2.79	59
80	Otsego	87.8	9.2	0.24	2.61	66
81	Otsego	87.4	10.2	0.26	2.55	64
82	Otsego	90.0	9.8	0.25	2.55	55
83	Cass	87.5	7.8	0.22	2.82	66
84	Cass	88.5	9.0	0.20	2.22	72
85	Cass	86.3	9.2	0.24	2.61	59
86	Cass	89.7	8.5	0.22	2.59	72
87	Cass	91.2	7.9	0.23	2.91	66
88	Lapeer	88.5	8.9	0.23	2.58	67
89	Cass****	90.0	18.7	1.25	6.68	N/A
90	Cass****	87.4	14.4	0.63	4.37	N/A
91	Gratiot	87.2	8.6	0.23	0.23	60
92	Eaton	86.6	8.6	0.23	0.23	65
93	Ottawa	88.4	8.8	0.26	0.26	60
98	Gratiot	88.2	8.6	0.24	0.24	58

* Crude protein data obtained from Tom Pilbeam

** Of whole sample

*** Of protein

**** Feeds

**Table 7 Distribution of Crude Protein and Lysine
Content in Corn Relative to Test Weight**

Corn (number)		County***	Test Weight (kg/hl)	Crude Protein (%)	Lysine (%)
10, 12, 23, 25, 27, 28, 30, 31, 33, 34, 36, 76, 79, 82, 85, 91, 93, 98		B, C, G, H, M, O, OT, SJ	54-61	7.3-10.2	0.20-0.26
		A, B, C, E, I, K, L, OS	62-65	8.1-10.2	0.20-0.26
6, 22, 26, 38, 74, 75, 78, 81, 92 5, 7, 8, 9, 32, 35, 37, 71, 72, 73, 77, 80, 83, 84, 86, 87, 88		A, B, C, E, K L, O, OS	66-75	7.6-9.6	0.20-0.27
		Mean	63	8.72	0.24
		NRC*	72**	8.50	0.25

* NRC, 1988

** US Grade No.1 corn

A	Allegan	K	Kalamazoo
B	Branch	L	Lapeer
C	Cass	M	Mecosta
E	Eaton	O	Ogemaw
G	Gratiot	OS	Otsego
H	Huron	OT	Ottawa
I	Ingham	SJ	St. Joseph

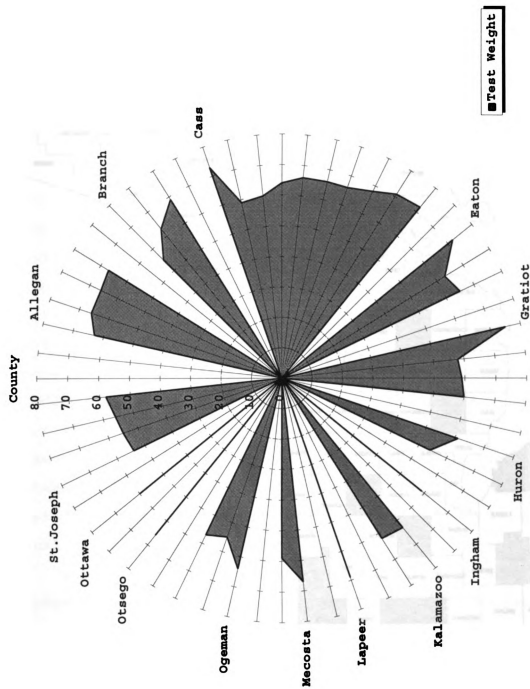


Figure 3 Distribution of Test Weight by Counties

Figure 4 Locations of Test Weight Corns by Counties

($P > .05$). There was no significant effect of test weight on crude protein (correlation coefficient=0.003). The distribution of crude protein and test weight and a regression plot of the original data, predicted values, and the regression line ($y = 8.27 + 0.003x$) are shown in Figures 5 and 6, respectively.

The lysine content of the corn samples averaged 0.24% compared to a NRC, 1988 value of 0.25%. There was significant effect of crude protein on lysine (correlation coefficient=0.32). Lysine content changed proportionally with crude protein content as shown in Figure 7 and in regression plot of crude protein and lysine ($y = 0.166 + 0.008x$) in Figure 8. In other words, lysine levels increased or decreased as protein levels changed. These findings are in agreement with the findings of Arnold et al. (1977), Paez et al. (1969), Davis et al. (1970), and Keney (1970) who also found a significant correlation between nitrogen and lysine in corn and stated, therefore, that lysine content on dry weight basis increases as the total nitrogen content increases.

There was no significant effect of test weight on lysine (correlation coefficient=-0.09). Lysine content did not change proportionally with test weight as shown in Figure 9 and in regression plot of lysine and test weight ($y = 0.252 - 0.0003x$) in Figure 10. It was not possible to compare distribution of lysine according to test weight from my findings with other authors' findings, since related data were not available.

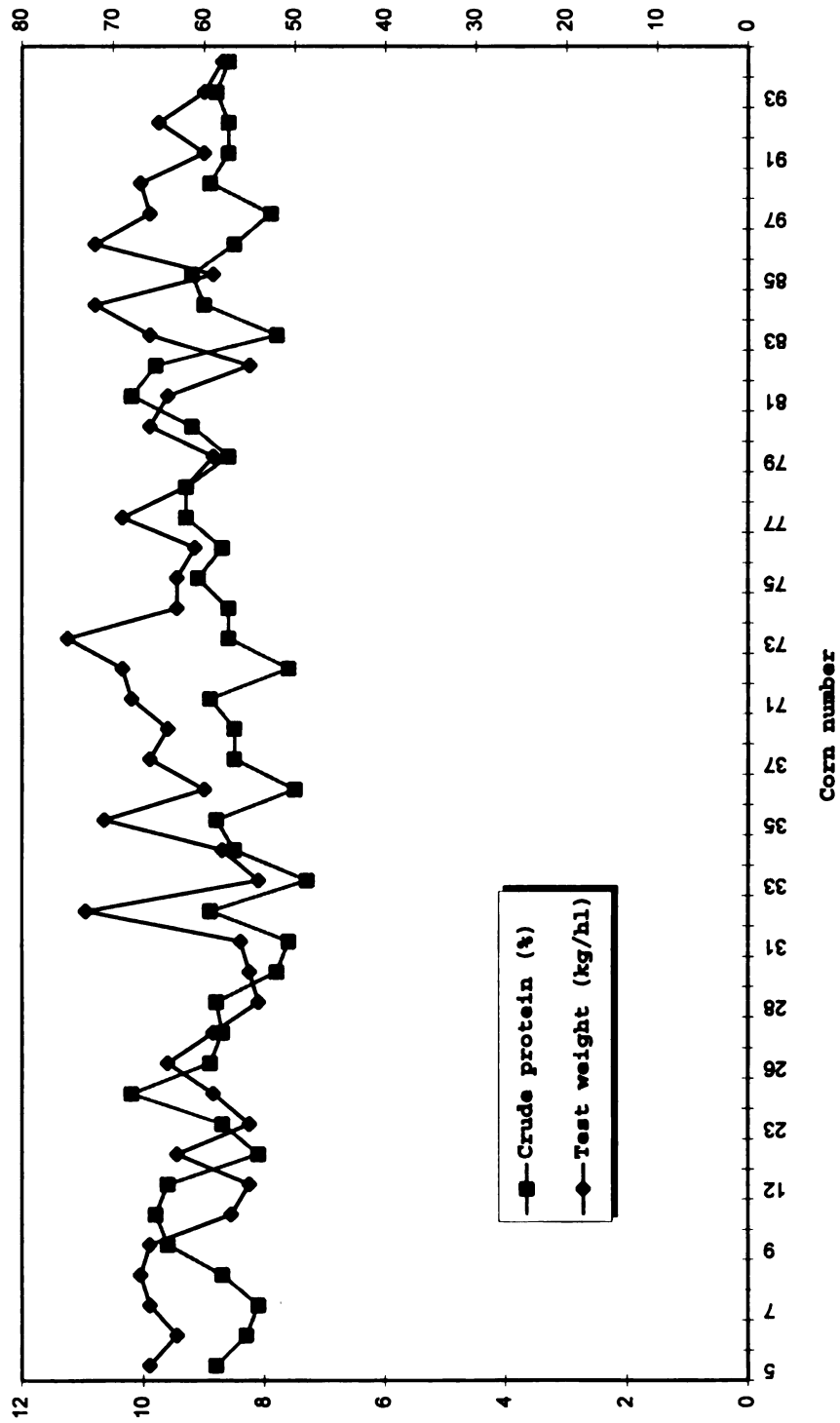


Figure 5 Distribution of Crude Protein and Test Weight ($r=0.003$)

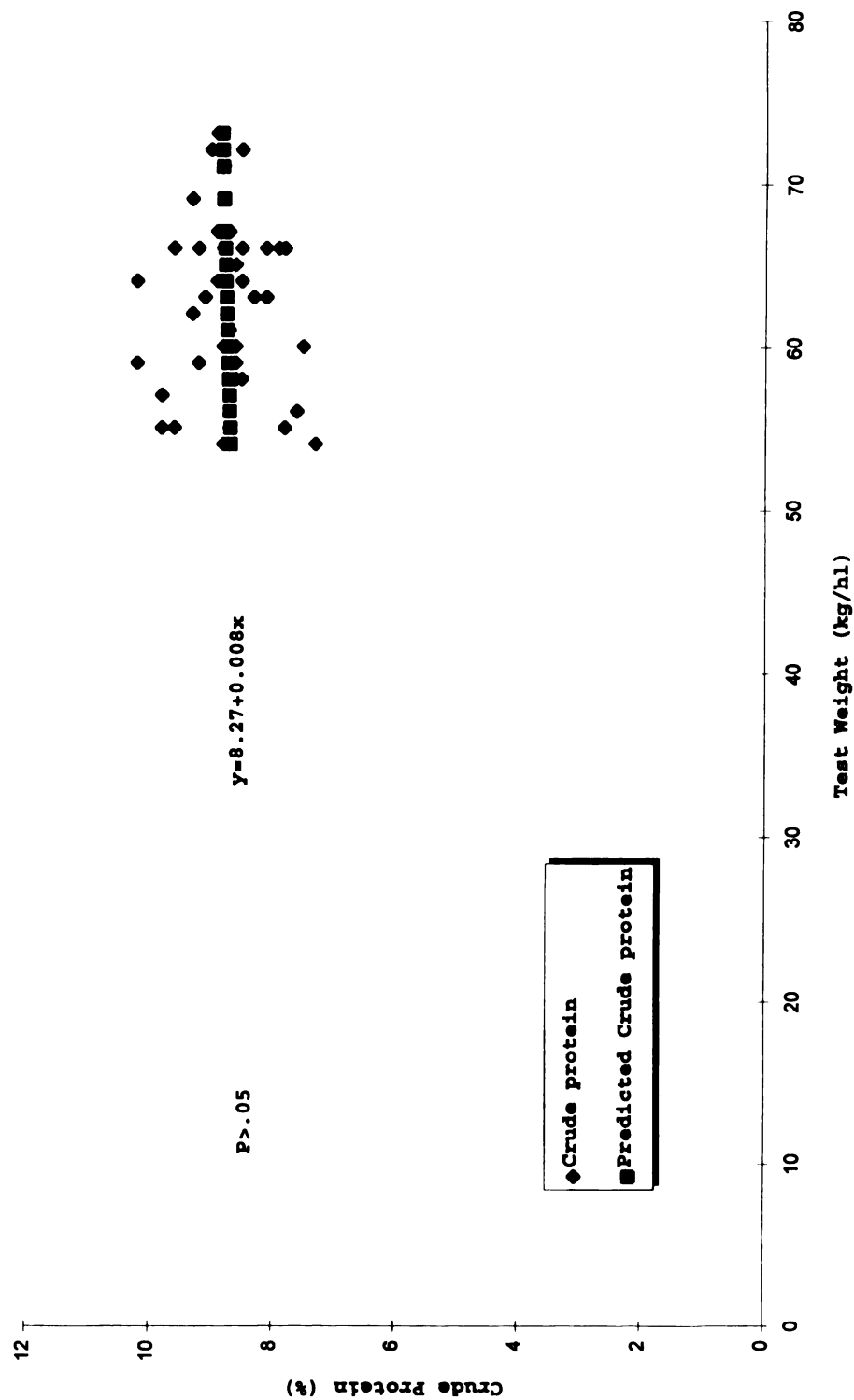


Figure 6 Regression Plot of Crude Protein vs. Test Weight

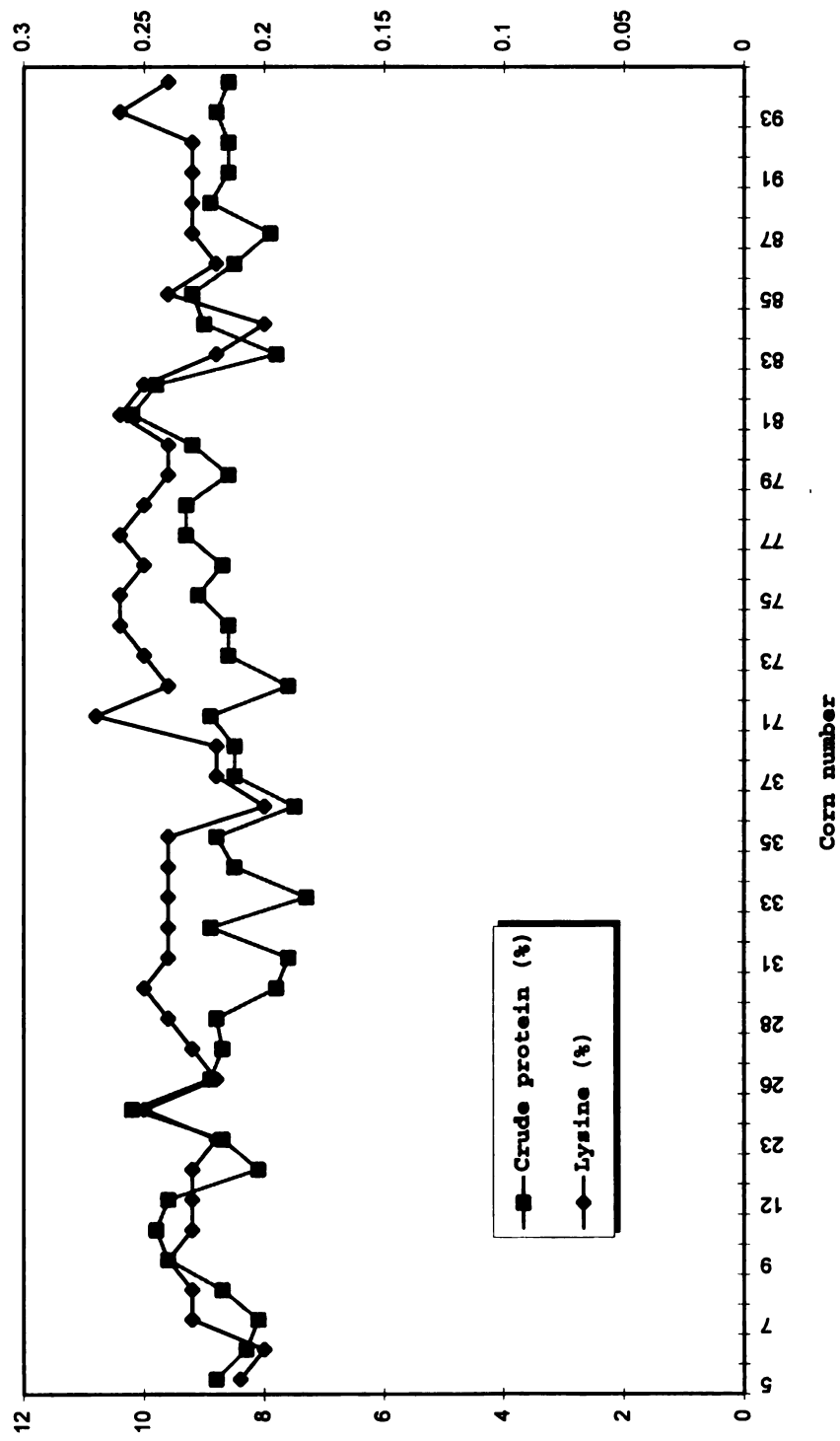


Figure 7 Distribution of Crude Protein and Lysine ($r=0.32$)

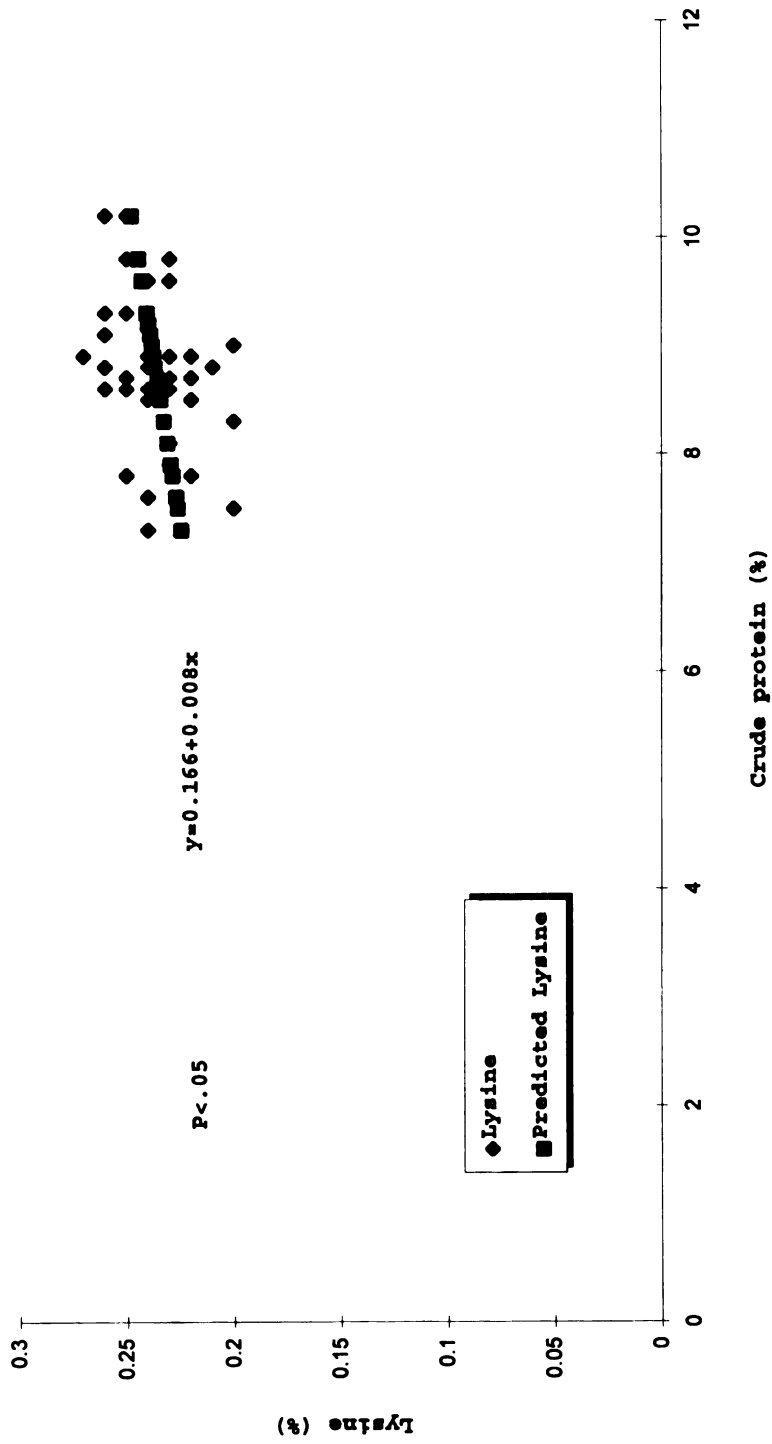


Figure 8 Regression Plot of Lysine vs. Crude Protein

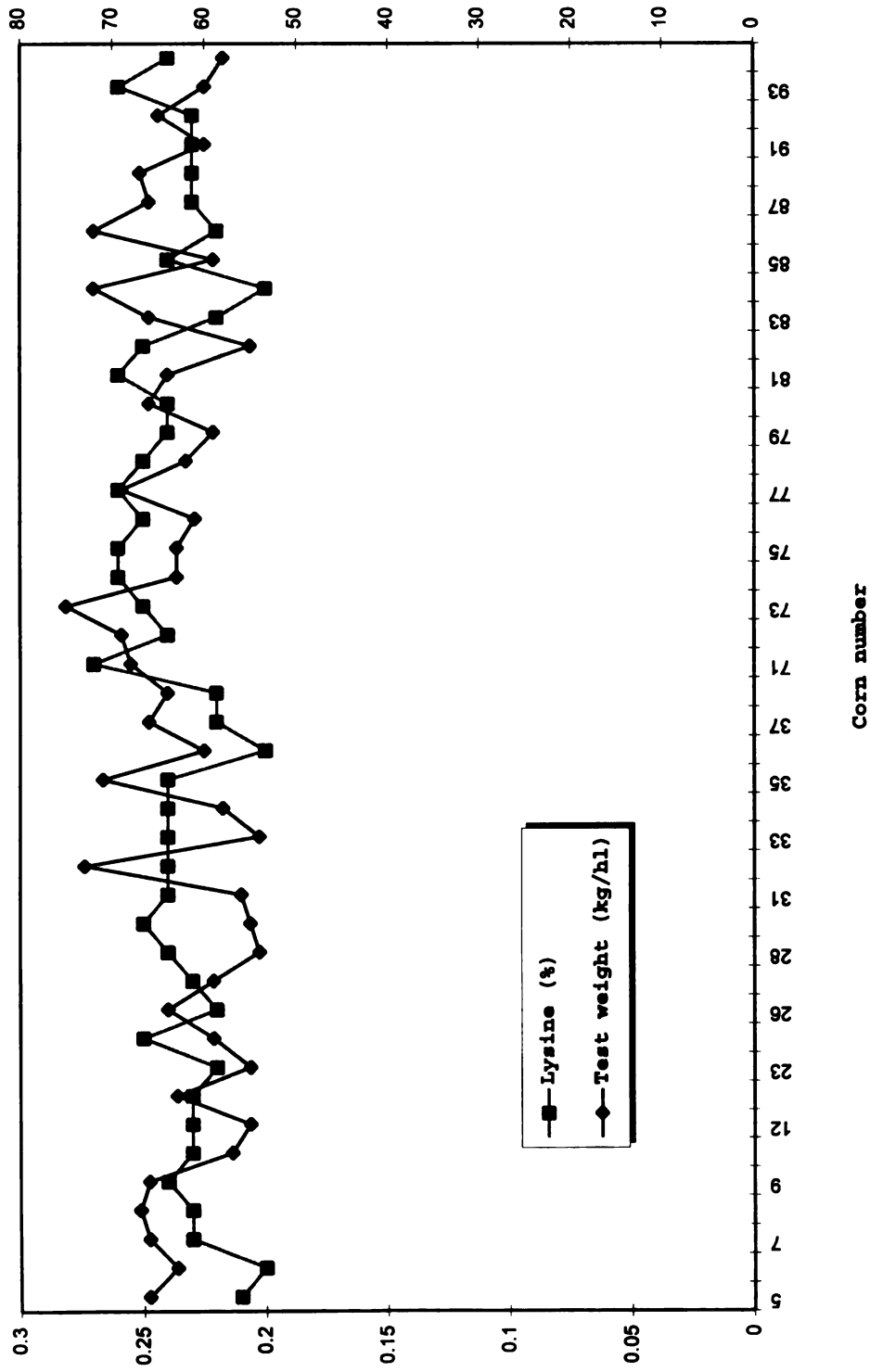


Figure 9 Distribution of Lysine and Test Weight ($r = -0.09$)

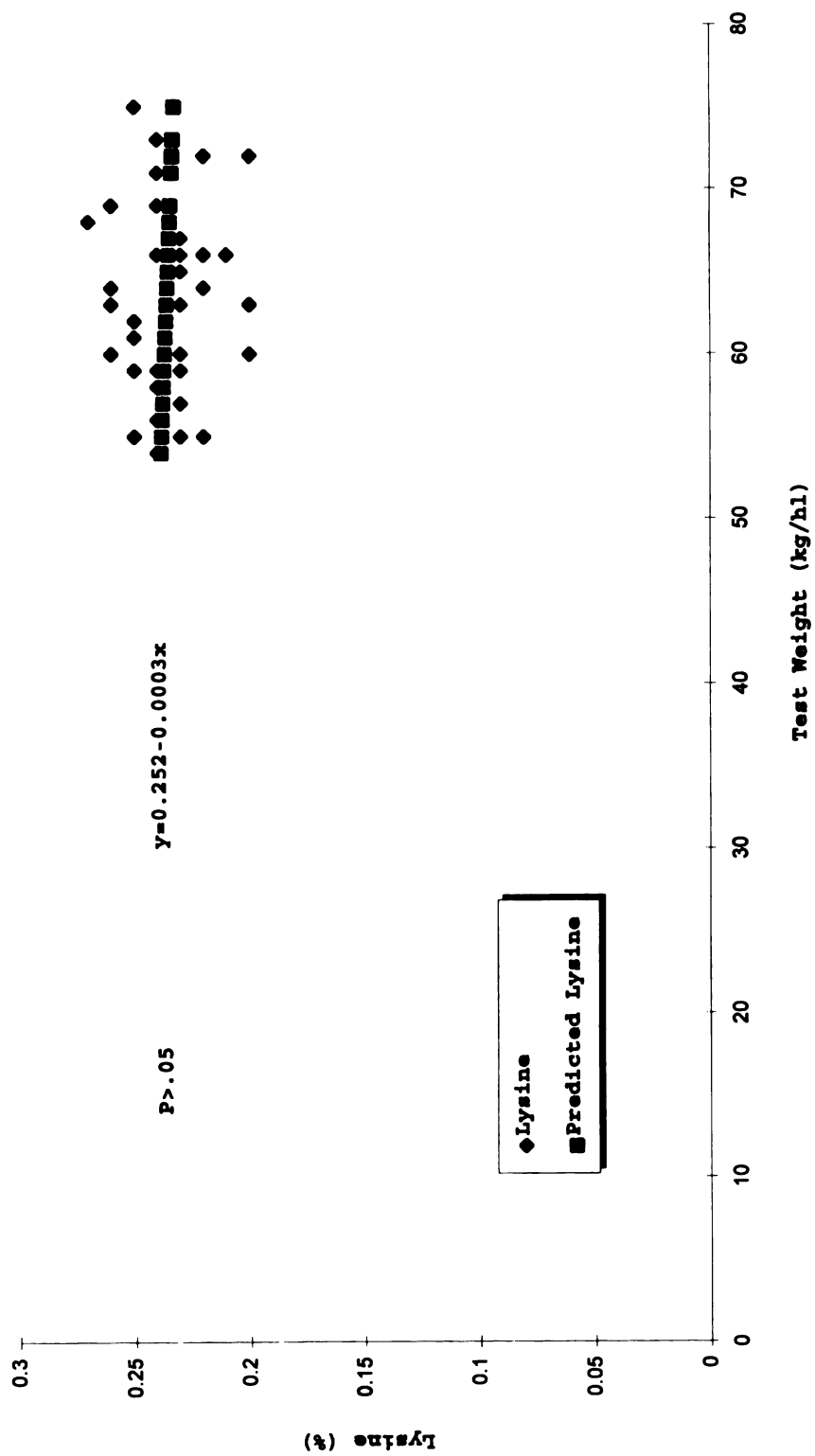


Figure 10 Regression Plot of Lysine vs. Test Weight

4.2 Energy and Nitrogen Balance Study

The corns were chosen for energy and nitrogen balance study according to their test weight of 54, 62, 66, and 76 kg/hl. The crude protein contents of test weight corns were 7.42, 8.03, 8.72, and 8.13%, respectively (Figure 11).

Table 8 presents gross energy and nitrogen intake, fecal and urinary gross energy and nitrogen, digestible and metabolizable energy, metabolizable and digestible energy ratio, absorbed and retained nitrogen, net protein utilization and biological value, dry matter, gross energy and nitrogen digestibilities.

The DE values of the 54, 62, 66, and 76 test weight corns were 3.75, 4.02, 3.88, and 4.09 kcal/g, respectively. While insignificant on corns 62 and 76 ($P > .01$), other pairwise comparisons were significant ($P < .01$). Similar DE in corns was reported by Adeola et al. (1986). However, DE of corn 66 was higher ($P < .01$) than DE of corn 54 but lower ($P < .05$) than DE of corn 62. Distribution of digestible energy (kcal/g) of test weight corns is presented in Figure 12.

The ME, because it accounts for energy losses from the animal via urine and is thus a more sensitive indicator of the animal's physiological state, is more accurate than DE in evaluating the energy available for maintenance and productive purposes. However, such a situation implies the

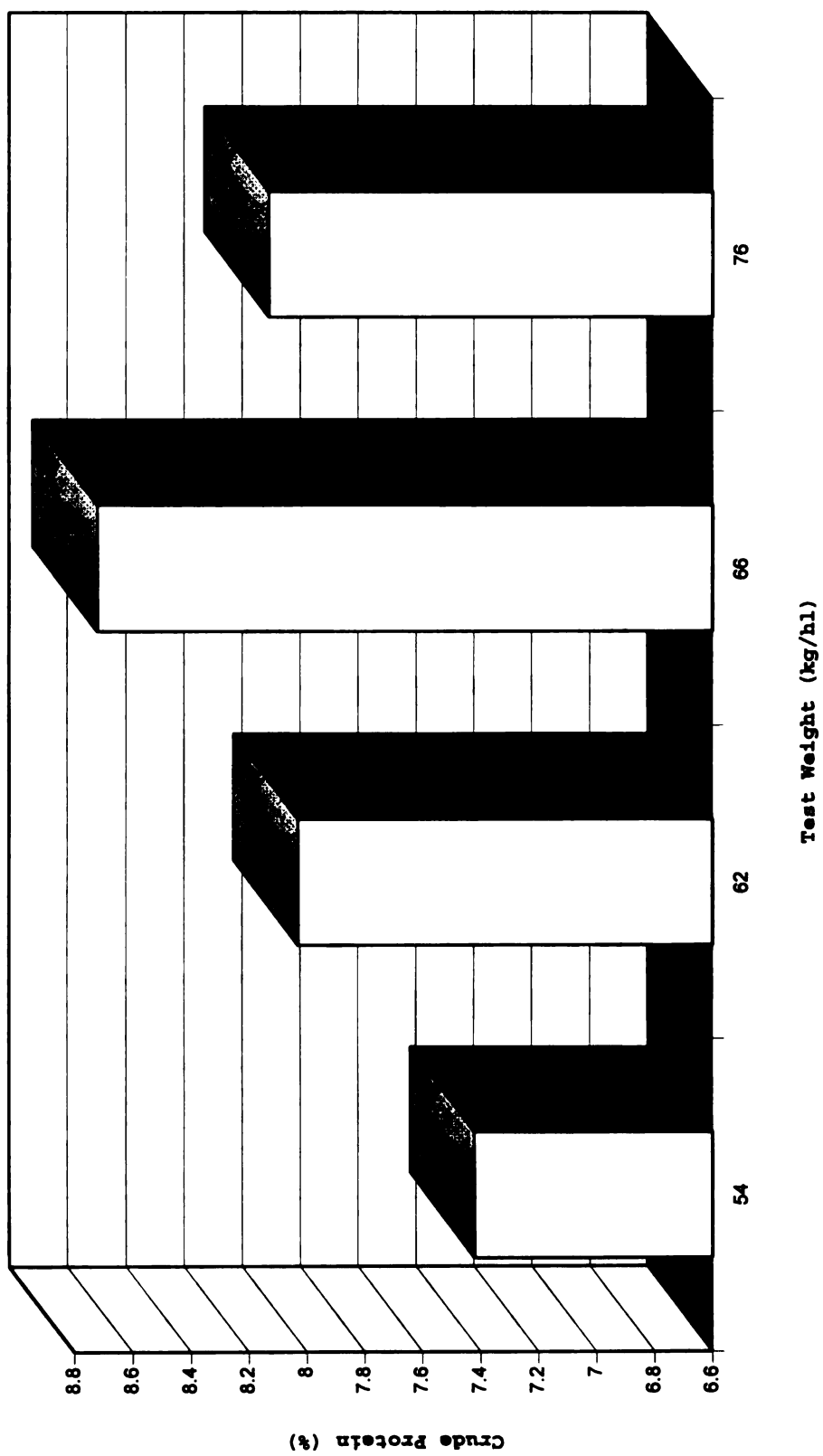


Figure 11 Distribution of Crude Protein (%)

Table 8 The Effect of Test Weight on Energy Balance and Nitrogen Balance in Young Pigs

Item	Corn 54 (kg/hl)	Corn 62 (kg/hl)	Corn 66 (kg/hl)	Corn 76 (kg/hl)	SEM ^a
Energy balance					
No. of pigs	6	6	6	6	N/A
Daily feed intake, g (as fed)	400	400	400	400	N/A
Daily GE intake, kcal	1,656 ^c	1,772 ^a	1,700 ^b	1,760 ^a	4.13
Daily fecal dry weight, g	51.5 ^{ab}	49.0 ^{bb}	46.9 ^{bc}	38.9 ^{cd}	0.58
Daily fecal GE, kcal	154.6 ^{ab}	161.8 ^a	145.3 ^{ab}	124.4 ^b	5.42
Daily DE, kcal	1,502 ^d	1,610 ^b	1,555 ^c	1,636 ^a	4.05
Digestible energy, kcal/g	3.75 ^b	4.02 ^a	3.88 ^{ab}	4.09 ^a	0.02
Energy digested, %	90.7 ^b	90.9 ^b	91.4 ^b	92.9 ^a	0.17
Daily urine, g	390 ^b	395 ^{ab}	367 ^c	403 ^a	1.90
Daily urine GE, kcal	23.4	24.1	22.0	24.2	2.81
Daily ME, kcal	1,478 ^d	1,586 ^b	1,533 ^c	1,612 ^a	2.89
Metabolizable energy, kcal/g	3.70 ^c	3.97 ^a	3.83 ^b	4.03 ^a	0.02
Energy metabolized, %	89.2 ^{bc}	89.5 ^{bc}	90.2 ^{bb}	91.6 ^{ab}	0.34
ME : DE	98.7	98.7	98.7	98.5	N/A
Nitrogen balance					
Daily nitrogen intake, g	4.75 ^e	5.12 ^d	5.56 ^b	5.21 ^c	N/A
Daily fecal nitrogen, g	1.08 ^{ab}	1.13 ^{ac}	1.08 ^{ab}	0.87 ^{bd}	0.02
Daily absorbed nitrogen, g	3.67 ^{ca}	3.99 ^{bd}	4.48 ^{ab}	4.34 ^{ac}	0.03
Daily urinary nitrogen, g	1.94 ^c	2.20 ^b	2.18 ^b	1.98 ^c	0.03
Daily retained nitrogen, g	1.73 ^c	1.79 ^c	2.30 ^b	2.36 ^b	0.04
Net protein utilization, %	36.4 ^c	35.1 ^c	41.4 ^{bc}	45.3 ^b	0.32
Biological value, %	47.1 ^c	44.9 ^d	51.3 ^{bc}	54.4 ^b	0.34
Apparent digestibility of DM, %	87.4 ^{bc}	88.0 ^b	88.5 ^{bb}	90.5 ^a	0.21
Apparent digestibility of GE, %	90.6 ^b	90.9 ^b	91.5 ^{bc}	92.9 ^{ab}	0.27
Apparent digestibility of N, %	77.3 ^b	78.1 ^b	80.6 ^{ab}	83.3 ^a	0.34

^aStandard error of the mean

^{bcd}Means in the same row with different subscripts differ (P<.05)

^{ABCD}Means in the same row with different subscripts differ (P<.01)

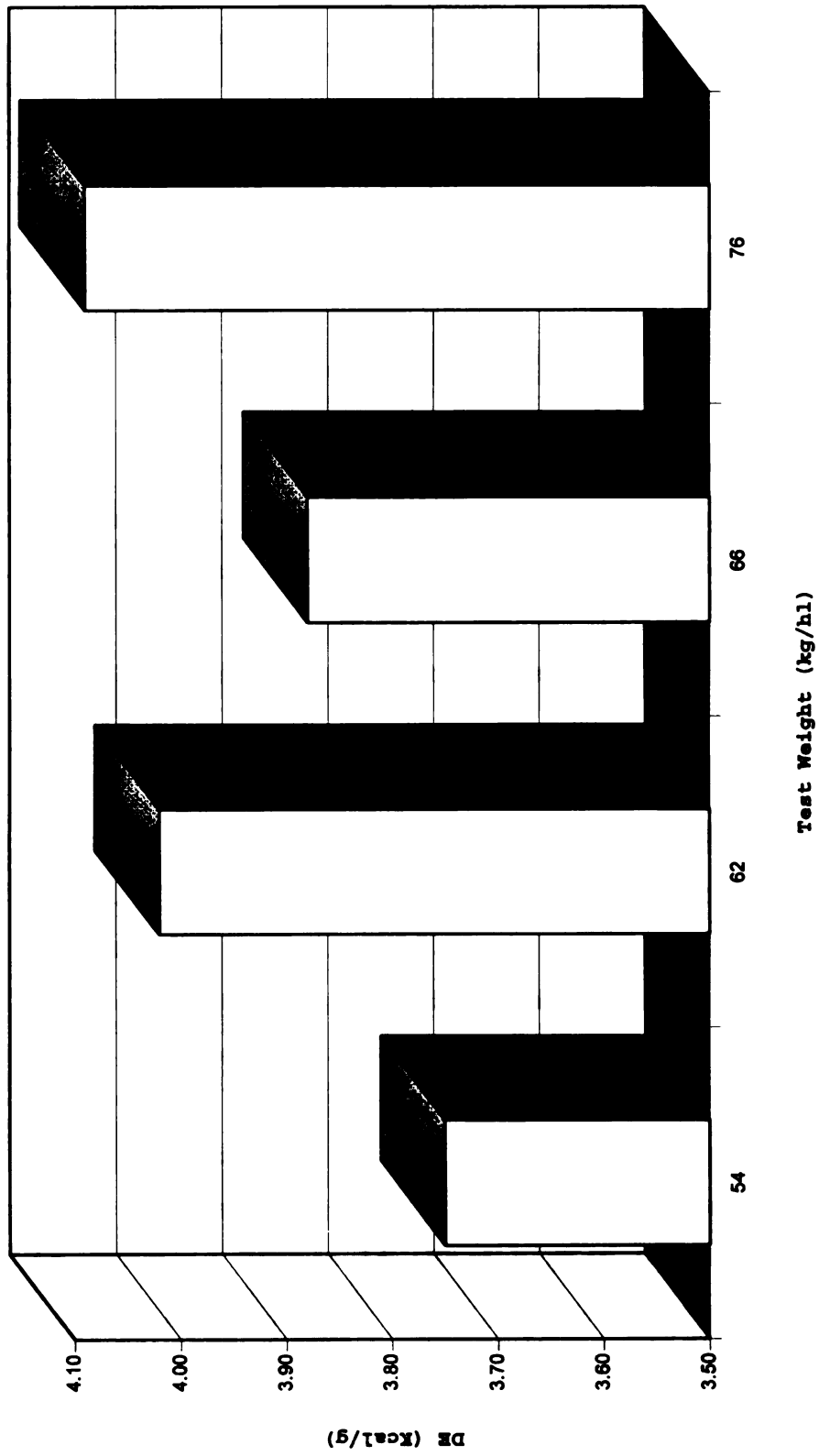


Figure 12 Digestible Energy (Kcal/g)

need to determine ME for each physiological state. DE has the advantage of ease of determination, which prompted May and Bell (1971) to suggest that to combine the advantages of the two (by assuming that ME is a constant proportion of DE) would be the most satisfactory approach.

The ME values of 54, 62, 66, and 76 test weight corns were 3.70, 3.97, 3.83, and 4.03, respectively. All pairwise comparisons were significant ($P < .01$) except for corns 62 and 76 ($P > .01$). ME of corn 54 was lower ($P < .01$) than other ME of corns, presumably a reflexion of its lower test weight and the gross energy content. These results are in close agreement with Morgan et al. (1975) and Lin et al. (1987). Distribution of metabolizable energy (kcal/g) is shown in Figure 13.

The amount of energy lost in urine is represented from 14.2-15.6% of dietary DE content (mean: 14.9%). The mean ME:DE ratio ($\times 100$), therefore, averaged 98.7%, what is similar to Morgan et al. (1975) findings. ME as a percentage of DE did not change significantly across corns as the test weight of corn increased.

The average daily nitrogen metabolism of pigs fed the four test weight corns is given in Table 8. The distribution of the ingested nitrogen of the test weight corns is shown in Figure 14. When higher amount of nitrogen was supplied by corns 66 and 76, a significantly ($P < .05$) greater percentage of the ingested nitrogen was retained from these corns than from corns 54 and 62. The absorbed

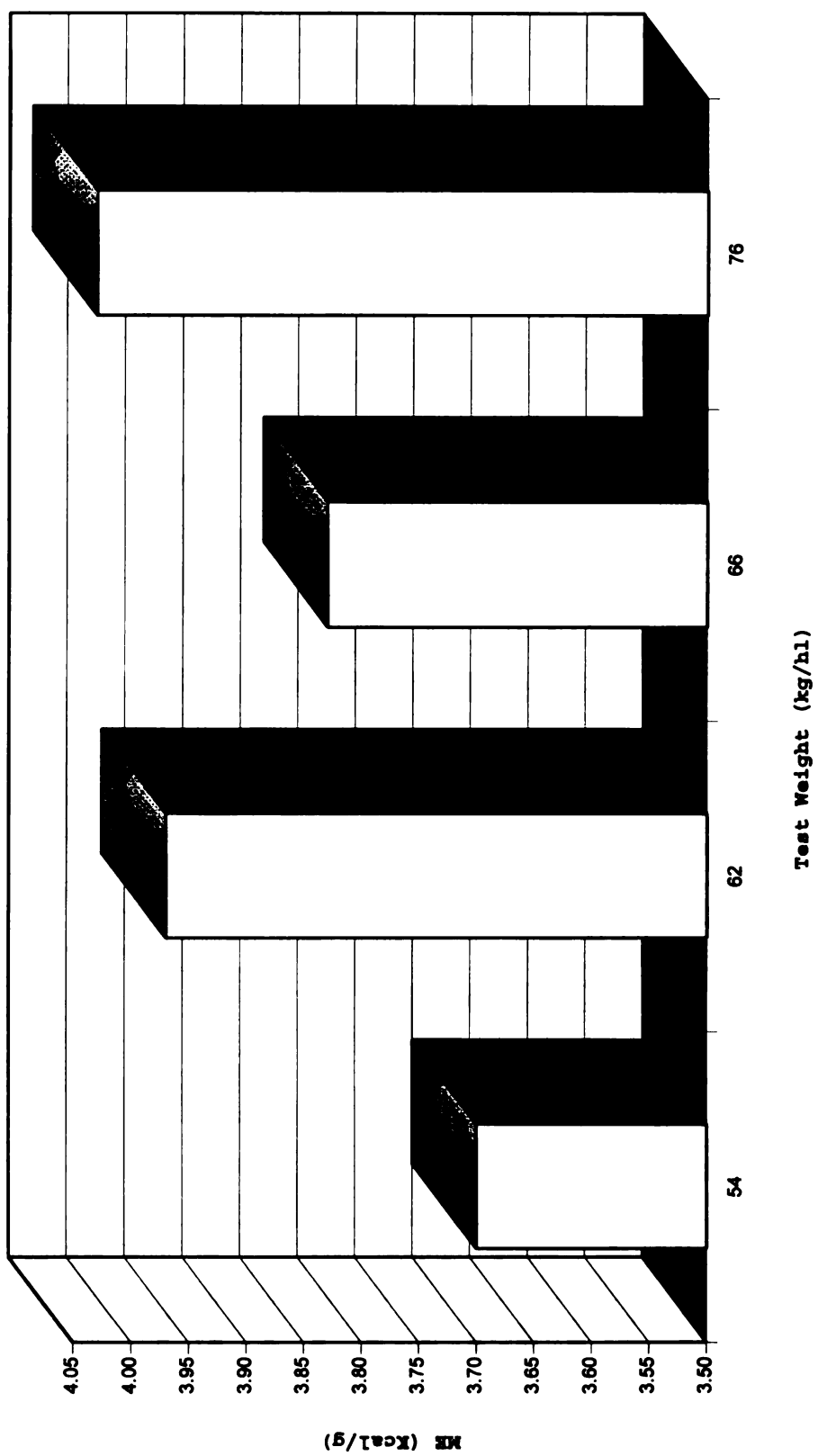


Figure 13 Metabolizable Energy (Kcal/g)

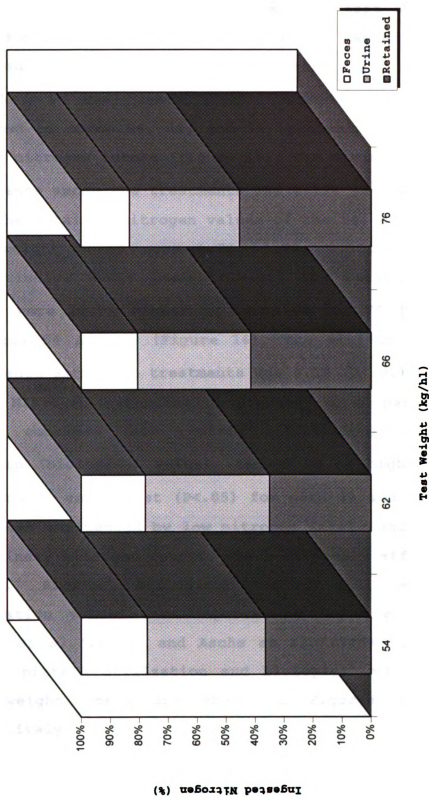


Figure 14 Distribution of Ingested Nitrogen (%)

nitrogen values of 54, 62, 66, and 76 test weight corns were 3.67, 3.99, 4.48, and 4.34 g, respectively. The absorbed nitrogen differed in all corns.

Corn 66 had higher ($P<.05$) absorbed nitrogen value compared to corns 54, 62, and 76, probably a reflexion of higher nitrogen intake (Figure 15). The minimum significant difference among the treatments was 0.124 ($P<.01$).

The retained nitrogen values of the 54, 62, 66, and 76 test weight corns were 1.73, 1.79, 2.30, and 2.36 g, respectively. While insignificant, the retained nitrogen values were 24.5% higher in corns 66 and 76 ($P<.05$) than in corns 54 and 62 (Figure 16). The minimum significant difference among the treatments was 0.19 ($P<.01$).

Nitrogen retention, expressed as a percentage of either consumed (net protein utilization) or absorbed nitrogen (biological value), tended to be highest ($P<.05$) for corn 76 and lowest ($P<.05$) for corn 62 and appeared to have been influenced by low nitrogen intake and high fecal and urinary nitrogen output, which adversely affected these values. Similar biological value and net protein utilization values were reported by Gupta et al.(1979), Adeola et al.(1986), and Asche et al.(1986). Distribution of net protein utilization and biological values of four test weight corns are shown in Figures 17 and 18, respectively.

The digestibility of dry matter, gross energy and nitrogen were significantly ($P<.01$) higher for corn 76 than

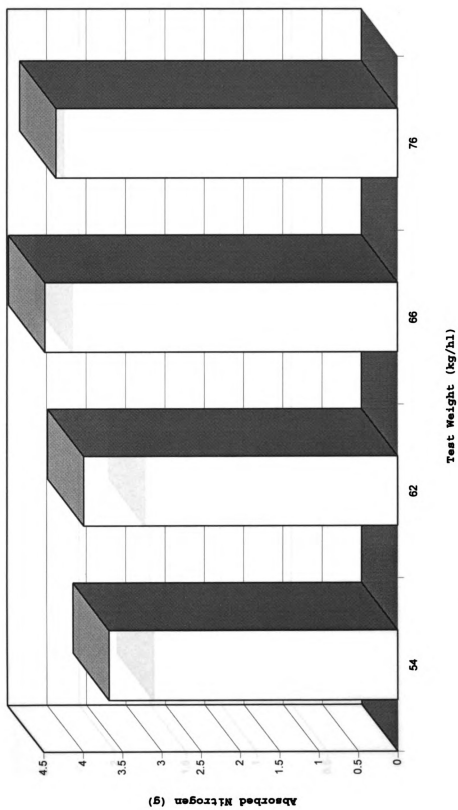


Figure 15 Daily Absorbed Nitrogen (g)

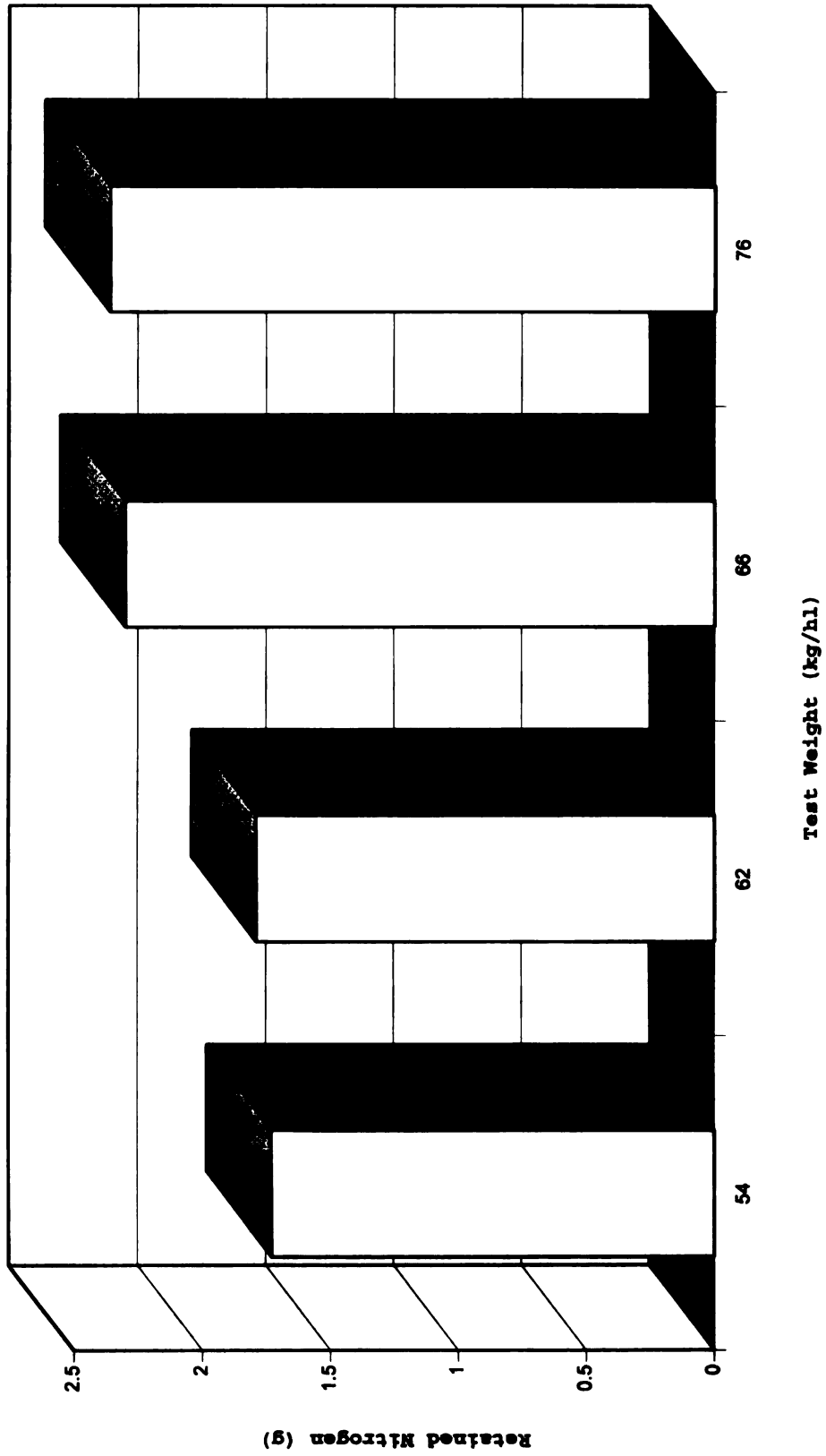


Figure 16 Daily Retained Nitrogen (g)

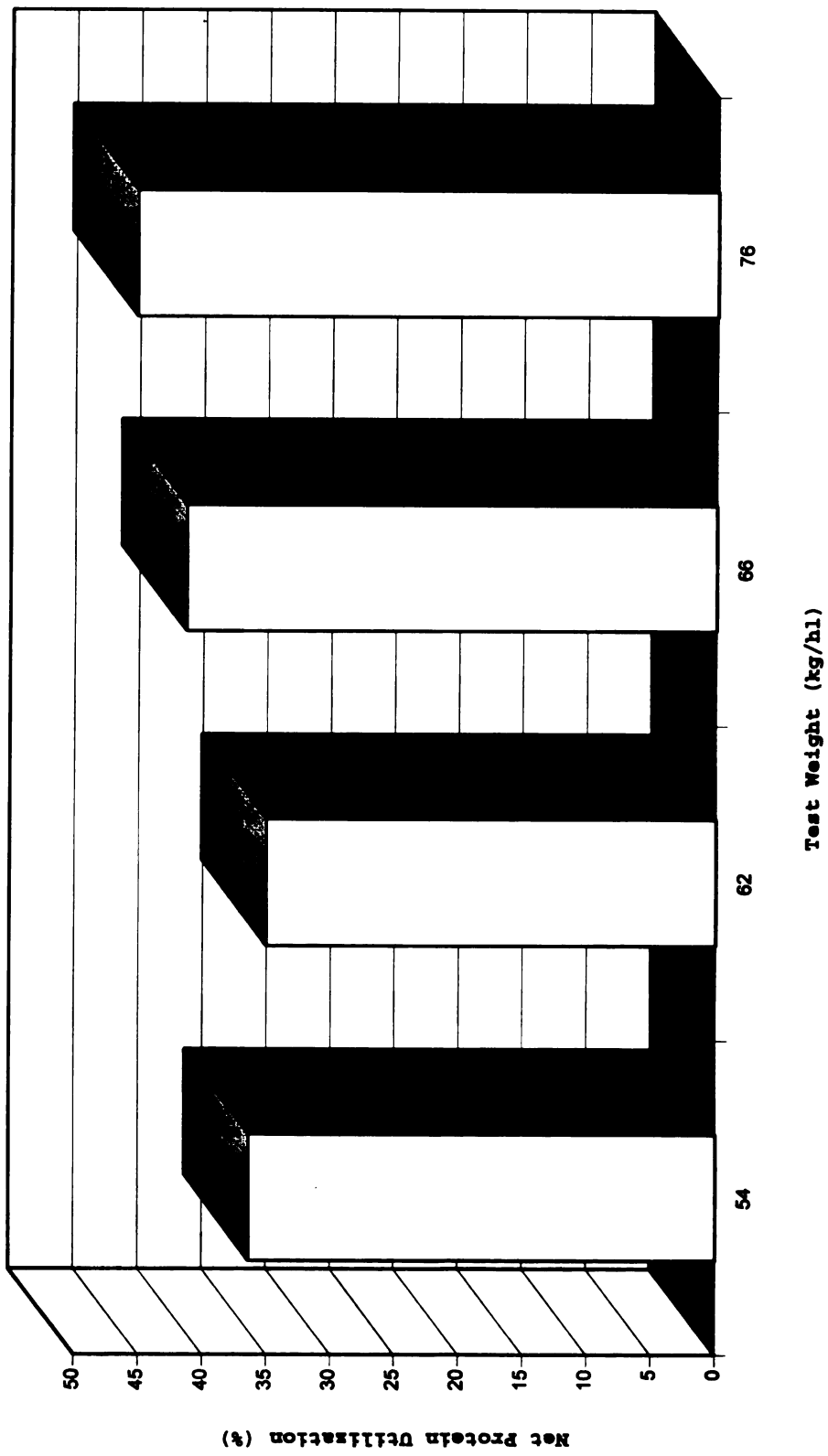


Figure 17 Net Protein Utilization (%)

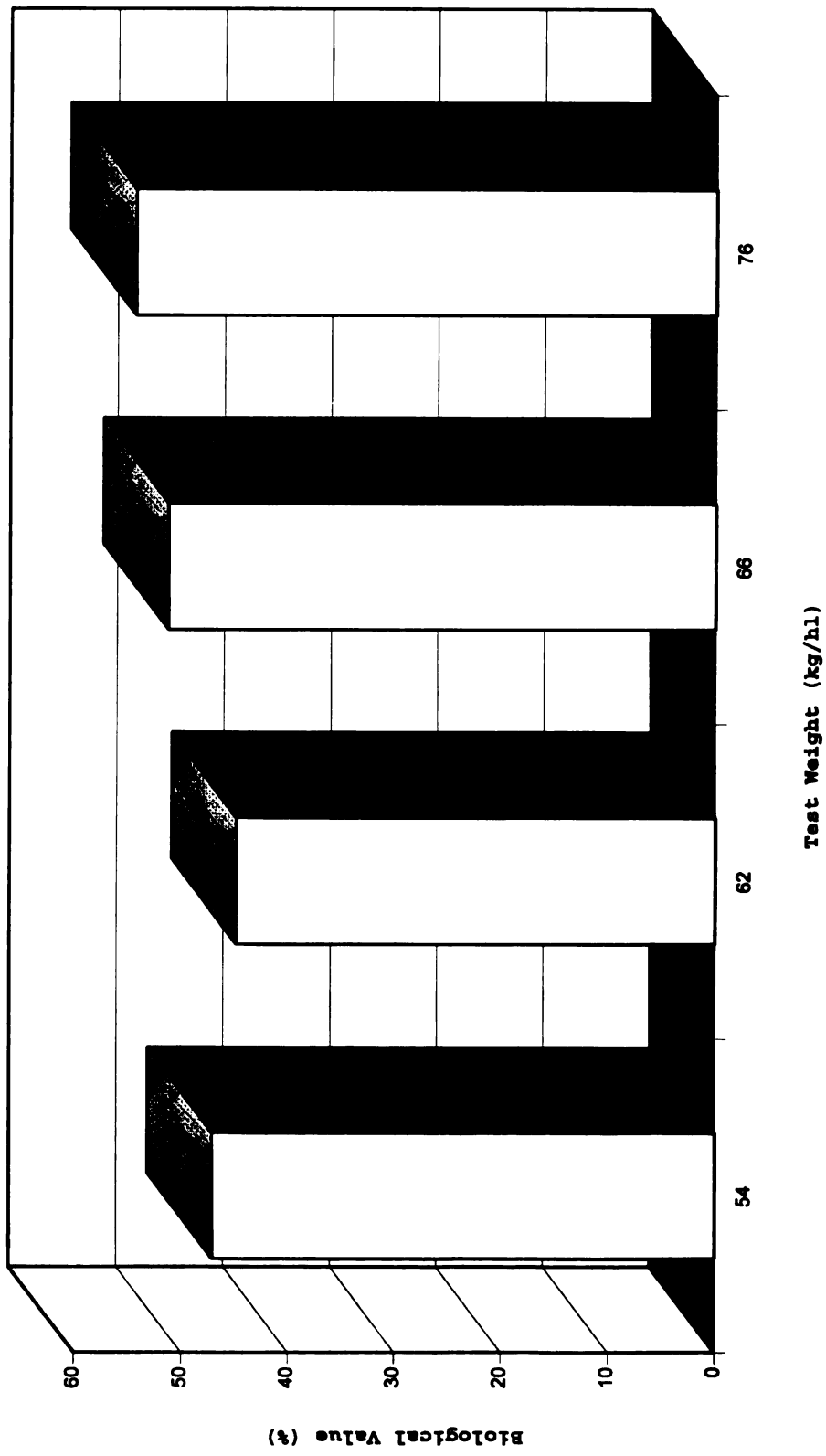


Figure 18 Biological Value (%)

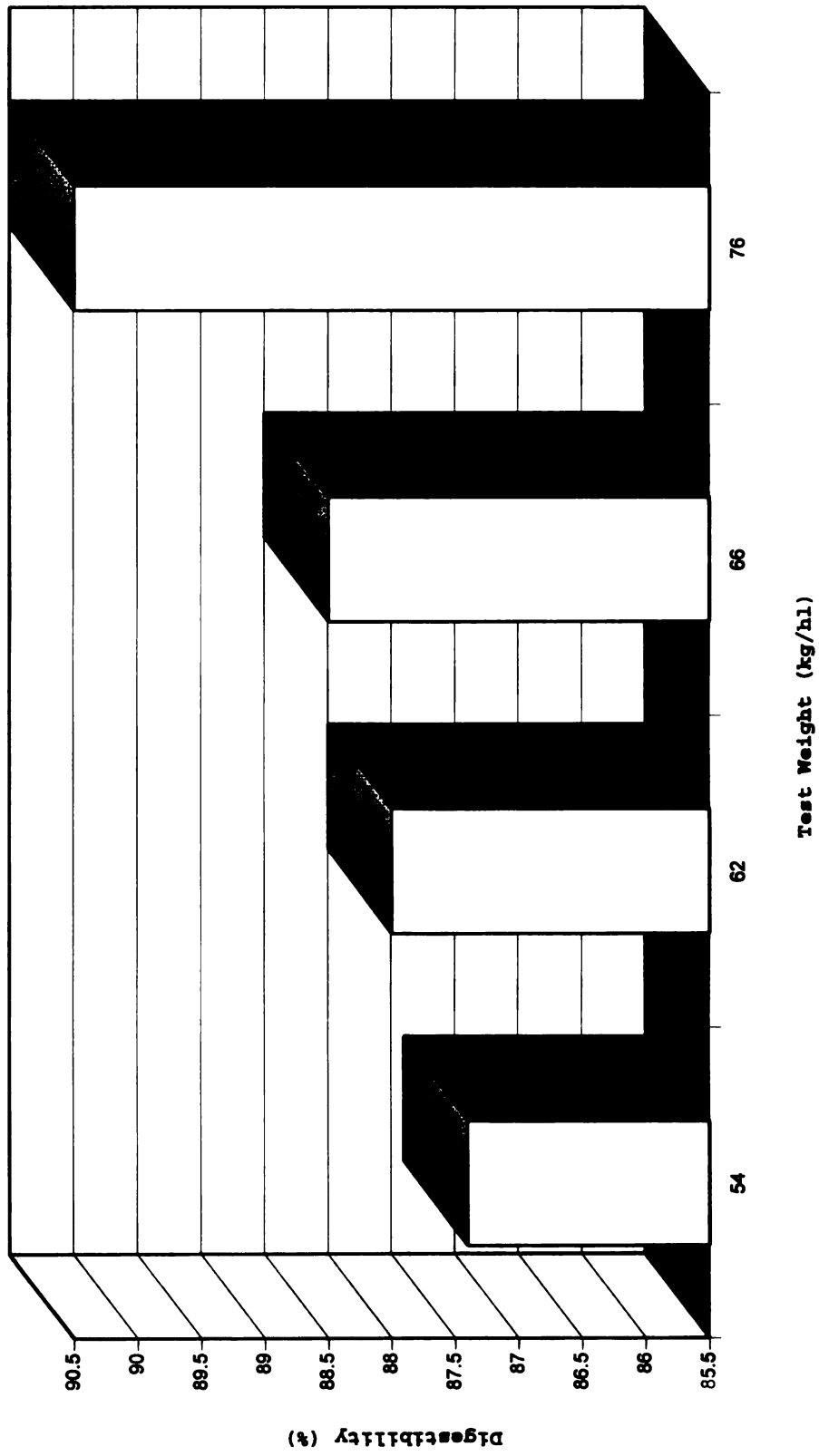


Figure 19 Apparent Digestibility of DM (%)

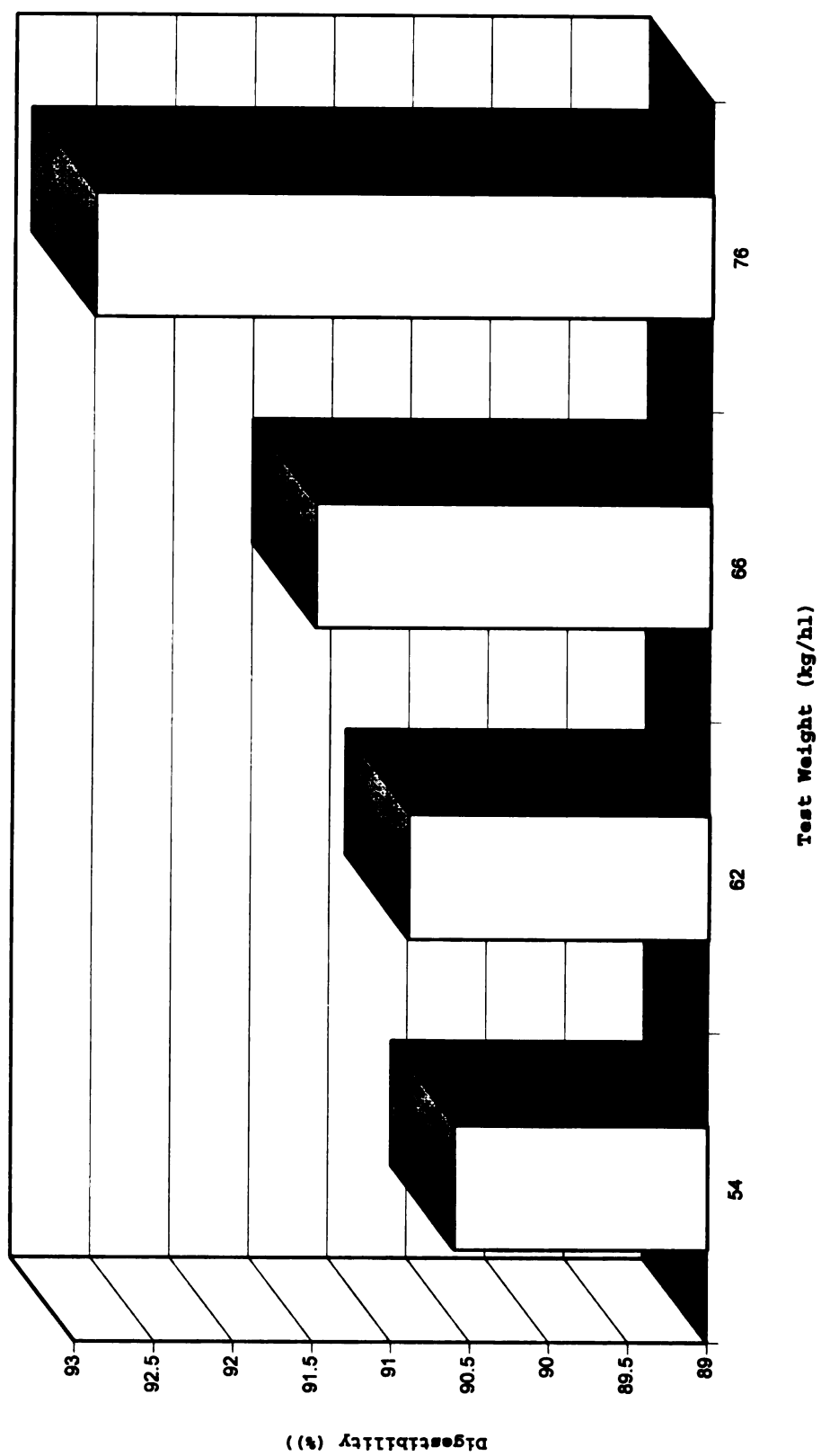


Figure 20 Apparent Digestibility of GE (%)

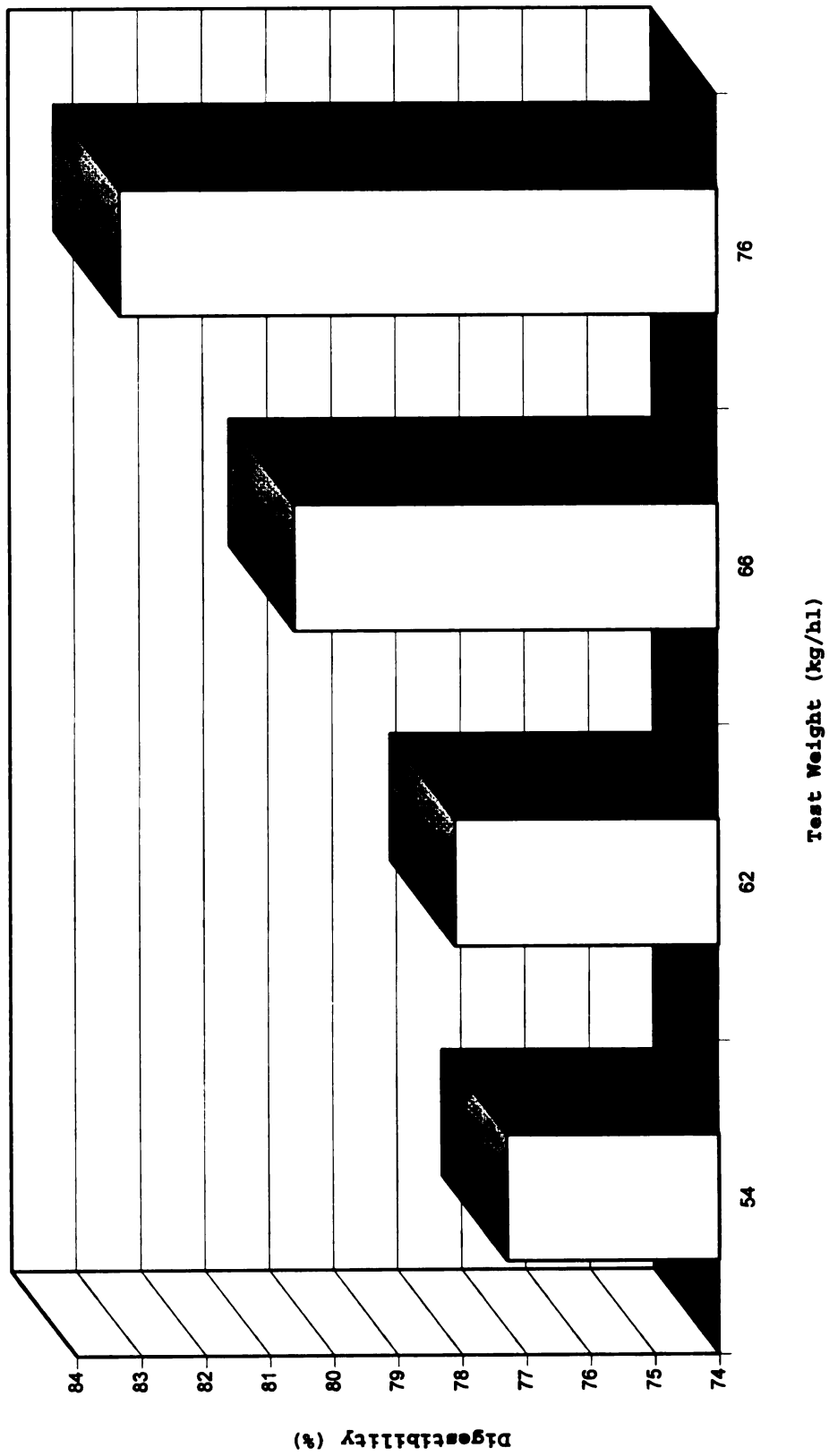


Figure 21 Apparent Digestibility of N (%)

for corns 54, 62 and 66 with no significant difference for nitrogen digestibility between corns 54 and 62. On average, there was an increase of 1.6% in dry matter digestibility, 1.3% in gross energy digestibility and 3.4% in nitrogen digestibility over a test weight range from 54 kg/hl to 76 kg/hl. Linear increase of all digestibility categories was probably due to decrease of fecal output. Distribution of dry matter, gross energy and nitrogen digestibilities are shown in Figure 19, 20 and 21 respectively. The higher digestibilities of dry matter, gross energy and nitrogen are consistent with past studies evaluating corn by Lawrence (1968), Scarbieri et al.(1977), Adeola et al.(1986), Asche et al.(1986) and Lin et al.(1987).

4.3 Minerals

Distribution of the minerals in corn by counties are presented in Table 9. As shown, data for major elements (Ca and P) fall within a fairly narrow range, while for trace elements (Zn, Fe, Se) greater differences exist between minimum and maximum values. Similar pattern was observed by Wolnik et al.(1983). Although the absolute concentrations of the elements vary from sample to sample, corns do not display distinct patterns of relative elemental variation even when grown across the state of Michigan. However, all analyzed corns samples were, as expected, insufficient when it comes to supplying swine diets with indispensable

Table 9 Distribution of the Minerals by Counties

Corn	County	Ca (%)	P (%)	Fe (ppm)	Zn (ppm)	Se (ppm)
5	Allegan	0.096	0.26	20.17	19.31	0.028
6	Allegan	0.012	0.28	21.45	19.04	0.029
7	Allegan	0.013	0.25	22.08	19.21	0.029
8	Allegan	0.015	0.31	21.48	19.06	0.027
9	Ogemaw	0.016	0.32	23.04	18.64	0.042
10	Ogemaw	0.016	0.28	18.71	17.43	0.033
12	Ogemaw	0.022	0.32	34.54	19.85	0.043
22	Branch	0.015	0.29	22.31	17.63	0.033
23	Branch	0.018	0.31	20.31	19.75	0.029
25	Mecosta	0.019	0.32	20.49	23.89	0.032
26	Mecosta	0.018	0.27	21.89	18.31	0.035
27	Huron	0.021	0.31	23.85	18.36	0.044
28	Huron	0.021	0.33	24.76	19.39	0.049
30	St. Joseph	0.018	0.31	18.42	17.64	0.051
31	St. Joseph	0.021	0.25	17.56	17.11	0.042
32	Branch	0.021	0.25	26.96	18.85	0.041
33	St. Joseph	0.021	0.27	23.22	17.17	0.058
34	St. Joseph	0.022	0.28	29.39	18.56	0.067
35	Cass	0.023	0.31	29.37	22.46	0.042
36	Cass	0.019	0.22	21.93	17.31	0.029
37	Cass	0.024	0.22	19.32	18.68	0.046
38	Cass	0.022	0.26	19.51	18.16	0.042
71	Cass	0.021	0.28	19.22	17.81	0.046
72	Branch	0.022	0.25	17.56	16.71	0.046

Table 9 (cont'd).

Corn	County	Ca (%)	P (%)	Fe (ppm)	Zn (ppm)	Se (ppm)
73	Eaton	0.028	0.24	20.91	19.34	0.073
74	Ingham	0.026	0.33	22.82	20.39	0.081
75	Eaton	0.025	0.29	22.59	17.54	0.094
76	Gratiot	0.026	0.31	20.41	17.73	0.122
77	Kalamazoo	0.027	0.28	21.91	20.35	0.086
78	Kalamazoo	0.029	0.26	25.31	21.71	0.082
79	Gratiot	0.031	0.27	23.98	18.07	0.082
80	Otsego	0.028	0.29	22.02	19.05	0.109
81	Otsego	0.028	0.28	24.11	18.55	0.082
82	Otsego	0.031	0.36	24.52	21.11	0.085
83	Cass	0.031	0.28	18.81	18.56	0.082
84	Cass	0.031	0.27	22.03	19.41	0.082
85	Cass	0.027	0.31	18.65	18.79	0.058
86	Cass	0.031	0.28	23.14	19.29	0.054
87	Cass	0.033	0.27	27.43	17.27	0.031
88	Lapeer	0.031	0.27	20.17	17.73	0.071
89	Cass*	1.54	1.04	604.71	244.27	0.313
90	Cass*	1.17	0.58	247.55	108.14	0.183
91	Gratiot	0.096	0.27	21.76	19.21	0.055
92	Eaton	0.096	0.31	18.68	18.27	0.054
93	Ottawa	0.096	0.34	21.21	19.56	0.071
98	Gratiot	0.099	0.29	22.65	25.63	0.038
Mean	N/A	0.032	0.28	22.30	19.04	0.056
NRC**	N/A	0.030	0.28	33.00	19.00	0.070

* Feeds (excluded from calculation of the mean)

** NRC, 1988

minerals. According to the requirements of a 25 kg pig (NRC, 1988), on average, tested corns can supply only 5.3% of calcium, 56% of phosphorus, 37.2% of iron, 31.7% of zinc and 37.3% of selenium. Generally, the mineral content of corn is lower compared to the mineral content in small grains. In order to prevent deficiencies in pigs, it is necessary to include supplemental sources of macro and micro minerals to diets. Comparisons of average values of individual minerals with NRC values show, that only iron (-32.4%) and selenium (-20%) were different from tabular values. Calcium, phosphorus and zinc values are almost identical to tabular values. Samples 89 and 90 are actually mixed, composited feeds; this is reflected by their high concentration of minerals.

4.4 Protein Fractions

The amounts of protein fractions extracted with various solvents from the test weight corns along with procedures leading to results are shown in Table 10. Literature on nutritional quality of corn is largely limited to interaction between protein content and amino acids of corn, nitrogen and energy utilization, and effect of protein fractions on nutritional quality of corn. However, literature is lacking data on compositional changes in protein fractions of corn in comparison to different test weight. Because of this fact, the author

Table 10 Distribution of Pertinent Constituents in Corn

Corn (kg/hl)	Crude Protein (Nx6.25) content (%)	Residue A* (CP%)***	Albumins Globulins (CP%)***	Albumins Globulins (%)	Residue B** (CP%)***	Albumins Globulins Prolamins (CP%)***	Prolamins (CP%)***	Prolamins (%)	Glutelins (%)
54	7.42	6.60	0.82	11.0	4.90	2.52	1.70	23.0	66.0
62	8.03	6.14	1.89	23.5	4.25	3.78	1.89	23.5	53.0
66	8.72	6.65	2.07	23.7	4.95	3.77	1.70	19.5	56.8
76	8.13	4.98	3.15	38.7	3.45	4.68	1.53	18.8	42.5

* Salt/Water Extraction Residue

** Salt/Water/Ethanol Extraction Residue

*** Crude Protein (%)

could not compare his results with other putative results on test weight-protein fraction relationships, but could only compare his results with protein fractions results from typical (normal test weight) corns.

Extraction of albumins and globulins was carried out with 0.5M NaCl and water and removed 11.0, 23.5, 23.7, and 38.7% of albumins and globulins from test weight corns 54, 62, 66, and 76 kg/hl, respectively. Data for corn 54 are similar to those found by Osborne and Mendel (1914). Corns 62 and 66 kg/hl are consistent with findings of Mertz (1957). However, amount of albumins and globulins of 76 kg/hl corn are significantly higher than any literature report. Partial explanation for this fact is that potential error was induced in salt/water extraction. Extractions were carried out in numerous experiments (8 times). Despite the fact that the fineness of the corn was improved through the procedures, results were identical to those from the beginning when corns were grounded through a 1 mm sieve.

Extraction of prolamins was accomplished with 70% ethanol solution and removed 23.0, 23.5, 19.5, and 18.8% of prolamines from test weight corns 54, 62, 66, and 76 kg/hl, respectively. Results are far below majority of other authors' findings, though similarity was observed with Boundy's et al.(1967) figures. These authors accounted for only 76.2% of total corn protein in their extracts. Most likely the difference (23.8%) was not extracted by salt, water or ethanol and was apparently detained in the

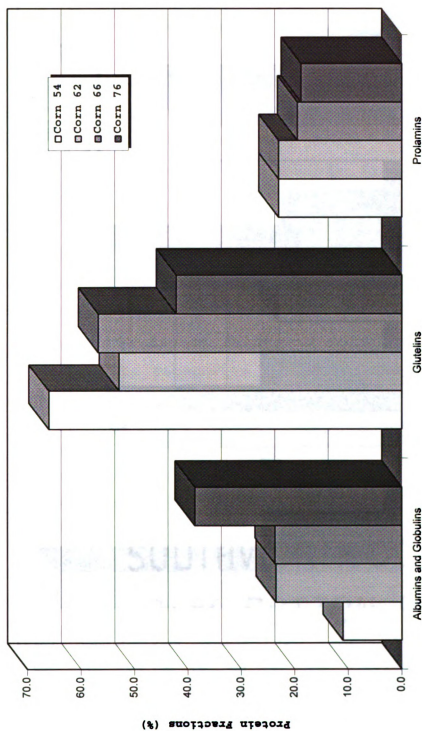


Figure 22 Corn Protein Fractions (As Categories)

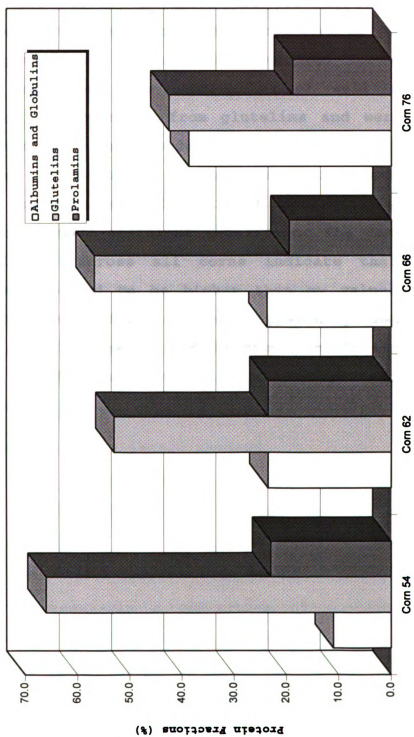


Figure 23 Corn Protein Fractions (As Percent of Corn)

residue. An analogous situation emerged from my observations when the apparent high glutelins levels of all test weight corns prompted me to hypothesize that prolamines were incompletely extracted from or precipitated in the glutelins. The methods I adopted for removal of protein fractions were apparently not well suited for separation of prolamins from glutelins and were probably complicated by the tendency for cereal proteins to associate, for instance alcohol soluble fraction binds strongly to glutelins (Bietz, 1983), consequently making it resistant to more efficient separation. The constant, low lysine levels across all corns indicate that prolamins concentrations had to be higher than my values and also show that protein fractions were apparently unaffected by test weight. Figures 22 and 23 show distribution of corn protein fractions as categories and as percent of corn, respectively.

5.0 SUMMARY

The results of the four experiments, within the limits of the experimental conditions employed, have led the author to make the following conclusions:

1. Wide variations in protein content (7.3-10.2%) were observed among test weight corns. However, similar data appeared to be the norm for all corn test weight categories. Apparently the variation in protein content within a given corn test weight category is about the same as the variation among test weight categories. There was no significant effect of test weight on crude protein content.

2. There was significant effect of crude protein on lysine. Lysine content changed proportionally with crude protein content. In other words, lysine levels increased or decreased as protein levels changed.

3. There was no significant effect of test weight on lysine. Lysine content did not change proportionally with test weight.

4. Lower test weight reduced the amount of energy available, presumably a reflection of a somewhat lower caloric density of low test weight corn. Consequently, producers should attempt to use lightweight corn in less critical phases of production such as for gestating sows or finishing pigs.

5. Protein quality values tended to increase with higher test weight corns.

6. The digestibility of DM, GE and N were significantly higher for corn 76 than for corns 54, 62, and 66 kg/hl.

7. Two corns with higher test weight retained more nitrogen (g/day) than the two corns with lower test weight.

8. Major elements (Ca,P) fall within a fairly narrow range, while for trace elements (Zn,Fe,Se), greater differences were found between minimum and maximum values.

9. Corns do not display distinct patterns of relative mineral variations across the State of Michigan.

10. Comparison of average values of individual minerals with NRC values shows, that only Fe (-32.4%) and Se (-20%) were different, while Ca, P and Zn are almost identical to NRC values.

11. The higher amounts of albumins and globulins obtained in this study were most likely due to errors induced during salt/water extraction and incomplete residue recovery. Similarly, the lower values for prolamins than usual or expected were probably the result of incomplete extraction from glutelins with our procedures.

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