LIVESTOCK FEED REQUIREMENTS FOR THE DESIGN OF MATERIALS HANDLING SYSTEMS

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This is to certify that the

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ABSTRACT

LIVESTOCK FEED REQUIREMENTS FOR THE DESIGN OF MATERIALS HANDLING SYSTEMS

by Patrick Joseph Comerford

The design of materials handling systems is a relatively new area in Agricultural Engineering. In it the designer must combine his engineering skill with a thorough knowledge of animal feed requirements to produce a satisfactory system for conveying, processing, and storing feeds and other materials on the farm. A preliminary investigation into the nature of these requirements revealed that it was essential to know the yearly and maximum daily feed consumptions of these animals; this information was not available in a readily usable form. It was the object of the present investigation to extract the information on these requirements from the available data on animal feeding, and to add to it allowances for eventualities such as variations in feed composition and availability, changes in animal appetite, etc., so that a system, designed in accordance with the recommendations would be adequate under all conditions, but not excessively large.

The feed requirements of dairy cattle, swine, sheep, beef cattle, and poultry were calculated on a nutrient requirement basis and compared with actual feed intakes obtained from results on feeding trials on similar animals. It was found that they usually ate more feed than they needed to meet their nutrient requirements, but the amount was influenced by factors such as, palatability and dry matter content of the feed, animal type, and system of management. Throughout the investigation it was assumed that animals were on artificial feeding

continually. This assumption simplified the calculations and avoided having to estimate the number of days the animal was able to forage for itself. It is more appropriate that these allowances should be made by the individual when studying actual conditions. Typical rations were selected for each animal group and balanced for protein (minor elements and vitamins were not taken into account as they were only needed in small quantities and did not constitute a storage or handling problem).

After the quantities of feeds required were decided, the type of management, amount of flexibility required in the system, and possible future trends were examined, to decide how much of a safety margin to add on for design purposes. This margin was found to vary from 10% when management was good and the feed was all grain, to more than 20% where roughages constituted part of the ration.

No consideration was given to estimates of water requirements or animal manure.

Approved F K Bucelow

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By

Patrick Joseph Comerford

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Although the term "materials handling" is of recent origin the problems associated with it are by no means new. From the time farmers ceased to be nomads they have had to contend with the difficulties of getting their crops harvested, stored, and fed to their animals. Before the advent of "high-powered" farming, farmers worked on a small scale and labor was cheap. Under these conditions the handling and storage of feed needed no special attention, as field operations were slow and no farmer had considered an alternative to hand feeding animals. With the advent of increased mechanization in industry, came increased prosperity and higher wages for employees; soon agriculture was fighting a losing battle with industry for its labor force. About this time farmers began to give serious consideration to mechanization on the farm. The first problems to receive attention were the ones which demanded the greatest labor concentration, particularly field cultivation and harvesting. Gradually engineers developed machines which not only replaced the workers but could do the same work better, and in only a fraction of the original time. While machines continued to be developed for the farm, very little attention was given to mechanization in the farmyard and soon facilities were inadequate to meet the high outputs of harvesting machines. In addition, farming had become more intensive over the years and much emphasis had been placed on confinement feeding of all types of animals. These conditions set up the need for immediate investigation into the problems of handling and processing the material from harvesting, through processing and storage, to the animals.

Because of the immense variations in feeds and farmsteads and the innumerable combinations of feed given to animals, no two materials handling problems are exactly alike. The present-day problems associated with materials handling are no longer the lack of equipment to handle, store, or process the feed but the estimation of the type and size of equipment to use and the design of a system such that all components combine to give a free-flowing system without "bottle-necks" at an economic cost. This involves, among other things, a thorough knowledge of the material being handled and the feed consumption capacities of the animals. When designing a materials handling system, one must know both the yearly and maximum daily requirements of the animal in order to estimate the storage and maximum conveying capacities required. To date the only reliable information available on these requirements are contained in the results of animal feeding experiments reported throughout the country. These figures vary considerably, depending on the conditions under which the tests were carried out and the type of feed used. In addition, very few experiments are set up specifically to test the maximum feed capacity of animals, so some interpretation is needed in order to extract reliable data. Even when the data have been obtained, adequate safety factors must be added when specifying equipment sizes to take care of year-to-year variations in feed intake and availability.

Materials handling system design is a relatively new field in agriculture and every effort must be made to provide additional information to speed the day when the services of a well informed materials handling advisory service will be available to all farmers. Farming is no longer a leisurely occupation but a well organized business. Industrial managers have seen the need for plant designers and efficiency experts in industry for many years; now agricultural managers require the same type of expert service.

The object of this study was to investigate as much literature on animal and poultry feeding as possible and to extract from it their feed intake characteristics under a variety of conditions. The data thus obtained was to be presented in such a way that it could be readily used by farm design engineers when designing materials handling systems under different conditions. It was hoped to bridge the gap between the design engineer and the animal nutritionist.

REVIEW OF LITERATURE

No known literature is available on the specific problem of estimating feed requirements of animals from a materials handling point of view. Most literature reviewed had as its main objective the examination of the effect of different types of feed on the animal's growth and production from a strictly nutritional point of view. Since the entire purpose of the present study is to examine this literature and extract from it material of use in estimating materials handling design parameters, it is more appropriate to review the literature in its respective section. The data compiled by Schneider (1947) on feed analyses were the most extensive for calculations involving nutrient contents of feeds. However, the analyses presented by Morrison (1956) and the National Research Council (1957) were adequate for common feeds. The data presented by Ensminger (1961) and the Editorial Service Co. Inc. (1959) on feed densities were used for estimating volumes of feeds.

PROCEDURE

The literature was first reviewed and useful data extracted. For most sections of this study the animal's requirements were first calculated from data giving net nutrient requirements for animals of different sizes and types. Following this the results of actual feeding trials for animals of similar type were presented and the differences in feed requirements noted. In a final discussion on materials handling requirements for these animals an attempt was made to present the factors which influenced the amount of feed actually required and suggestions were made as to the size of safety margin necessary to avoid underestimating the capacity requirements of handling, storing, and processing equipment.

FEED REQUIREMENTS OF DAIRY CATTLE

Nutrient Requirements

The nutrient requirements of dairy cattle may be considered under two main headings--maintenance and production. The requirement for maintenance is that needed by the animal to supply energy for normal activities and to replace wear and tear of the body. Maintenance requirements are closely associated with body weight.

The nutrient requirements for production are those which the animal needs to synthesize the milk which it produces. These are normally estimated on the weight of milk being produced, but accurate requirements are governed by many factors.

In addition to the nutrient requirements for lactating cows, those for growing and pregnant animals are also available. The National Research Council (1958) recommendations on basic nutrient requirements of dairy animals are reproduced in Table 1, while Table 2 presents the findings of recent investigations by Reid (1961) on requirements for milk production at various levels. When using these tables one should remember that the quantities quoted are net requirements. A safety margin of 5 to 10 percent above these figures is recommended, to provide for unknown variables.

Practical Limitations to Estimating Daily Feed Consumption From Nutrient Requirements

From what has been said in the previous section it is apparent that, to meet the exact requirements, the animal must be fed accurately measured quantities of feed, the composition of which is equally as accurately known. Experience shows that such is seldom the case and that at least one feed is fed *ad libitum*. Under these conditions there is no guarantee that the animal will eat just the exact amount to meet

TABLE 1

DAILY NUTRIENT REQUIREMENTS OF DAIRY CATTLE
(From National Research Council publication 464. 1958)

Body Weight	Daily Gain		Daily Nutrients Per Animal		
	Small Breeds	Large Breeds	Crude Protein	Digestible Protein	T.D.N.[a]
	lb.	lb.	lb.	lb.	lb.
Normal Growth of Dairy Heifers					
50	0.5	-	0.31	0.20	1.0
100	1.0	0.8	0.62	0.40	2.0
150	1.3	1.4	0.78	0.50	3.0
200	1.4	1.6	0.94	0.60	4.0
400	1.2	1.8	1.25	0.80	6.5
600	0.8	1.4	1.33	0.85	8.5
800	1.1	1.2	1.40	0.90	10.0
1000	-	1.3	1.48	0.95	11.0
1200	-	1.2	1.56	1.00	12.0
Maintenance of Mature Cows[b]					
800	-	-	0.95	0.50	6.0
1000	-	-	1.13	0.60	7.0
1200	-	-	1.32	0.70	8.0
1400	-	-	1.51	0.80	9.0
1600	-	-	1.64	0.87	10.0
Reproduction (Add to Maintenance, last 2-3 months)					
-	2.0	2.0	1.13	0.60	6.0
Maintenance of Breeding Bulls					
1200	-	-	1.56	1.00	10.3
1600	-	-	1.87	1.20	12.9
2000	-	-	2.20	1.45	15.6
2400	-	-	2.50	1.60	18.2

[a]T.D.N.--Abbreviation for Total Digestible Nutrients.

[b]When calculating the intake of lactating heifers that are still growing, it is recommended that one use the figures for growth rather than maintenance.

TABLE 2

DAILY NUTRIENT REQUIREMENTS FOR MILK PRODUCTION
(From Reid 1961)

Milk Yield (4% F.C.M.[a])	Protein[b]	Dig. Protein[b]	T.D.N.
lb.	lb.	lb.	lb.
0 - 10	.067	.043	0.30
11 - 20	.068	.044	0.31
21 - 30	.070	.045	0.32
31 - 40	.072	.047	0.33
41 - 50	.075	.049	0.35
51 - 60	.078	.052	0.37
61 - 70	.083	.055	0.40
71 - 80	.088	.058	0.43
81 - 90	.094	.062	0.47
91 - 100	.098	.065	0.53

[a]F.C.M.--Abbreviation for Fat Converted Milk.

[b]By interpolation. (Added by author.)

its immediate requirements. It may on the one hand eat much more than is actually required, in which case the excess feed is usually converted to body fat, or it may eat less than its requirements and have to draw on body reserves or become under-productive. The amount of free-choice feed eaten depends on such factors as palatability of feed, and conformation, physical condition and age of the animal. These must all be taken into account for accurately estimating the daily feed intake.

Variations in palatability are most frequently found in forage feeds. Many factors may affect palatability. Stone et al (1960) reported on the effect of time of cutting on dry matter intake of hay. Table 3 presents a summary of their findings.

TABLE 3

EFFECT OF DATE OF CUTTING ON CONSUMPTION OF HAY BY DAIRY COWS (From Stone et al 1960)

Date of Cutting	Dry Matter Intake per 100 lb. Body Weight
June 3 - 4	2.72
9 - 10	2.64
11 - 12	2.36
14 - 15	2.45
15 - 18	2.28
July 1	2.30
5	2.13
7 - 8	2.05
9	1.95

Dry matter also affects intake. Table 4 has been compiled by Thomas et al (1962) and gives the findings of many investigators when comparing the voluntary intake of animals fed silage having different dry matter percentages, and hay. A trend for high intake can be noted in practically every comparison.

Thomas et al (1961) also concluded that some other undesirable chemical factors in silage were contributing to the low voluntary intake of direct cut silages. This was further substantiated by Hillman (1959).

How Much Will a Cow Eat?

Because of the infinite variety of feeds available and the varied conditions under which dairy cows are kept, much diversity exists among published results. In addition, many of the workers were primarily concerned with the effects of varying the quantity and quality of different feeds on the milk production, and gave no indication of the actual limits of the animals feed intake. Table 5 presents a summary of experiments carried out where total feed intake was measured, and where at least one feed was offered ad lib.

Roughages Only

Based on the data presented in Table 5, a 1200 lb. cow can be

TABLE 5

SUMMARY OF FEEDING TRIALS WITH DAIRY COWS

Ration	Body Wt.	Total Intake	Intake per 100 lb. Body Wt.	F.C.M. 4%	Total D.M.	D.M. per 100 lb. Body Wt.	Percent of D.M.	Ref.
	lb.	lb.	lb.	lb.	lb.	lb.		
Silage[a]	1073	114	10.6	26.6	26.2	2.44	100	
Silage[a]+		87	8.21		19.9	1.88	69.6	
Hay	1060	10	0.94	26.1	8.7	0.82	30.4	
Silage[a]+		66	5.98		16.2	1.47	49.4	Hillman
Hay	1104	19	1.72	29.2	16.6	1.50	50.6	(1959)
Silage[a]+		44	3.75		10.7	0.91	30.5	
Hay	1174	28	2.30	31.0	24.4	2.08	69.5	
Hay[a]	1165	47	4.03	30.7	41.0	3.52	100	
Silage[a]	1135	115	10.1	30.4	25.8	2.27	100	
Silage[a]+		81	7.57		18.2	1.70	68.2	
Hay	1070	10	0.93	30.1	8.5	0.79	31.8	
Silage[a]+		70.5	6.32		15.85	1.42	49.5	Brown
Hay	1115	19	1.70	31.2	16.15	1.45	50.5	(1961)
Silage[a]+	1160	54	4.66		12.1	1.04	33.7	
Hay		28	2.41	31.4	23.8	2.05	66.3	
Hay[a]	1155	44	3.81	31.2	37.3	3.23	100	
Silage[a]	1060	106.4	10.0	27.4	26.0	2.45	100	
Silage[a]+		93.2	8.13		23.2	2.02	71.6	
Grain	1147	11.0	0.96	36.7	9.2	0.80	28.4	

Hay[a]+		28.6	24.0		24.8	2.08	73.6	Brown
Grain	1190	10.7	0.90	29.6	8.9	0.75	26.4	(1961)
Hay[a]	1120	32.2	2.88	24.1	27.9	2.49	100	
Silage[a]	1106	109	9.9	28.4	27.0	2.46	100	Hillman et al
Hay[a]	1118	40.0	3.58	28.3	34.3	3.14	100	(1958)
Silage[a]+		93.4	8.3		21.1	1.88	85.4	
Grain	1123	4.1	0.83	29.0	3.6	0.32	14.6	
Hay[a]+	1135	24.5	2.16		21.6	1.90	70.6	Huffman et al
Grain		10.2	0.90	32.5	9.0	0.79	29.4	(1956)
Hay[a]+		27.4	2.46		23.8	2.13	86.5	
Grain	1115	4.2	0.38	34.2	3.7	0.33	13.5	
Silage[a]+		77.0	7.55		19.1	1.87	73.7	
Grain	1020	7.5	0.74	28.4	6.8	0.67	26.3	
Silage[a]+		66.3	6.4		16.4	1.59	62.6	
Hay +	1030	3.4	0.33	28.0	3.1	0.30	11.8	
Grain		7.5	0.73		6.7	0.65	25.6	Nicholson
Silage[a]+		57.4	5.62		14.5	1.42	52.2	(1957)
Hay +	1020	6.8	0.67	28.0	6.4	0.63	23.0	
Grain		7.5	0.74		6.9	0.68	24.8	
Silage[a]+		50.0	4.95		12.5	1.24	43.1	
Hay +	1010	10.2	1.01	28.2	9.4	0.93	32.4	
Grain		7.8	0.77		7.1	0.70	24.5	
Silage[a]+		94.0	6.51		23.4	1.62	73.1	
Grain	1445	9.8	0.68	36.1	8.6	0.60	26.9	

TABLE 5--Continued

Ration	Body Wt.	Total Intake	Intake per 100 lb. Body Wt.	F.C.M. 4%	Total D.M.	D.M. per 100 lb. Body Wt.	Percent of D.M.	Ref.
	lb.	lb.	lb.	lb.	lb.	lb.		
Hay[a]+		35.2	2.66		29.9	2.66	74.4	
Grain	1322	11.7	0.89	34.8	10.3	0.78	25.6	
Silage[a]+		81.0	5.89		2.03	1.48	57.0	
Hay +	1376	10.0	0.73	38.2	8.5	0.62	23.9	
Grain		7.7	0.56		6.8	0.49	19.1	Brown (1961)
Silage[a]+		54.0	4.09		13.6	1.03	35.3	
Hay +	1320	19.0	1.44	34.7	16.2	1.22	42.1	
Grain		9.9	0.75		8.7	0.66	22.6	
Silage[a]+		64.0	4.71		16.0	1.18	31.2	
Hay +	1360	28.0	2.06	36.0	23.9	1.78	46.6	
Grain		13.0	0.96		11.4	0.84	22.2	
Silage[a]+	880	56.0	6.36		14.1	1.60	65.2	
Grain		8.5	0.96	24.13	7.5	0.85	34.8	
Silage[a]+		45.0	5.60		11.2	1.38	43.6	
Hay +	810	8.1	1.0	30.6	6.9	0.85	26.8	
Grain		8.6	1.06		7.6	0.94	29.6	
Silage[a]+		53.0	5.76		13.2	1.43	52.5	Waugh (1955)
Hay +	920	5.6	0.50	32.42	3.9	0.42	15.5	
Grain		9.1	0.99		8.0	0.87	32.0	
Silage[a]+		54.0	6.14		13.5	1.53	59.2	
Hay +	880	2.2	0.25	29.12	1.9	0.22	8.3	
Grain		8.4	0.95		7.4	0.84	32.5	

Hay[a]+		34.6	3.15		30.4	2.76	80.0	
Grain	1100	8.4	0.76	41.3	7.4	0.67	20.0	Stone
Silage[a]+	1100	104.0	9.50		26.0	2.36	73.7	(1960)
Grain		10.6	0.96	43.2	9.3	0.85	26.3	
Hay[a]+		31.6	2.37		26.7	2.00	76.0	
Grain	1333	9.6	0.72	39.6	8.5	0.64	24.0	Stone
Silage[a]+		103.6	7.77					(1960)
Grain	1333	9.6	0.72	39.6				

[a]Fed _ad lib_.

expected to consume an average of 112 lb. of silage or 41 lb. of hay, and provided these quantities contain sufficient protein, she should produce 28 lb. of 4% F.C.M. per day without the addition of grain. If, however, all the silage is made from corn, it will only contain sufficient protein for 17 lb. of 4% F.C.M. Knowing these limits one can reason that one pound of hay replaces 2.73 lb. of silage when some hay is substituted into an all-silage ration. It might be well to remember that these quantities are actual amounts consumed and reflect the appetite of the animal rather than its actual nutrient requirements. In general more feed is consumed than is actually required. For animals of other weights the necessary corrections for maintenance may be made by reference to Table 1.

Roughages plus Grain

As has just been pointed out, cows fed only roughages are restricted in output. To meet the requirements of the higher producing animals some of the bulky roughages must be replaced by more concentrated grain. Table 6 presents the annual feed requirements in grain and hay equivalents of high and low yielding Holstein cows as compiled from Tables 1 and 2.

TABLE 6

ESTIMATED FEED REQUIREMENTS OF HOLSTEIN COWS GREATER THAN 3 YEARS OF AGE

Annual Production	Lactation		Dry Period		Total	
	Hay Equivalent	Grain	Hay Equivalent	Grain	Hay Equivalent	Grain
lb. milk	tons	tons	tons	tons	tons	tons
8,000	2.44	2.00	0.66	0.17	3.10	2.17
	3.05	1.58	0.66	0.17	3.71	1.75
	3.66	1.16	0.66	0.17	4.32	1.33
	4.27	0.77	0.66	0.17	4.93	0.94
	4.88	0.44	0.66	0.17	5.54	0.61
	5.49	0.17	0.66	0.17	6.15	0.34
10,000	2.44	2.50	0.66	0.17	3.10	2.67
	3.05	2.08	0.66	0.17	3.71	2.25

TABLE 6--Continued

Annual Production	Lactation: Hay Equivalent	Lactation: Grain	Dry Period: Hay Equivalent	Dry Period: Grain	Total: Hay Equivalent	Total: Grain
lb. milk	tons	tons	tons	tons	tons	tons
	3.66	1.66	0.66	0.17	4.32	1.83
	4.27	1.24	0.66	0.17	4.93	1.41
	4.88	0.88	0.66	0.17	5.54	1.05
	5.49	0.51	0.66	0.17	6.15	0.68
12,000	2.44	3.00	0.66	0.17	3.10	3.17
	3.05	2.58	0.66	0.17	3.71	2.75
	3.66	2.16	0.66	0.17	4.32	2.33
	4.51	1.74	0.66	0.17	4.93	1.91
	4.88	1.32	0.66	0.17	5.54	1.49
	5.49	0.97	0.66	0.17	6.15	1.14
14,000	2.44	3.50	0.66	0.17	3.10	3.67
	3.05	3.08	0.66	0.17	3.71	3.25
	3.66	2.66	0.66	0.17	4.32	2.83
	4.27	2.24	0.66	0.17	4.93	2.41
	4.88	1.82	0.66	0.17	5.54	1.99
	5.49	1.40	0.66	0.17	6.15	1.57
16,000	2.44	4.00	0.66	0.17	3.10	4.17
	3.05	3.58	0.66	0.17	3.71	3.75
	3.66	3.16	0.66	0.17	4.32	3.33
	4.27	2.74	0.66	0.17	4.93	2.91
	4.88	2.32	0.66	0.17	5.54	2.49
	5.49	1.90	0.66	0.17	6.15	2.07
18,000	2.44	4.50	0.66	0.17	3.10	4.67
	3.05	4.08	0.66	0.17	3.71	4.25
	3.66	3.66	0.66	0.17	4.32	3.83
	4.27	3.24	0.66	0.17	4.93	3.41
	4.88	2.82	0.66	0.17	5.54	2.99
	5.49	2.40	0.66	0.17	6.15	2.57
20,000	2.44	5.00	0.66	0.17	3.10	5.17
	3.05	4.58	0.66	0.17	3.71	4.75
	3.66	4.16	0.66	0.17	4.32	4.33
	4.27	3.74	0.66	0.17	4.93	3.91
	4.88	3.32	0.66	0.17	5.54	3.49
	5.49	2.90	0.66	0.17	6.15	3.07

The lactation requirements have been arrived at by increasing the hay equivalent in the ration by increments of four pounds per day and calculating the grain required to supply the remaining nutrients. Assuming a T.D.N. value of 50% for the hay equivalent, 16 pounds of hay is sufficient only to maintain the cow, so grain must be added for each pound of milk produced. Assuming that grain contain 72% T.D.N. and that the average T.D.N. requirement per gallon of milk produced is 0.36 lb., one pound of grain must be fed for each two pounds of milk produced. Similarly 20 lb. of hay equivalent contains sufficient T.D.N. for maintenance and 5-1/2 pounds of milk, so one pound of grain must be added for each two lb. produced in excess of this quantity. By reference to lactation curves (Fig. 1) produced from data calculated by McGilliard (undated) it was possible to determine the monthly meal requirements for different breeds, having various production levels.

The requirements during the dry period were determined on the basis that grain feeding was discontinued (where grain was being fed) immediately after the cow was put dry, and only roughages, consisting of some hay and corn silage were fed. Grain was again introduced about 3 weeks before calving and the daily ration was increased by 2 lb. daily until 20 lb. were being consumed daily. The cow was maintained on this level of feeding until she calved. This system of feeding should be used irrespective of whether or not the cow is a poor yielder as it provides a good start to her lactation and encourages higher yields.

It might be pointed out here that the estimates of animal needs to this point have been based on T.D.N. requirements only. When poor quality roughages are fed in large quantities they do not contain sufficient protein to produce as much milk as their T.D.N. value would suggest, hence a grain supplement must be fed sooner than would otherwise be necessary. A more complete discussion of this aspect is presented in the following section.

The data presented in Table 6 are for Holstein cows over 3 years of age. Similar data may be prepared for other animal groups by reference to Fig. 1 and Tables 1 and 2. Generally the requirements for each group differ very little after allowances have been made for differences

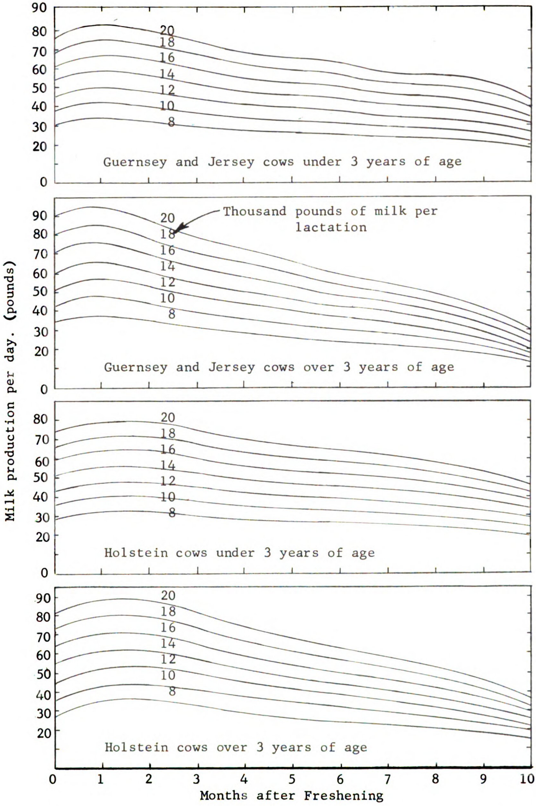

Fig. 1.--Lactation curves for Holstein, Guernsey, and Jersey cows with various milk production capabilities. (From data compiled by McGilliard, undated.)

in body weight. In preparing this table the roughages were calculated in hay equivalents on the assumption that 3 lb. of silage were equal to one pound of "Hay Equivalent." For high quality silages with higher dry matter a more realistic approximation is 2-1/2 lb. silage equal to 1 lb. hay equivalent, and for haylage 2 lb. equal to 1 lb. hay equivalent.

Balancing the Feeds for Protein

In many instances the roughages are low in protein, so supplements must be added to the grain ration to bring the protein up to the required amount. If grain is fed at the rate of one pound per 2 pounds of milk produced above that which the T.D.N. in roughage will support, the following formula can be used to estimate the percentage protein required in the meal mix to balance the ration:

$$\text{Protein percentage in grain mix} = \frac{(M + P - R)2}{Y - (W - 16)1.375} \times 100$$

Where:

M = Daily protein requirements for maintenance (lb.).
R = Pounds of protein supplied by roughage daily.
P = Pounds of milk produced per cow daily.
H = Weight of "Hay Equivalent" consumed daily.
Y = Daily milk yield (lb.).

In arriving at this formula, T.D.N. values were assumed for the roughages such that 16 lb. of Hay Equivalent supplied just enough energy for maintenance. If the numerator in the above formula is a negative quantity, the roughages are supplying adequate protein without including any in the grain. If the denominator is negative the amount of grain fed cannot supply sufficient protein.

Using this formula curves were prepared (Figs. 2-7) which illustrate the trends in protein content of grains when good, medium, and poor quality roughages were fed. Notice that all curves approach a limit of about 15%. This can be explained by pointing out that the calculations are based on a crude protein requirement of .076 lb. per pound of milk produced. When it is realized that grain is being fed at the rate of one pound per 2 pounds of milk produced it becomes obvious that a 15.2% grain mix supplies exactly the required amount of protein for that amount of milk. With high quality hay (curve A) it can be seen that

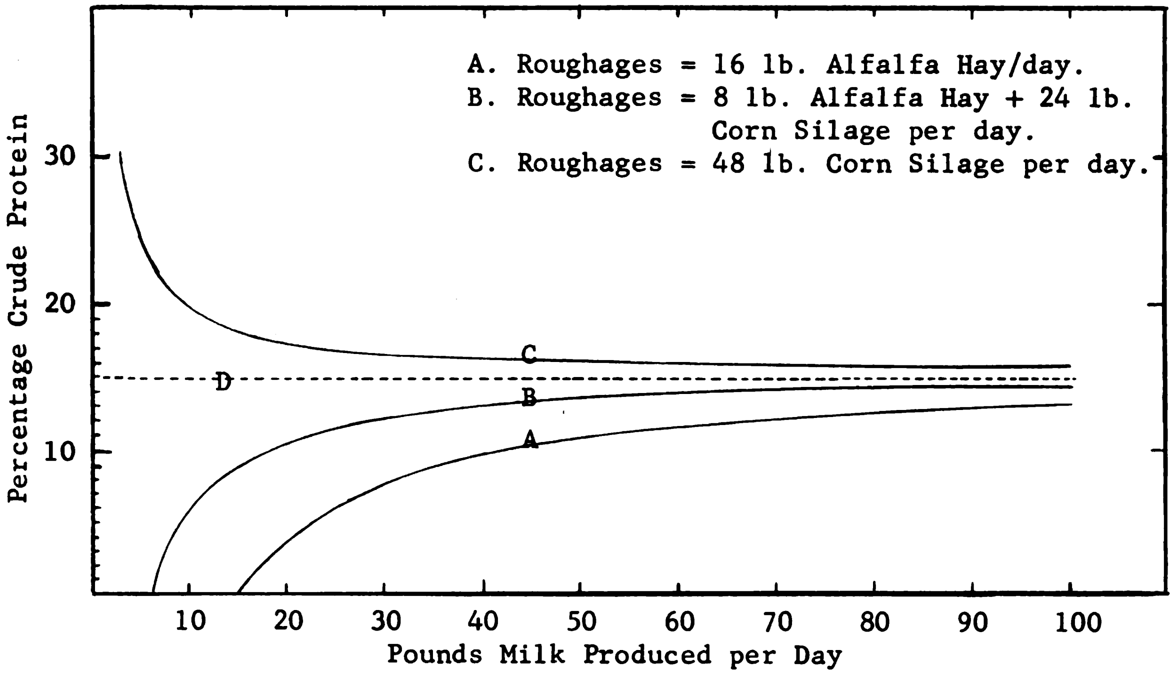

Fig. 2.--Crude protein required in meal-mix for 1200 lb. dairy cows when roughages are fed at the rate of 16 lb. Hay Equivalent per day.

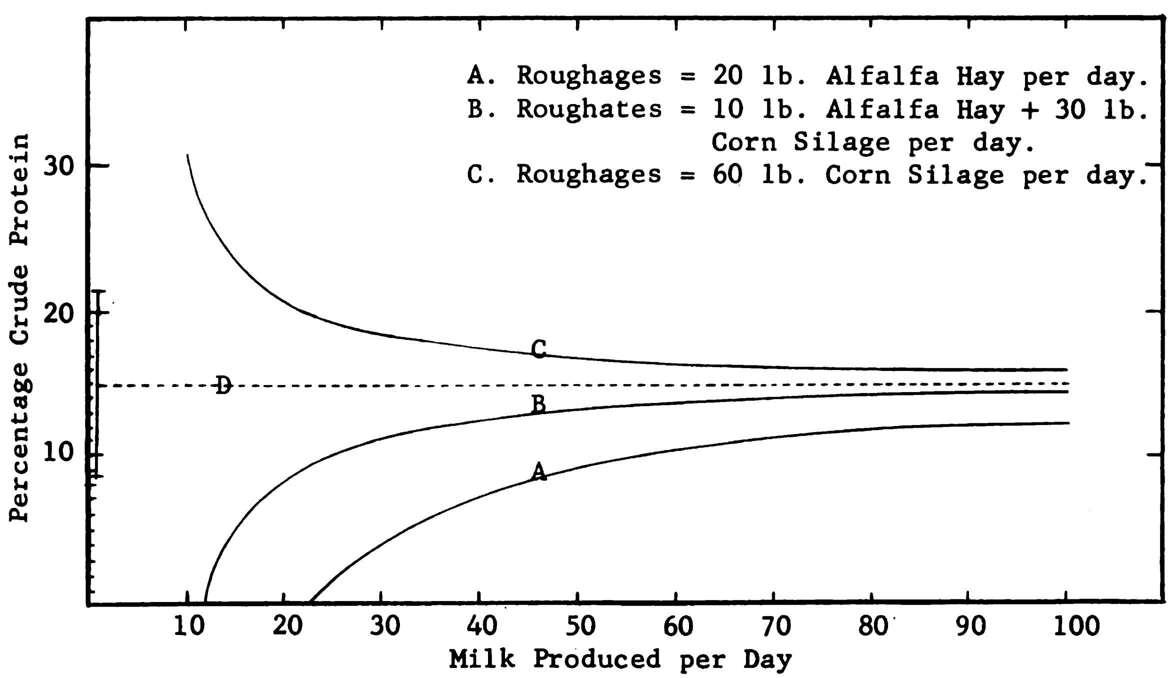

Fig. 3.--Crude protein required in meal-mix for 1200 lb. dairy cows when roughages are fed at the rate of 20 lb. Hay Equivalent per day.

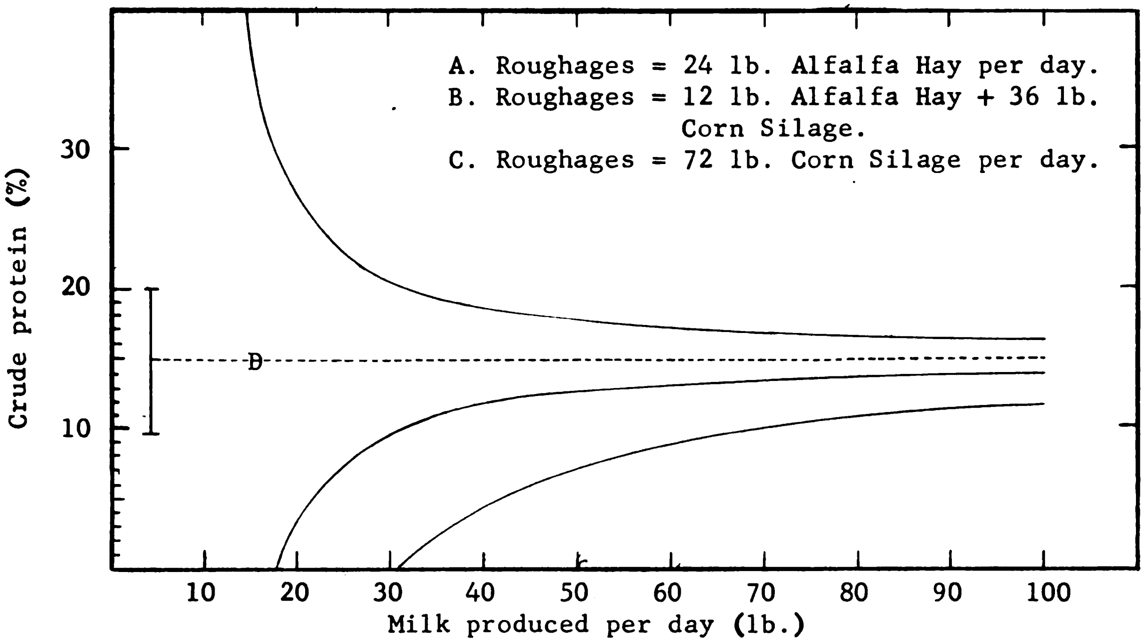

Fig. 4.--Crude protein required in meal-mix for 1200 lb. dairy cows when roughages are fed at the rate of 24 lb. Hay Equivalent per day.

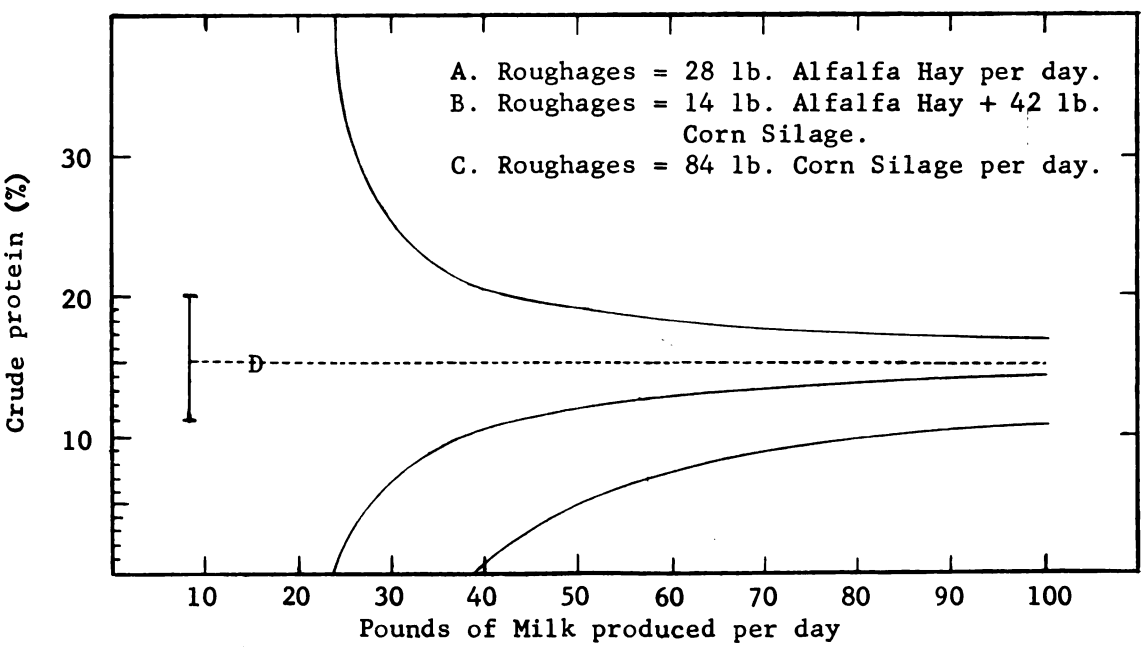

Fig. 5.--Crude protein required in meal-mix for 1200 lb. dairy cows when roughages are fed at the rate of 28 lb. Hay Equivalent per day.

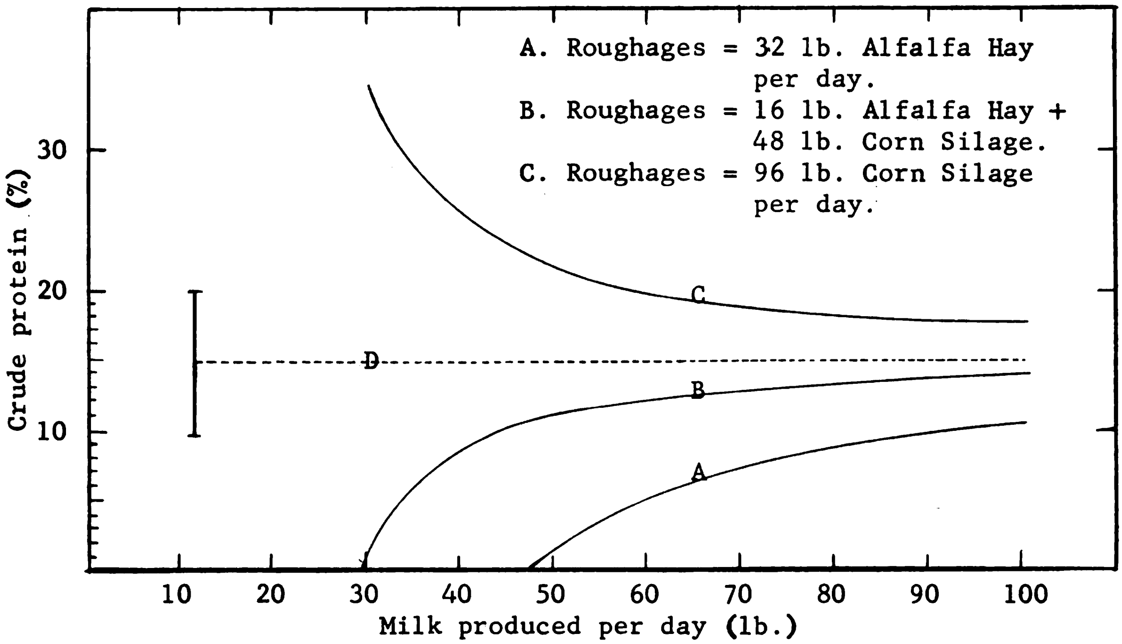

Fig. 6.--Crude protein required in meal-mix for 1200 lb. dairy cows when roughages are fed at the rate of 32 lb. Hay Equivalent per day.

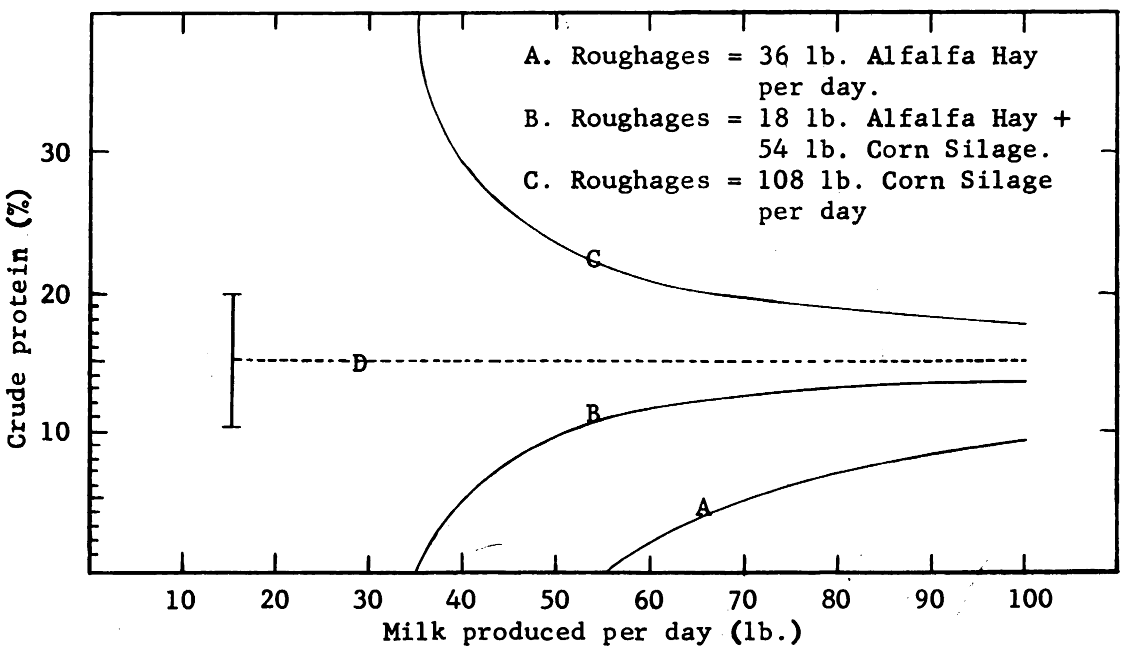

Fig. 7.--Crude protein required in meal-mix for 1200 lb. dairy cows when roughages are fed at the rate of 36 lb. Hay Equivalent per day.

the roughages supply protein for more milk than their T.D.N. will support, hence a very small protein percentage will suffice in the grain when the milk production is low. However, as the production and grain requirement increases the influence of the good roughages becomes less apparent and the protein percentage must be increased. Where the roughage is low in protein (curve C) it does not contain sufficient to keep pace with its T.D.N. potential, consequently, where the milk production is only slightly greater than the point at which grain is introduced to the ration their protein content will need to be very high. If, however, you introduce grain at the stage where the protein content of the roughage ceases to be adequate, the crude protein content need only be 15 percent no matter how much grain is fed. Line D (Figs. 2-7) represents the stage at which grain must be introduced to the ration under these conditions.

By combining the information contained in Table 6 with that in Figs. 1 to 7 an estimate can be made of the amount of protein which must be added to the grain to supply the protein needs of the animal. (See Appendix A for method of estimating weight of protein supplement required to supply the protein needed.)

The net protein requirements during the dry period are supplied by a grain mixture containing 12% crude protein but a slightly higher percentage will be needed if the roughage is of poor quality.

Discussion

It must be remembered that all the quantities specified in the preceding sections have been based on theoretical estimations of a cow's feed requirements. No allowances have been made for body weight changes in the animal, variations in appetite, wastage, inconsistancy in feed analysis etc. Under normal conditions grain is rationed and at least some of the roughages fed ad lib. Under these conditions a more realistic estimate of the feed intake could be gotten by increasing the roughage estimates by about 15%. No alteration need be made to the grain since this is being rationed.

Based on these assumptions and those presented in the preceeding sections, charts have been prepared which present the estimated feed consumption of cows yielding from 8,000 to 20,000 lb. of milk per lactation under a variety of conditions (Figs. 8 - 10). These charts should assist in estimating the annual feed intakes under specific conditions.

Example

A 1200 lb. holstein cow can produce 16,000 pounds of milk per lactation. Half the roughage dry matter is fed in the form of corn silage and the other half as alfalfa hay. If the cow is fed 2.75 tons grain per year, find the quantities of hay and silage required, assuming a two months dry period.

Entering chart for cows producing 16,000 lb. milk per lactation at a point on slope A corresponding to 2.75 tons grain. Extend vertically from this point until a point is reached on curve B. Continuing horizontally from this point it is found that the annual hay equivalent requirement is 6 tons. Converting this to hay and silage, the requirements become 3 tons of hay and 9 tons silage. Should the silage be of high quality and dry matter, the requirements would be 3 tons hay + 7.5 tons silage.

If all the roughages had been composed of corn silage the chart would have been entered at a point on slope X and extended to a point on Y.

Economic Consideration in Feeding Grain

No specific rate of feeding grain can be selected to give optimum production under all conditions. Factors such as milk and grain prices, basic production abilities of animals, housing and labor have a considerable effect on the amount of grain which can be fed economically.

The tendency over the years has been to increase the amount of grain being fed to dairy cows. In a 9 year survey by the United States Department of Agriculture (U.S.D.A.), (1942) of ten Agricultural Experiment Stations it was discovered that the best all round results were obtained by feeding one pound of grain for every 3.5 to 4 lb. milk produced. In a recent summary by the Dairy Herd Improvement Association

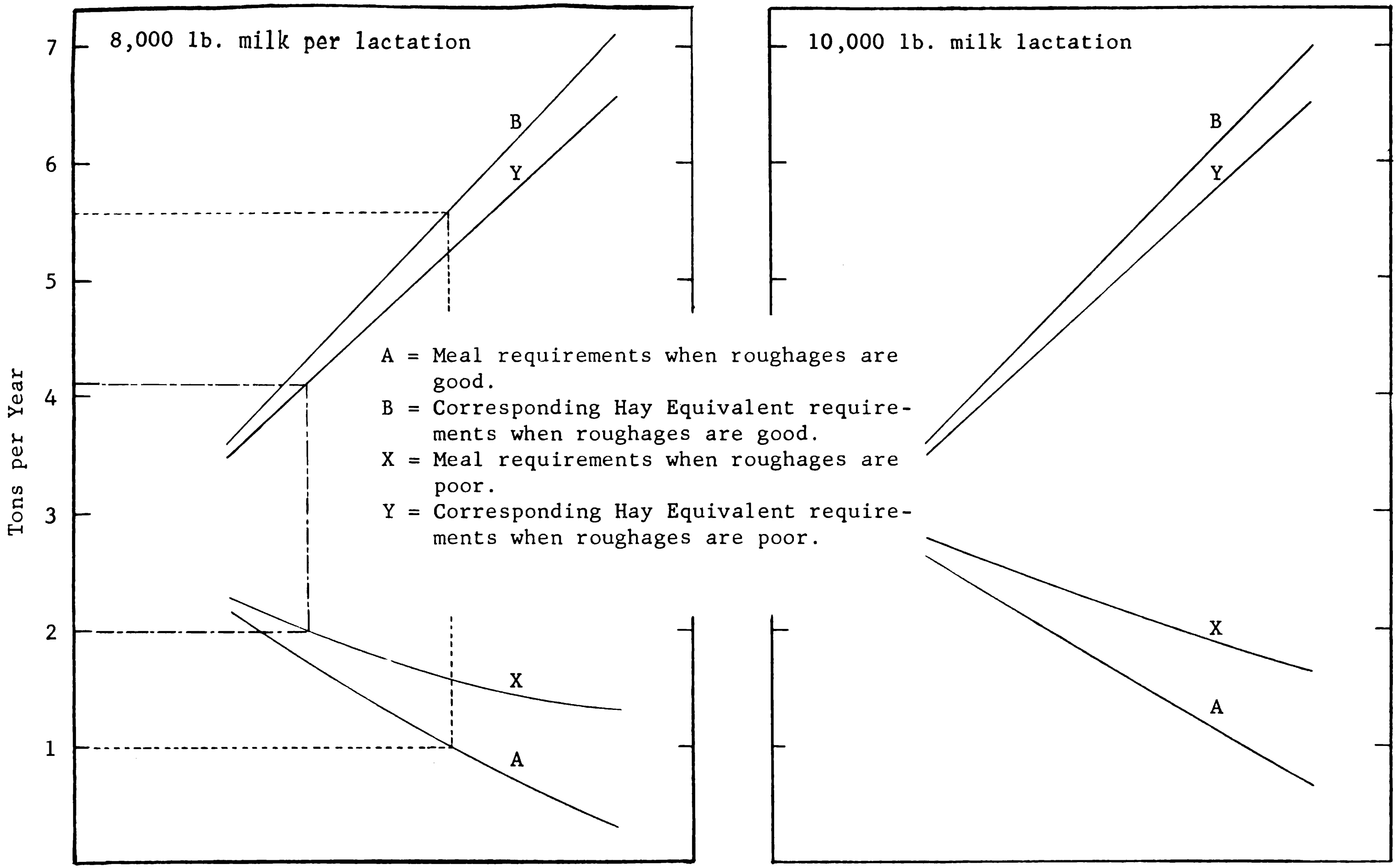

Fig. 8.--Estimated feed requirements of Holstein cows over 3 years of age yielding 8,000 and 10,000 pounds of milk per lactation.

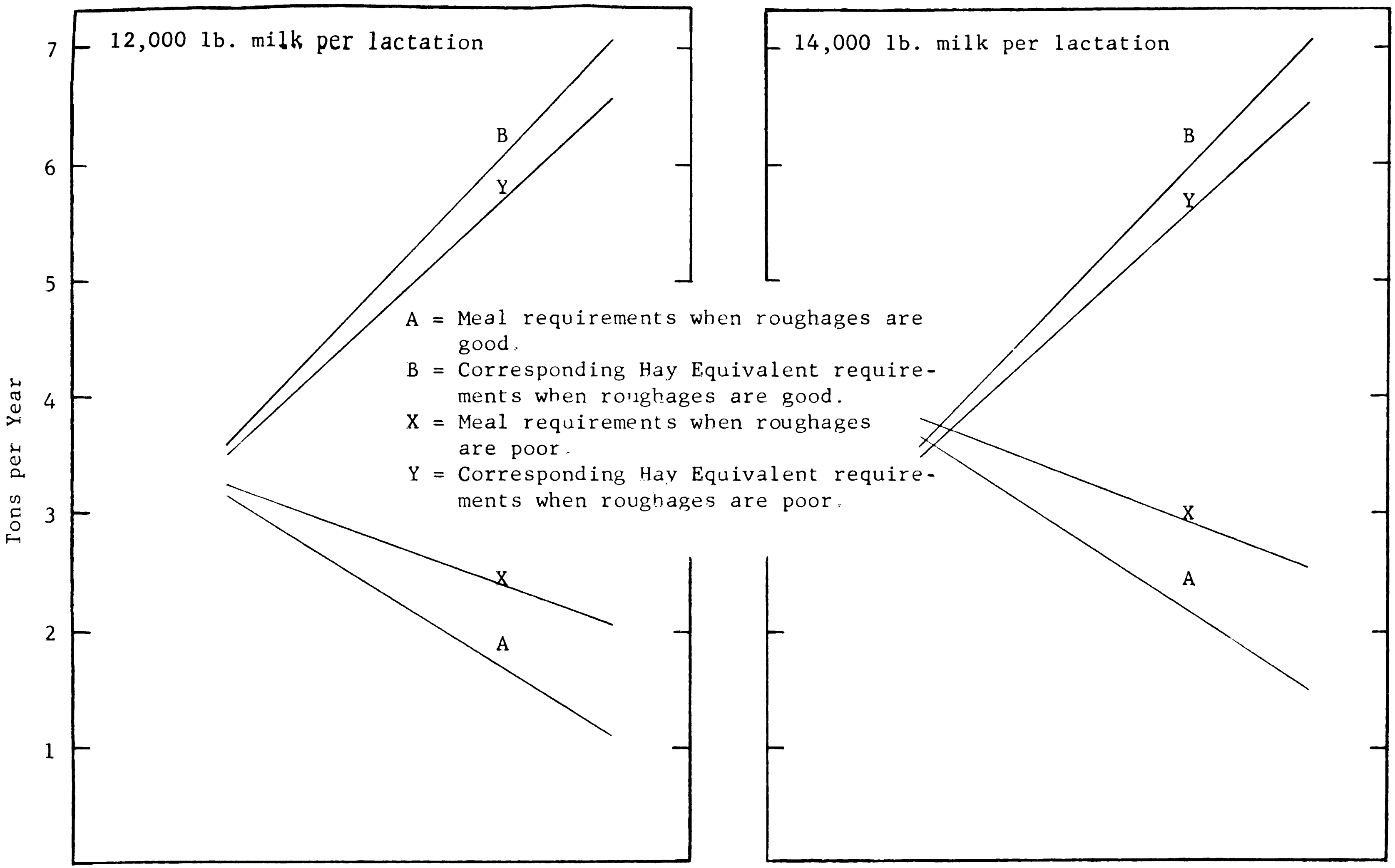

Fig. 9.--Estimated feed requirements of Holstein cows over 3 years of age when yielding 12,000 and 14,000 lb. of milk per lactation.

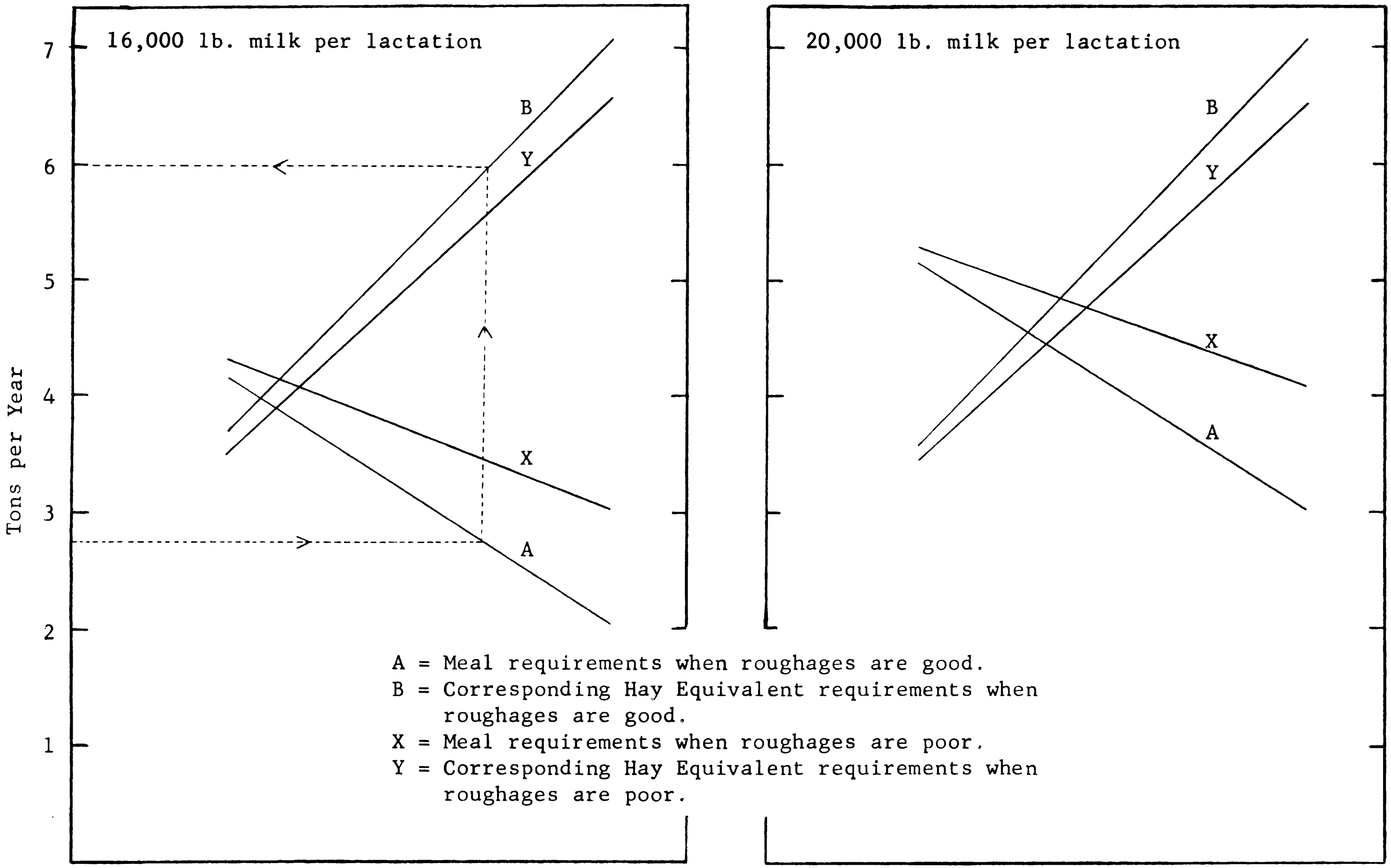

Fig. 10.--Estimated feed requirements of Holstein cows over 3 years of age when yielding 16,000 and 20,000 lb. of milk per lactation.

(D.H.I.A.) (1962) the average production for all breeds was 11,626 lb. of milk per year and the average grain intake per cow was 3,944 lb. (one lb. per 2.95 lb. milk produced). This represents an increased grain intake of 427 lb. per cow over the previous year. Brown *et al.* (1962) in an investigation into the effect of high level grain feeding on milk production pointed out that yields of corn in certain areas had increased to such an extent that the cost of 100 lb. of T.D.N. from ear corn was less than from hay crop silage or hay. Their investigation showed that cows fed high levels of grain over a period of 260 days produced more milk than was expected and the increase in income, even when grain was fed *ad lib.*, more than balanced the extra outlay on the grain. These conclusions were drawn on the basis of $40, $20 and $7 per ton for grain, hay and silage respectively, and a price of $4.60 per 100 lb. for milk.

Hoglund (1962) compared the economic returns on a 65 acre dairy farm when two qualities of forage and two milk prices were considered for cows with basic production abilities of 10,000 and 13,500 pounds per annum (Fig. 11). It is conspicuous that, with the low producing animals the point of diminishing returns was reached much sooner. It was also worthy of note that it was economically justifiable to feed more grain when the roughages were of average quality. Table 7 briefly summarizes the grain feeding allowances for maximum income under various sets of conditions.

Feed Requirements for Replacements

Many dairy farmers rear their own replacements and for this reason some estimate should be given of the amount of feed needed for this purpose. This involves estimating the feed intake of young animals from birth to about 24 months, after which they are incorporated into the dairy herd.

The requirements may be expressed in one of two forms, as actual requirements per animal or as extra allowances per cow to provide for replacements. The former has the advantage that it gives unit animal requirements which can be applied to any condition, whereas the latter

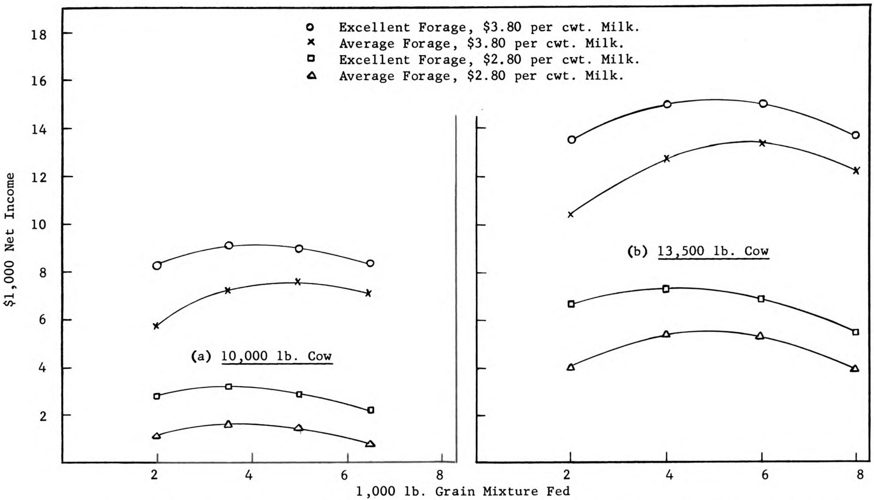

Fig. 11.--Net income for a 65 cow Dairy Farm, two qualities of forage and two levels of milk prices, Holstein Cows with basic producing abilities of 10,000 and 13,500 lb. of 3.5% milk per lactation. (From Hoglund 1962).

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is a convenient "rule-of-thumb" method which is reasonably accurate under normal conditions.

TABLE 7

GRAIN INTAKE BY DAIRY COWS FOR MAXIMUM ECONOMIC RETURNS
(From Hoglund 1962)

Basic Milk Production lb/year	Milk Price $/cwt.	Forage Quality	Grain Intake for Max. Production lb.
13,500	3.80	Excellent	5,000
13,500	3.80	Average	6,000
13,500	2.80	Excellent	4,000
13,500	2.80	Average	5,000
10,000	3.80	Excellent	4,000
10,000	3.80	Average	5,000
10,000	2.80	Excellent	3,500
10,000	2.80	Average	4,000

Both Keener _et al_. (1958) and Sykes _et al_. (1955), investigating the effect of varying the type of roughage while limiting the grain and milk, found that animals consumed considerably more dry matter when the roughage contained mainly hay. Holstein calves fed an all hay roughage maintained satisfactory growth and were above the Morrison Normal (Morrison 1956) at 24 months, whereas those fed all silage weighed only from 82 to 94 percent of the normal. Based on the results of these experiments and the recommendations of Hillman _et al_. (undated), a table has been prepared (Table 8) which gives the average feed requirements of Holstein heifers from birth to 24 months.

The requirements for smaller breeds were correspondingly less. However, the slower growing animals did show a tendency towards more efficient utilization of roughages containing high proportions of silage.

When expressing feed requirements for replacements as extra allowances per cow a number of assumptions were made (1) Culling in the dairy herd was at the rate of 25% per annum. (2) Half the calves reared were heifers. Based on these assumptions it was reasoned that for every two cows in the herd, additional feed had to be provided to bring one animal from birth to 12 months and another from 12 to 24 months each year. On an annual per cow basis this amounted to half the recommended quantities in Table 8.

TABLE 8

FEED REQUIREMENTS OF HOLSTEIN HEIFERS
(Birth to 24 months.)

Type of Roughage	Milk	Grain	Hay	Silage	Hay Equivalent[a]
	lb.	lb.	tons	tons	tons
All Hay	400	550	6.3	-	6.3
Hay & Silage	400	1400	3.0	7.5	5.5

[a]The total hay equivalent requirements may be reduced by 2 tons if the animal is allowed out to grass for 5 months.

Another recommendation frequently found is to increase the cows roughages 50 per cent and add 300 to 400 lb. grain per cow.

Materials Handling Considerations in Feeding Dairy Cattle

The feeding of dairy cattle is such a complex system, with so many different feeds and feeding methods that no single materials handling system can be described as the most ideal. In fact, any set of feeding conditions can be mechanized efficiently using several different materials handling systems. When designing a system around a given set of conditions one should take into consideration the following points.

1. The annual feed consumptions as presented in Figs. 8 - 10 only indicate what a cow should eat in one year. They do not take into account the amount of feed which is wasted or deteriorates in storage. In addition, allowances must be made for under-estimation of requirements

and year to year variations in quality of feed.

2. In estimating hay storage requirements it is important to know whether the hay is loose, baled, or pelleted.
3. It may be feasible in many instances to contract with a local feed merchant to supply protein supplement at regular two-monthly or such intervals. This relieves the farmer of the worry of making exact estimates of yearly requirements and guards against deterioration in prolonged storage.
4. It should be remembered that most of the discussions in previous sections concerned typical 1200 lb. Holstein cows. When designing systems for smaller breeds the necessary reductions should be made.
5. Although the recommendations in the previous sections are set up on the basis of a 305 day lactation and a 60 day dry period, these are not rigid and frequently the period between the beginning of one lactation and the next is longer than one year. When this occurs the feed requirements are slightly over-estimated.
6. Cows are sometimes allowed to pasture during the Summer months. Under normal conditions the amount of grass consumed is sufficient only to supply the roughage portion of the ration, without any reduction in the quantity of grain being fed.
7. From the lactation curves in Fig. 1 it can be seen that cows reach their peak production (hence maximum feed requirements) at from 4 to 6 weeks after calving. In view of the evidence presented by Brown et al. (1962) in favor of increased levels of grain feeding, and the suggestions of Hillman (1961) and Reid (1961) on rates of feeding in early lactation, it seems reasonable to assume that many cows would peak at from 120 to 130 pounds of milk per day. In addition, since many of the cows calf in the same period each year the feed handling equipment should have the capacity to handle at least 75 percent of the total possible daily feed requirements of the entire herd within the allotted time. If some of the grain is being fed in the milking parlor the maximum capacity of the outside feeders may be scaled down accordingly.
8. In "year-round" feeding, silos should be designed so that at least one is ready for filling whenever material is available. In order

to avoid excessive spoilage the diameter of the silos should be such that a depth of at least 3 inches of feed is removed daily.

9. In specifying materials handling equipment it should be remembered that silage is a corrosive substance.

FEED REQUIREMENTS OF SWINE

The feeding of swine may be divided into three main sections, depending on the age and type of animal being fed, (1) growing and finishing pigs (2) pigs from birth to weaning, and (3) breeding stock.

Feeding Growing and Finishing Swine

From a feeding point of view, two periods may be recognized in the production of slaughter pigs, (1) growing period when animals are using most of their feed for body building and (2) finishing period when bones and organs have been fully developed, and most of the feed is being used to "condition" the animal. All pigs are fed alike in the growing period but the type of carcase required will determine the rate and type of feeding for finishing. If bacon type carcases are desired the pigs are finished at a slow rate with feeds having high protein contents to encourage lean meat production, while with "meat" type pigs less emphasis is placed on the production of lean carcases and the animals are finished as quickly as possible. Table 9 presents The National Research Council (1959) recommendations on rate of gain, and feed consumption for pigs of different weights and types as well as the protein percentage required in the meals.

By plotting daily weight gain versus bodyweight (Fig. 12), it was possible, by taking weight increments of 20 lb. and noting the mean daily weight gain for that period, to calculate the number of days taken to gain each 20 lb. By referring the figures obtained to the mean daily feed consumption for the same period it was possible to estimate the amount of feed consumed by the pig during any period. By using this method and assuming a weaning weight of 40 lb. (Hoefer 1963) estimates were obtained of the amount of feed consumed by pigs of different types, from weaning to slaughter (Table 10).

TABLE 9

PRODUCTION REQUIREMENTS OF GROWING AND FINISHING PIGS
(From National Research Council 1959)

	Growing Pigs		Finishing Pigs					
			Meat Type			Bacon Type		
Liveweight (lb.)	25	50	100	150	200	100	150	200
Expected daily gain (lb.)	0.8	1.2	1.6	1.7	1.9	1.5	1.7	1.7
Total feed (air-dry)	2.0	3.2	5.3	6.8	8.0	5.2	6.5	7.1
Crude Protein (%)	17	15	13	12	12	16	14	14

TABLE 10

INCREMENTAL FEED CONSUMPTION OF 'MEAT' AND 'BACON' TYPE PIGS

Body Weight (lb.)	Meat Type		Bacon Type	
	Age (days)	Feed Consumed to Date (lb.)	Age (days)	Feed Consumed to Date (lb.)
40	56	0	56	0
50	65	25	65	25
60	72.5	53.3	72.5	53.3
80	87	112.2	87.5	114.0
100	100	176.9	101	179.6
120	112	245.4	113.5	249.2
140	123.5	317.6	125.5	322.6
150	130	355	131.5	360
160	134.5	393.2	137.5	399
180	145.5	472.1	149	479.5
200	156	554.6	161	562.2
220	166.5	639.8	172.5	646.4

Daily weight gain (lb.)

Daily weight gain (lb.)

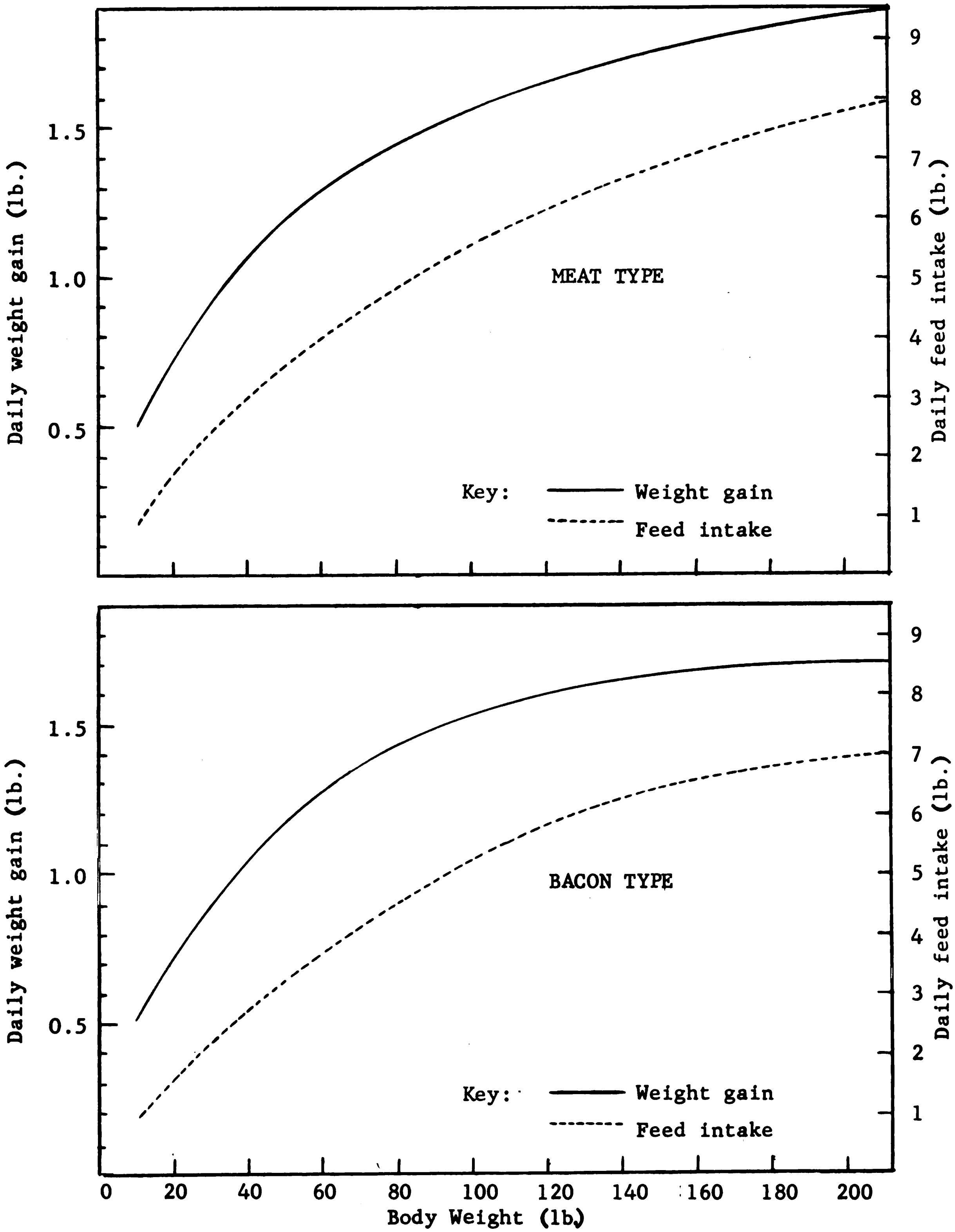

Fig. 12.--Weight gain and feed intake of growing and finishing swine.

Balancing the Feed for Protein

Approximately 98 percent of the feed eaten by pigs is composed of a combination of carbohydrate and protein feeds, with the carbohydrate or energy feeds comprising by far the greatest proportion. For this reason, only these two feed types are worthy of consideration from a materials handling point of view. The energy feeds consist mainly of shelled corn and similar grains containing small amounts of protein, whereas the protein supplement usually consists of three separate feeds (1) animal protein (2) plant protein and (3) alfalfa meal. Under normal conditions these protein constituents are mixed in the approximate ratio of 1:2:1 by weight, and the supplement contains approximately 40 percent crude protein. As already indicated (Table 9) the amount of protein required in the feed ration varies depending on the age of the animal and the type of carcase desired. Table 11 presents the proportion of energy and protein feeds required when the ration varies from one with all corn to one containing no corn. In some instances (such as the finishing period) where the protein requirement is low and where the energy feeds supply almost all the protein needed, it still remains necessary to include some animal protein and alfalfa meal to supply essential amino acids and carotene. In these cases the protein content of the ration for pigs in the older age groups is higher than would otherwise be necessary.

Combining the data in Tables 10 and 11 curves were drawn which illustrate the quantities of energy and protein feeds required for satisfactory growth from weaning at 40 lb. to market at 220 lb., using a ration containing all corn (Fig. 13) and one containing barley and oats (Fig. 14) along with a 40 percent protein supplement.

Feeding Swine From Birth to 8 Weeks

According to Ensminger (1961) each thrifty pig should consume about 25 lbs. of "creep" feed before the age of eight weeks, with about two-thirds of this consumption between the sixth and eighth week.

TABLE 11

PROPORTIONS OF ENERGY AND PROTEIN FEEDS REQUIRED BY PIGS OF VARIOUS WEIGHTS WHEN FED DIFFERENT RATIONS

No.	Ration	Protein Content %	Meat Type		
			40-50	50-100	100-150
1.	Corn	9.3	.739	.806	.874
	+				
	Protein supp.	38.75	.261	.194	.126
2.	Corn 65% Barley 35%	10.1	.759	.829	.899
	+				
	Protein supp.	38.75	.241	.171	.101
3.	Corn 66% Barley 17% Wheat 17%	10.27	.764	.834	.902
	+				
	Protein supp.	38.75	.236	.166	.098[a]
4.	Corn 33.3% Barley 33.3% Oats 33.3%	10.9	.781	.853	.902
	+				
	Protein supp.	38.75	.219	.147	.098[a]
5.	Corn 33.3% Barley 66.7%	10.84	.779	.851	.902
	+				
	Protein supp.	38.75	.221	.149	.098[a]
6.	Barley 70% Oats 30%	11.66	.803	.877	.902
	+				
	Protein supp.	38.75	.197	.123	.098[a]

[a]A minimum of 10% protein supplement to supply essential amino-

TABLE 11--Continued

(lb.)		Bacon Type (lb.)				
150-200	200-220	40-50	50-100	100-150	150-200	200-220
.902	.902	.739	.772	.772	.840	.840
.098[a]	.098[a]	.261	.228	.228	.160	.160
.902	.902	.759	.794	.794	.864	.864
.098[a]	.098[a]	.241	.206	.206	.136	.136
.902	.902	.764	.799	.799	.869	.869
.098[a]	.098[a]	.236	.201	.201	.131	.131
.902	.902	.781	.817	.817	.889	.889
.098[a]	.098[a]	.219	.183	.183	.111	.111
.902	.902	.779	.815	.815	.887	.887
.098[a]	.098[a]	.221	.185	.185	.113	.113
.902	.902	.803	.840	.840	.902	.902
.098[a]	.098[a]	.197	.160	.160	.098[a]	.098[a]

acids and carotene.

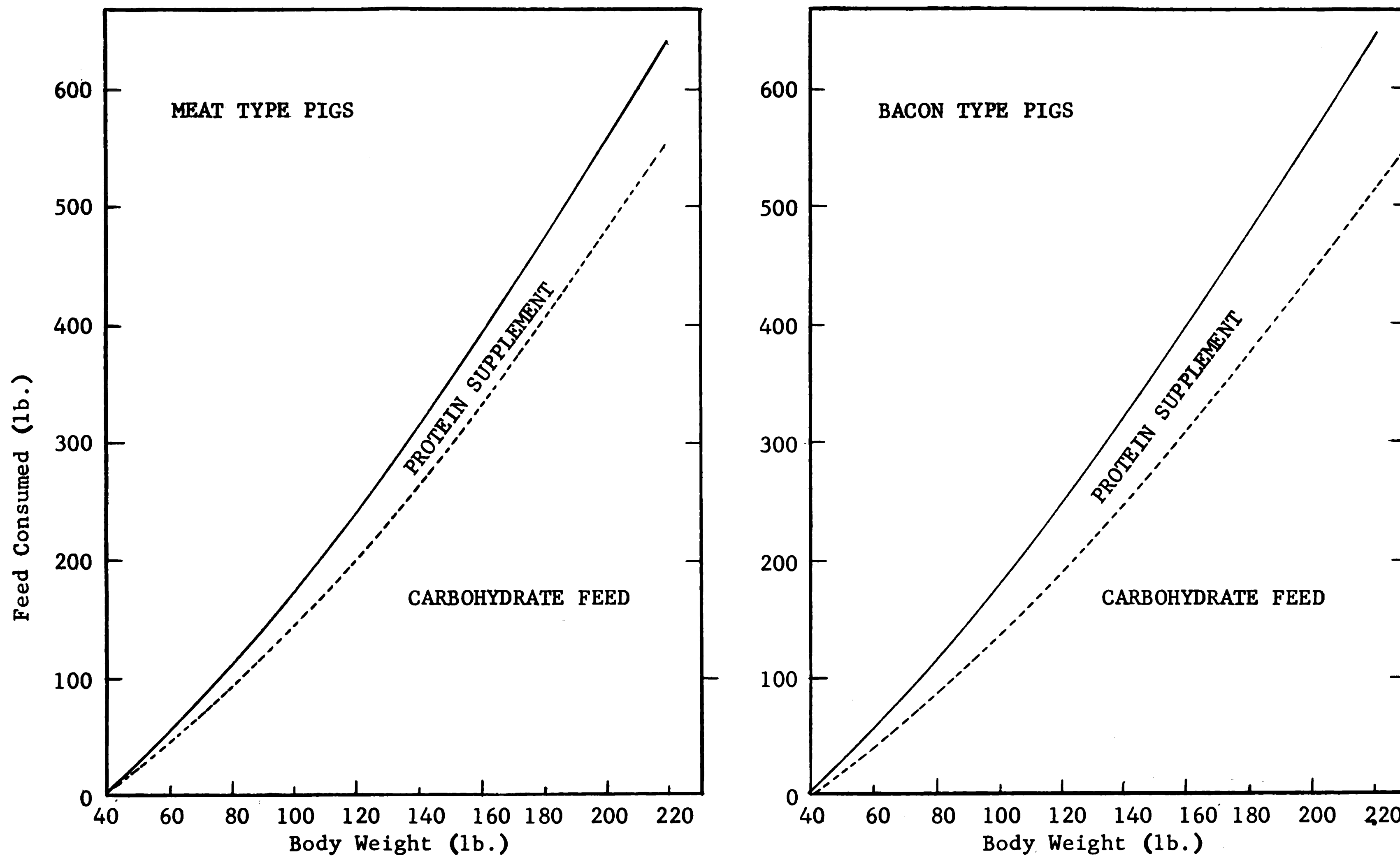

Fig. 13.--Carbohydrate and Protein feeds consumed by pigs, from weaning at 40 lb. to slaughter at 220 lb. using a ration of: corn (9.3% crude protein) and protein supplement (38.75% C. protein).

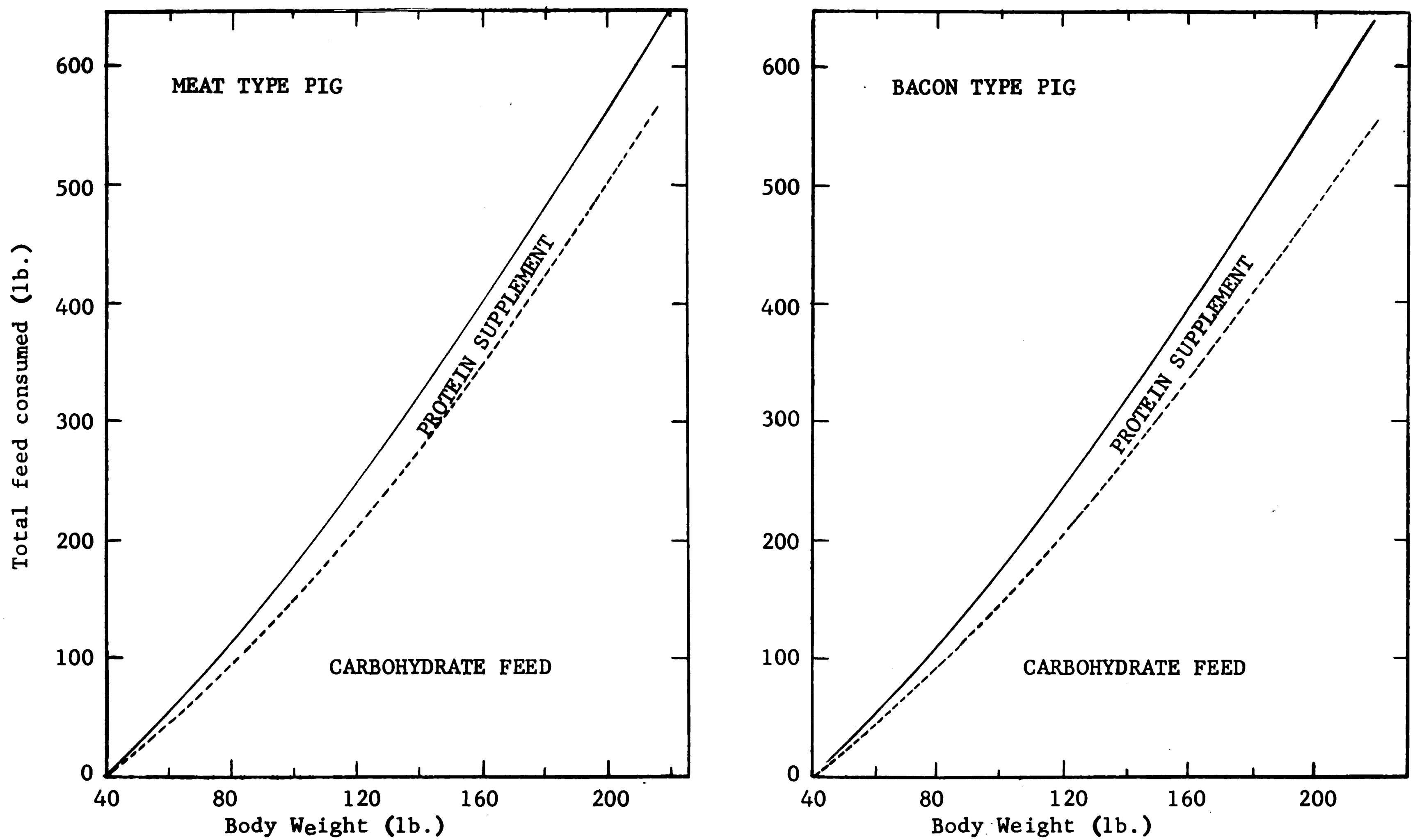

Fig. 14.--Carbohydrate and protein feed consumed by "Meat" and "Bacon" type pigs from weaning at 40 lb. to slaughter at 220 lb. using a combination of: Barley and Oats (11.66% C. protein) and protein supplement (38.75% c. protein).

Feeding Breeding Stock

The feed requirements of breeding stock are summarized in Table 12.

TABLE 12

BASIC NUTRIENT REQUIREMENTS OF BREEDING PIGS
(From National Research Council 1959)

	Gestating		Lactating	
	Gilts	Sows	Gilts	Sows
Liveweight (lb.)	300	500	350	450
Expected daily gain (lb.)	1.0	0.7	-	-
Total feed (air dry) (lb.) per day	6.0	7.5	11.0	12.5
Crude Protein (%)	15.0	13.0	15.0	13.0

Based on the data in the above table, the total feed consumed by a gilt during gestation and lactation is about 1306 lbs. and by a mature sow is about 1562 lbs. These requirements may be itemized as follows--(Table 13).

TABLE 13

POUNDS FEED CONSUMED BY BREEDING ANIMALS
FROM CONCEPTION TO WEANING

Type of Breeding Animal	Period	Food Type	
		Energy	Protein
Gilt	Bred	556	134
	Lactating	496	120
	Totals	1052	254
Sow	Bred	754	108
	Lactating	612	88
	Totals	1366	196

The above quantities are for ration number 1 as set out in the section dealing with growing and finishing pigs. The necessary alterations can be made to the above quantities for other rations by referring to the proportions in Table 11.

Discussion

The nutrient requirement presented in Tables 9 and 12 have been extracted from reliable experimental data and do not have built in safety margins. A number of factors, such as management, breed, thriftiness, and environment can appreciably affect the amount of feed eaten by animals. In addition, many feeds do not have a consistent analysis and frequently deteriorate in storage. Thus swine producers must, in most cases, incorporate a liberal margin of safety when compounding feeds. This will invariably mean that the amount of protein fed will be somewhat higher than that recommended. The data in Table 14 (Hoefer 1962) will help to illustrate the variations which can exist in feed requirements among different groups of animals.

TABLE 14

FEED CONSUMED BY PIGS FED IN DRY LOT FROM 40 TO 215 POUNDS UNDER VARIOUS DEGREES OF MANAGEMENT (From Hoefer 1962)

		Management		
		Excellent	Average	Poor
Corn	(lb.)	477	537	661
Supplement	(lb.)	92	110	127
Total	(lb.)	569	683	788

The quantities for breeding animals specified in Table 12 are for average conditions and must not be expected to cater for all conditions. The breed of sow, milking capabilities, size of litter, etc. will have an appreciable effect on the amount of feed required. When estimating feed consumed by breeding animals deductions should be made for periods during which the animals have access to other feed types such as hay or pasture. During the bred period either good legume hay or pasture can replace approximately one third of the meals normally consumed. (Carroll et al. 1962)

Occasionally, systems are encountered where growing pigs are allowed on pasture. Because of the variations which may exist among these systems each should be examined individually and the savings in meals assessed on the evidence.

Materials Handling Consideration in Feeding Pigs

The design of a satisfactory materials handling system for feeding swine is much simplified by the fact that the entire feed is composed of grain. Since all grains are within approximately the same density range and have the same flow characteristics (compared to hay, silage, etc.) the proportions of grains of different kinds fed can be changed without appreciably affecting the handling or storing facilities. In designing storage facilities it should be remembered that the figures quoted for total feed consumption do not make allowances for feed spoilage, wastage, variations in both feeds and animals, and other factors. In order to insure that the storage is adequate a safety margin of not less than 10 percent should be incorporated. On farms where corn is the main feed, sufficient storage should be supplied to accommodate one whole year's requirements. With protein supplement it is usually better to contract for regular supplies as this feed is frequently used as a "balancer" and contains some trace-element ingredients which deteriorate in prolonged storage.

In designing feeding equipment, one needs to take account of the fact that pigs are usually arranged in pens according to their weights. This means that the feeders in certain pens should have a greater capacity than in others. The size of feeder units may be determined from the daily feed consumption estimates in Table 9 or Fig. 12 after due allowances are made for wastage, overeating etc. The amount of feed wasted is much greater in dry feeding than wet.

FEED REQUIREMENTS OF SHEEP

The feed requirements of sheep may be considered in three sections--(1) Feed requirements of breeding ewes, (2) Feed requirements of feeder lambs, (3) Feed requirements of Spring lambs. Because of the varied climatic conditions and systems of management throughout the country it is impossible to draw a dividing line between where the animals are fed pasture and where they are brought indoors for artificial feeding. For this reason, the discussion which follows pre-supposes artificial feeding in all stages, on the assumption that the necessary allowances can be made when actual conditions are being studied. It should also be pointed out at this juncture that the feed requirements for ewes in the period between weaning and conception are not discussed because sheep are scarcely ever artificially fed at that time.

The National Research Council (1957) recommendations on nutrient requirements of sheep are widely accepted and should be consulted whenever there is doubts as to the adequacy of any ration. Their recommendations for Total Digestible Nutrients (T.D.N.) and Total Protein are presented in Table 15.

TABLE 15

DAILY NUTRIENTS REQUIREMENTS OF SHEEP
(Based on air-dry feed containing 90 percent dry matter)
(From National Research Council 1957)

Body Weight (lb)	Gain or loss (lb)	Feed		Daily Nutrients	
		Per Animal (lb)	% Liveweight	Protein (lb)	T.D.N. (lb)
Ewes--Non-lactating and First 15 Weeks of Gestation					
100	0.07	2.6	2.6	0.20	1.3
120	0.07	3.0	2.5	0.23	1.5
140	0.07	3.4	2.4	0.27	1.7
160	0.07	3.8	2.4	0.29	1.9

TABLE 15--Continued

Body Weight (lb)	Gain or loss (lb)	Feed		Daily Nutrients	
		Per Animal (lb)	% Liveweight	Protein (lb)	T.D.N. (lb)
Ewes--Last 6 Weeks of Gestation					
100	0.37	3.8	3.8	0.31	2.0
120	0.37	4.2	3.5	0.32	2.2
140	0.37	4.6	3.3	0.36	2.4
160	0.37	4.8	3.0	0.36	2.5
Ewes--First 8 to 10 Weeks of Lactation					
100	- 0.08	4.6	4.6	0.40	2.7
120	- 0.08	5.0	4.2	0.42	2.9
140	- 0.08	5.4	4.0	0.45	3.1
160	- 0.08	5.6	3.5	0.47	3.2
Ewes--Last 12 to 14 Weeks of Lactation					
100	0.07	3.8	3.8	0.31	2.0
120	0.07	4.2	3.5	0.32	2.2
140	0.07	4.6	3.3	0.34	2.4
160	0.07	4.8	3.0	0.36	2.5
Ewes--Replacement Lambs					
60	0.30	2.7	4.5	0.29	1.6
80	0.20	3.2	4.0	0.27	1.7
100	0.14	3.4	3.4	0.25	1.7
120	0.07	3.4	2.8	0.25	1.7
Rams--Lambs and Yearlings					
80	0.40	3.2	4.0	0.31	2.0
100	0.30	3.7	3.7	0.31	2.1
120	0.20	4.2	3.5	0.31	2.2
140	0.10	4.6	3.3	0.32	2.3
160	0.10	4.8	3.0	0.32	2.4
Lambs--Finishing					
60	0.30	2.7	4.5	0.31	1.6
70	0.40	3.1	4.4	0.33	1.9
80	0.40	3.4	4.3	0.35	2.1
90	0.40	3.8	4.2	0.36	2.4
100	0.35	4.0	4.0	0.36	2.6

Feed Requirements of Breeding Ewes--
Conception to Weaning

From the time a sheep conceives until her lambs are weaned some 9 months later, she has passed through phases where her feed requirements differed considerably. For the first 100 days there is relatively little development of the foetus and her demands scarcely exceed those for maintenance. During the last 60 days of gestation the foetus is developing rapidly so the sheep must receive feeds of higher energy and protein content. After the lambs are born and during the early lactation period, her demands are greatest due to high milk production. As the lactation progresses and her milk yield declines her demands decrease until she is back on maintenance at weaning time. Sheep are efficient users of roughage and good quality alfalfa hay forms the basis for almost all rations. According to the National Research Council's recommendations (Table 15) alfalfa hay containing 50 percent T.D.N., fed ad lib will supply all the major nutrients for the first 100 days of pregnancy. For the remaining periods some higher energy grains must be added to the hay to meet the increased demand for T.D.N. If the hay contains more than about 10 percent protein no additional protein supplements are needed. Table 16 summarizes data presented by various researchers on the daily feed requirements of ewes.

From these data it appears that the total feed consumed by light sheep is approximately 915 lb. alfalfa hay and 143 lb. grain, and by heavy sheep is 1372 lb. alfalfa hay and 240 lb. grain. More precise requirements may be calculated for a sheep of particular weight by referring to Table 15 and assuming 50 and 75 percent T.D.N. and 15 and 8.7 percent protein contents for alfalfa hay and grain respectively.

When part of the roughage is composed of non leguminous hay, additional feed must be consumed to supply the required nutrients. Ensminger (1952) in his ewe feeding guide (Table 17) illustrates the amount of extra feed needed when part and all of the alfalfa hay is replaced by other less nutrient feeds.

When ewes are on pasture there is usually no need to supply artificial feeding. When introducing ewes and lambs to pasture in Springtime there is a transition period when some hay is fed in addition

TABLE 16

DAILY FEED REQUIREMENTS OF BREEDING EWES

First 100 Days of Gestation (Weighing 100 to 150 lb.)		Last 6 Weeks of Gestation (Weighing 115 to 165 lb.)		First 10 Weeks of Lactation		Last 14 Weeks of Lactation		
Alfalfa lb./day	Grain lb./day	Alfalfa lb./day	Grain lb./day	Alfalfa lb./day	Grain lb./day	Alfalfa lb./day	Grain lb./day	Reference
3 to 4	0	3 to 4	0.75 to 1.00	3[a] to 4	0.75[a] to 1.00	3[a] to 4	0.75[a] to 1.00	Ensminger (1952)
3.6 to 4.5	0	3.6 to 4.5	0.50 to 0.75	3.6[a] to 4.5	1.00[a] to 1.25	3.6[a] to 4.5	1.00[a] to 1.25	Morrison (1956)
3.5 to 4.5	0	3.5 to 4.5	0.50 to 0.75					Kammlade (1955)
3.0 to 3.6	0	3.5 to 4.0	0.75	3.0 to 3.5	2.00	3.5 to 4.0	0.75	N.R.C. (1957)

[a]Duplicate figures represent average requirements for entire lactation period.

TABLE 17

HANDY EWE FEEDING GUIDE
(From Ensminger 1952)

Type of Ration	First 100 days of Gestation (Weighing 100 to 150 lb.)	Last 6 weeks of Gestation (Weighing 115 to 165 lb.)	Ewes in Lactation
	lb./day	lb./day	lb./day
Legume hay or grass-legume mixed hay, good quality..........	3 to 4	To each of the rations listed in the first column add 0.75 to 1 lb. grain daily	To each ration listed in the first column add 0.75 to 1 lb. grain daily plus 0.25 lb. protein supplement to each ration having less than 2 lb. legume hay
Legume hay or grass-legume mixed hay, good quality..........	1.5 to 2		
Grass hay or other non legume dry roughage....	1.5 to 2.25		
Legume hay or grass-legume mixed hay, good quality..........	1.5 to 2		
Corn or Sorghum silage.	4 to 6		
Grass hay or other non legume dry roughage....	3 to 4		
Protein Supplement	0.75 to 0.5		
Corn or other non legume silage.........	8 to 10		
Protein Supplement	0.25 to 0.5		

Roots..................	5 to 6
Legume hay or grass-legume mixed hay, good quality...........	2.25 to 3.25
Grass hay or other non legume dry roughage....	2 to 2.5
Corn or Sorghum silage.	3 to 4
Protein Supplement.....	0.25 to 0.5

to the pasture (Morrison 1956). In estimating feed requirements of lactating ewes before going on pasture, the most reliable figures are those presented by the National Research Council; since other references only give average daily requirements over the entire period (see Table 16).

Feed Requirements of Feeder Lambs

Feeder lambs are usually purchased by commercial feeders and fed in specialized lots until they are ready for slaughter. Generally these lambs weigh from 55 to 80 lb. when purchased and are fed to a slaughter condition of from 90 to 100 lb. in 90 to 120 days (Ensminger 1952). Lambs are efficient users of roughage and their feed may consist of a single high quality hay and a low protein grain; in fact, alfalfa hay and shelled corn have become established as the standard feed for fattening lambs (Kammlade 1955).

How Much Feed is Required to Fatten a Lamb?

As with other enterprises where meat production was the primary concern, the most important consideration in feeding lambs is the efficiency of feed utilization. This efficiency is governed by such factors as--type and quality of feed consumed, method of feeding, proportions of various feeds, and type of animal. In summarizing data presented by Blakeslee (1959), Morrison (1956), Ensminger (1952), Kammlade and Kammlade (1955), McKenney (1959), Cate *et al*. (1955) and Jordan *et al*. (1950), (see Table 18) it appeared that lambs could make faster gains and more efficient use of feed when it was pelleted and self-fed. When comparing hand and self-feeding of unpelleted feed it was noted that the efficiency of feed utilization for both groups was approximately the same, but the self-fed group eat more feed per day and maintained a considerably higher rate of gain. The proportion of roughage to grain also had a marked effect on the rate of gain and efficiency of feed utilization (see Table 18). In most of the discussions, considerable emphasis was placed on the danger of overeating when grain was fed too liberally. In the majority of feeding trials

TABLE 18

SUMMARY OF FEEDING EXPERIMENTS ON FEEDER LAMBS, INCLUDING ESTIMATES OF MAXIMUM DAILY FEED REQUIREMENTS

Experiments	Average Daily Feed	Average Daily Gain	Feed per 100 lb. Gain	Maximum Daily Feed Requirements
	lb.	lb.	lb.	lb.
Pelleted (Self-fed)	3.63	0.53	703	4.28
Not Pelleted (Self-fed)	3.71	0.41	912	4.38
Meal, Self-fed	3.2	0.42	764	3.78
Meal, Hand-fed	2.8	0.37	758	3.30
Ratios of Corn to Hay				
1 to 1	2.50	0.32	792	2.95
1 to 1.3	2.54	0.30	870	3.00
1 to 2.2	2.55	0.25	1011	3.01
Miscellaneous (Including tests on over-eating control chemicals, various grain and roughage ratios, grains and roughages other than corn and alfalfa hay, as well as general recommendations on feed requirements.)	2.80	0.34	852	3.30

the animals were introduced to grain very gradually. By the end of the third week the proportion had been increased to 50 percent and remained at that for most of the feeding period. Sometimes the proportion was increased to 60 percent later in the feeding period but at this level there was a much greater risk of overeating losses. On the basis of these conclusions it seems reasonable to assume that the total feed consumed will consist of half and half roughage and grain. Other feeding systems such as separate feeding of hay (both long and chopped) and grain were discussed but the general trend was towards chopping the hay and mixing it with the grain. One experiment reported by Jordan (1950) compared twice-a-day with three-times-a-day feeding and found very little difference.

From the data available it seems that under the most suitable conditions lambs can be expected to put on one pound of gain for every 7 lb. of a feed consumed, when the ration is composed of half-and-half alfalfa hay and shelled corn. Under less ideal conditions of management the requirement for a similar gain is between 8 and 8.5 lb. feed. Where the proportion of roughage to grain is greater than 1 to 1 the amount required to put on one pound of gain may exceed 10 lb.

If feeds other than alfalfa hay and shelled corn are used the ration should be balanced for T.D.N. and protein according to the recommendations of the National Research Council.

What are the Maximum Daily Feed Requirements of Fattening Lambs?

If lambs are purchased at 60 lb. and finished to 100 lb. at an average rate of gain of 0.37 lb. per day the average and maximum daily feed consumptions are 3.4 and 4.0 lb. respectively. (N.R.C. data, Table 15) If this relation of rate of gain, average feed consumption, and maximum daily consumption are assumed constant the maximum daily consumption for other conditions may be calculated provided the daily gain and average daily consumption are known. This has been done for the data in Table 18 and recorded in the column at the right of the table.

Feed Requirements of Spring Lambs

Spring lambs are ones which receive additional "creep feed" while suckling their mothers and are ready for market when weaned in April through July 1. Well fed Spring lambs will weigh from 55 to 100 lb. at slaughter. The amount of feed consumed by these lambs depends to a large extent on the milking ability of the ewe and whether the lamb is a single or one of a pair of twins. One experiment quoted by Morrison (1956) showed that for each additional pound of milk produced by ewes, the average daily gains of their lambs was 0.16 lb. more than those of the lower yielding sheep, and the lambs getting the most milk gained 59 percent more from birth to 12 weeks than the ones from the low milk producers. The National Research Council (1957) states that twin lambs only get about two thirds as much milk as singles. It further states that lambs begin to consume supplemental feed at about two weeks of age and by the time they are 90 days old they have consumed an average of 0.75 lb. concentrates and 0.5 lb. good legume hay per day over that period. At the end the lambs were consuming 2 lb. of concentrates per day. Because of the high protein content of sheep's milk, no protein supplement is necessary in addition to the feeds just mentioned. Kammlade (1955) suggests that nursing lambs under three months may make 100 lb. gain on 125 to 150 lb. grain and 100 to 125 lb. roughage in addition to the milk of the ewes.

Materials Handling Considerations in Sheep Feeding

The finishing of feeder lambs is the most specialized and intensive section in sheep production, hence it presents the greatest opportunity for mechanization. The production of finished lambs is a seasonal operation extending from August through May (Ensminger 1952); and feeders tend to fill their yards with one or two shipments. Because it is possible to have a situation where almost all the lambs are ready for slaughter simultaneously, it is necessary, in estimating capacities of feeding equipment to do it on the basis of all animals at maximum daily feed intake at once. Figures for maximum daily intake of feeder lambs under a variety or conditions have been presented in Table 18. These figures are for air-dry feeds based on rations of alfalfa hay and shelled corn, but the quantities will not vary appreciably (as indicated in the figures for miscellaneous tests--Table 18) if other feeds are used.

In estimating feed storage space, the important considerations are--type of feed, proportions of feeds, and efficiency of feed utilization. These have been discussed in the preceeding section on feeder lambs. If the quantities of feed required to produce one pound of gain are known,it is a simple matter to estimate the total feed required,by subtracting the average initial body weight from the final body weight and multiplying by the number of sheep and the quantity of feed required to produce one pound of gain.

What Allowances Should be Made in Designing a Materials Handling System on Estimated Feed Requirements?

A number of factors must be taken into account when estimating a safety margin in the design of a materials handling system for feeder lambs. (1) Wastage--Most experiments quote actual consumption figures and take no account of the feed wasted, or spoiled and weighed back when fresh feed was given. Kammlade, quoting experiments conducted in Illinois indicated that lambs wasted 26 lb. of alfalfa hay or 102 lb. of soybean hay per 100 lb. of gain. Having the feeder troughs in the open increased spoilage losses. (2) Variations in abilities of sheep to utilize feed--As with other animals, some strains of sheep can make more efficient gains than others. While the figures quoted are from experiments on large numbers of sheep, the possibility still exists, especially if the operator is inexperienced at purchasing the right type of lamb, of having to provide more feed than anticipated to make the necessary gain. (3) Variations in feed--This problem has already been discussed for conditions where the variations are known, but even feeds with well established analyses may vary considerably from one year to another, and the animals may not make the expected gains due to these unknown deficiencies. (4) Animal deaths--Provided estimates of total feed requirements are made on the basis of the number of sheep purchased, this factor tends to overestimate feed requirements. The normal death rate is about 3 to 4 percent (Ensminger 1952) (Morrison 1956) and if the animals are assumed to die at regular intervals, the feed requirement is overestimated by an amount equal to that required to finish half the sheep which die. The best approach is to ignore this factor as it may compensate for some unknown factors tending to underestimate requirements.

In conclusion it seems that under the most suitable conditions where the feeds consist of good alfalfa hay and shelled corn, and where the feeding system is well defined, an allowance of 10 percent above the specified requirements is adequate. On the other hand, where the feeder wishes his system to remain more flexible, especially where feeds are concerned, the safety margin should be increased to 15 percent.

FEED REQUIREMENTS OF BEEF CATTLE

Since most of the beef feeders buy in their animals for fattening, only the final finishing period will be discussed in this presentation. Almost all these animals are placed in dry lot and fed intensively until they attain choice or good slaughter condition. The type of animal fattened depends on many factors, such as relative cost of feeds, personal preference of the stockman, and buying-in price. In general, the animals are bought in as either calves, yearlings, or two-year-olds. The calves weigh about 400 lbs, and are fed to choice condition in from 8 to 9 months; the yearlings weigh about 650 lbs. at purchase and are ready for slaughter after 6 to 7 months, while the two-year-olds weigh 850 lbs. on the average when purchased and only take from 5 to 6 months to reach slaughter condition (Snapp and Neumann, 1960).

Average Daily and Total Feed Requirements

The average daily and total feed requirements for fattening calves and yearlings have been prepared by Henderson (Undated) and are reproduced in Appendix B. In estimating similar figures for two-year-old steers, the first phenomenon noted was that if total feed requirements are estimated on an air dry basis, the amount of feed consumed by calves, yearlings and two-year-olds from the time of purchase until they reach choice condition is approximately the same. Evidence of this is presented by Snapp and Neumann (1960), (Table 19) in which they summarized data from seven trials on the effect of age on amounts of feed needed to reach choice condition.

Assuming that two-year-old steers purchased at 840 lbs. consume 4400 lbs. feed before being turned out as choice animals at 1200 lbs. and being fed at two rates such that their daily gain is 2.25 and 2.5 lbs. per day, the number of days required is $\frac{360}{225} = 160$ and $\frac{360}{250} = 144$ days respectively. The corresponding average daily feed consumptions are $\frac{4400}{160} = 27.5$ and $\frac{4400}{144} = 30.5$. Using these as a basis and allowing the same minimum quantities of feed as specified for calves and yearlings in Appendix B, Table 20 has been prepared which gives the average daily and total feed requirements of two-year-old steers.

TABLE 19

EFFECT OF AGE ON THE AMOUNT OF FEED NEEDED BY BEEF CATTLE TO ATTAIN CHOICE CONDITION
(From Snapp and Neumann 1960)

	Calves	Yearlings	Two-Year-Olds
FEED (lbs)			
Shelled Corn	2735	2696	2811
Protein Concentrate	452	405	372
Dry Roughage	1139	1183	1203
TOTAL	4326	4284	4386
DAYS FED	235	177	151
AVERAGE daily gain	2.09	2.36	2.60

Day-to-Day Feed Requirements

The daily feed requirements vary somewhat depending on the ration and rate of gain being made. Table 21 presents the daily, per head consumption of calves at different stages in the fattening program as obtained by Newland (1963) in an experiment involving more than 200 animals.

Similarly, recommendations on daily feed requirements are presented by the National Research Council (1958) for calves, yearlings, and two-year-olds. Their findings, together with those of Newland, are presented in graphic form in Fig. 15. By using this chart it is possible to predict the daily feed requirements of animals at any stage of their fattening program, and hence, to design a feed handling and feeding system for maximum requirements.

When designing a materials handling system, additional safety margins must be added to these figures to insure that both storage and handling capacities are valued safely above the minimum estimated requirements. Another point worthy of consideration is whether the animals

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TABLE 20

FEED REQUIREMENTS FOR MEDIUM 850-LB TWO-YEAR-OLD STEERS FED TO GOOD-CHOICE 1200-LB SLAUGHTER STEERS

	Average Daily Feed Intake (lb)	Total Feed Intake (lb)
Feeding Period 144 days		
Expected Daily Gain 2.50 lbs.		
A. Steers confined to dry-lot, making optimum use of Corn Silage		
Corn Silage (full-fed).....................	62.0[a]	8930
Shelled Corn (0.75 lb/100 lb body weight)..	8.0	1152
Protein Supplement (44%)..................	1.5	216
B. Steers confined to dry-lot, making optimum use of Shelled Corn		
Shelled Corn (full-fed)....................	24.75	3565
Alfalfa Hay (0.50 lb/100 lb body weight)...	5.25	756
Protein Supplement (44%)..................	0.50	72
Feeding Period 160 days		
Expected Daily Gain 2.25 lbs.		
A. Steers confined to dry-lot, making optimum use of Corn Silage		
Corn Silage (full-fed).....................	74.5[a]	11940
Protein Supplement (44%)..................	2.5	400
B. Steers confined to dry-lot, making optimum use of Corn Silage with limited grain		
Corn Silage (full-fed).....................	52.5	8400
Shelled Corn (0.75 lb/100 lb body weight)..	8.0	1280
Protein Supplement (44%)..................	2.0	320
C. Steers confined to dry-lot, making optimum use of Shelled Corn		
Shelled Corn (full-fed)....................	21.75	3480
Alfalfa Hay (0.50 lb/100 lb body weight....	5.25	840
Protein Supplement (44%)..................	0.50	72

[a]It may be difficult to achieve these intakes unless the animals are fed three times per day.

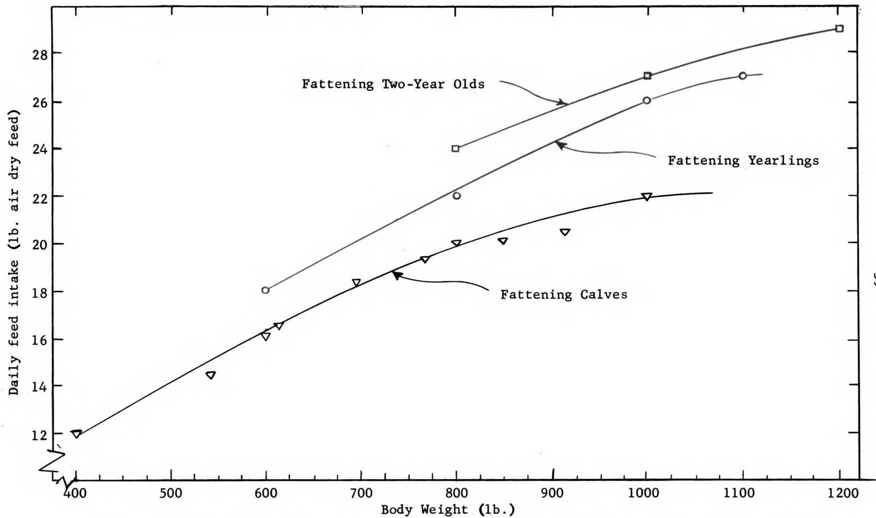

Fig. 15.--Daily feed requirements of calves, yearlings and two-year-olds at various stages of fattening (feeding commenced when animals were in a thin "feeder" condition).

are fattened as a group or whether some are being sold off and replaced each week. The former places a much greater demand on feeding equipment since almost all animals are at maximum feed requirements simultaneously.

TABLE 21

DAILY FEED CONSUMED BY FATTENING CALVES AT VARIOUS STAGES OF GROWTH (From Newland 1963)

Days in Period	Days to Date	Average Body Weight During Period (lb)	Average Daily Feed Consumed, Period			
			Corn Silage (lb)	Shelled Corn (lb)	Protein Supplement (lb)	Total Air Dry (lb)
21	21	544	23.7	5.8	0.98	14.29
35	56	611	27.4	6.3	1.02	16.44
28	84	691	31.6	6.9	1.01	18.38
28	112	767	32.6	7.3	1.00	19.20
35	147	846	33.1	8.1	1.02	20.09
16	163	913	32.7	8.7	1.00	20.55

Protein Requirements of Beef Cattle

When feed requirements are specified in pounds of air dry feed, it is necessary to determine the amount of the different feeds which go to make up this quantity. This invariably involves determining the quantity of protein supplement to add in order to satisfy the animal's individual requirements. Table 22 presents the total and digestible protein required by feeder cattle of different ages and body weights as recommended by the National Research Council (1958).

If the approximate protein content of the other ingredients is known, it should be possible, by using this table, to determine the amount of protein supplement to add per day. See Appendix A. All rations presented in Appendix B and Table 19 have been balanced for protein.

TABLE 22

DAILY PROTEIN REQUIREMENTS OF FEEDER CATTLE
(From National Research Council 1958)

Body Weight (lb)	Average Daily Gain (lb)	Total Protein (lb/day)	Digestible Protein (lb/day)
Finishing Calves, Finished as Short Yearlings			
400	2.3	1.3	1.0
600	2.4	1.8	1.3
800	2.2	2.0	1.5
1000	2.2	2.2	1.6
Finishing Yearlings			
600	2.4	1.8	1.4
800	2.8	2.2	1.6
1000	2.5	2.6	2.0
1100	2.3	2.7	2.0
Finishing Two-Year-Olds			
800	2.8	2.4	1.8
1000	3.0	2.7	2.0
1200	2.6	2.9	2.2

FEED REQUIREMENTS OF POULTRY

Laying Hens

Two methods are in common use for expressing the feed requirements of laying hens. (1) Pounds of feed per year as a function of number of eggs produced per year and (2) Pounds of feed per day per 100 birds as a function of percentage production (daily egg production of 100 birds). Each of these estimates are further influenced by such factors as weight of bird, age of bird, time of year, management, etc.

Pounds of Feed as a Function of Eggs Produced Per Year

This method is based on allowing a certain amount of feed for maintenance and adding additional feed depending on the number of eggs produced annually. Although most references agree within reasonable limits on the amount of feed required to maintain a bird of known weight, some diversity exists concerning the amount required for egg production. The National Research Council (1960) recommendations on feed requirements for laying hens are based on a figure of 0.14 lb. feed per egg produced. Data presented by Haberman (1956), Hartman (1956), Heuser (1955) and Parnell (1957) reflect an almost similar per-egg requirement. Titus (1955), working with White Leghorn chickens weighing 3.5 lbs., found the feed requirement per egg produced to be as low as 0.0888 lb. He also quoted an independent source, working with White Leghorns and Rhode Island Reds averaging 4.75 lb. body weight as obtaining a per-egg feed requirement of 0.0865. An almost similar figure is used by Schaible (1957) in preparing his table on total feed requirements per hen per year.

Based on these recommendations, a chart has been prepared (Fig. 16) which illustrates the total feed requirements, per year, of birds of various sizes. The "full" lines represent the total requirements based on a per egg requirement of 0.14 lb., whereas the "broken" lines represent requirements when a figure of 0.089 lb. feed per egg is used.

Pounds of Feed per Day per 100 Birds as a Function of Percentage Egg Production

This method also allows a certain amount of feed for maintenance and adds additional feed depending on the daily egg production from the 100 birds. Using similar figures for maintenance and egg production as those used in the previous section, a chart has been prepared (Fig. 17) which presents the daily requirements of 100 birds of different weights and production levels.

Hartman also presents a chart (reproduced in Fig. 18) which is designed to predict the feed requirements of hens of any weight and egg production. By selecting the weight of the bird on the left-hand line and the egg production on the right line, the point at which a line joining these points intersects the center line represents the annual feed requirement. It will be noted that the figures thus obtained coincide to a large extent with the higher requirements in Fig. 16.

It should be remembered that the figures quoted are average and do not reflect day-to-day or season-to-season variations. Heuser presents tables in which the month-by-month feed consumptions are recorded. From these tables it is apparent that hens consume more feed in the winter and less in the summer, depending on weather conditions. One reference quoted, suggested an increase of 10 percent in feed estimates in winter and a reduction of from 15 to 20 percent in very hot weather. This reference also suggested that for older birds the feed estimates may be reduced from 5 to 15 percent. Titus further suggested that variations can occur among strains of the same breed and between breeds of similar size in their ability to utilize feed for egg production.

Feed Requirements of Broilers

Broilers, as defined by Morrison (1956), are chickens of either

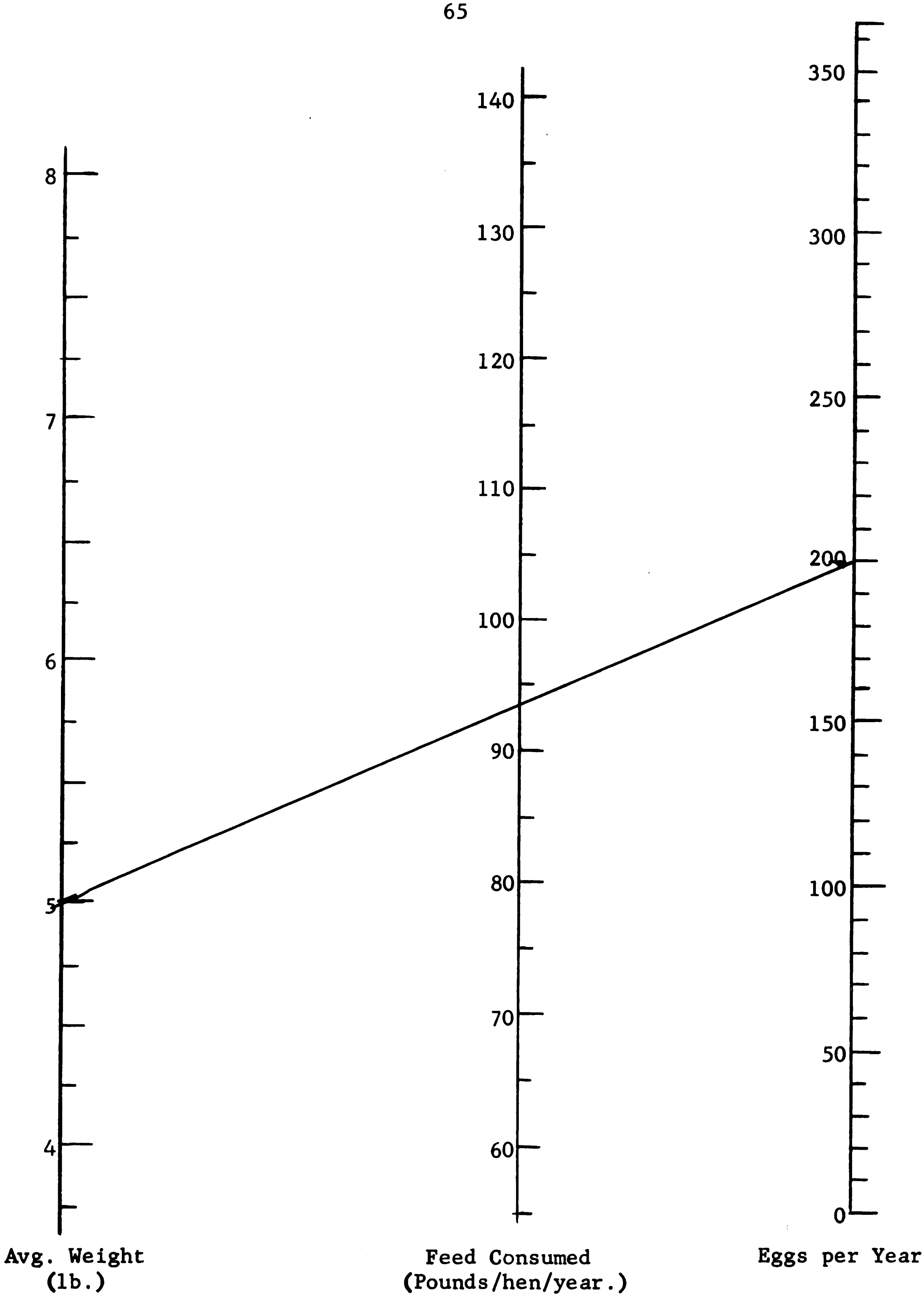

Fig. 18.--Nomograph for determining the total yearly feed consumption of laying hens of various weights and production levels.

sex which are finished for marketing when 8.5 to 12 weeks old and which weigh 3 to 4 lbs. alive. The most important consideration in broiler production is efficiency of feed utilization, and this forms a basis for estimating total feed consumption. With modern feeding techniques, it is possible to raise 3.5 lb. broilers on a feed conversion ratio of 2.5 lb. feed per pound of broiler. Heuser (1955) quotes figures from large-scale broiler operations for 10 to 11 week old broilers in which the body weight ranged from 3 to 3.75 lbs. and the feed conversion varied between 2.5 and 3 lbs. feed per pound of broiler. These figures are in agreement with recommendations by Schaible (1957) on broiler growth and feed consumption. Allowing a feed conversion of from 2.5 to 3 lbs. feed per pound of bird, the amount of feed consumed by a 3 lb. broiler varies from 7.5 to 9 lbs. Similarly, a 3.75 lb. broiler could be expected to consume from 9.4 to 11.25 lbs. feed. Since the rate of conversion increases as the bird gets heavier (Schaible, 1957) and (Heuser, 1955) it is reasonable to assume that, for a 3 lb. bird, the feed requirement approaches the lower limit, whereas with the heavier birds the higher requirement is appropriate.

Schaible, Heuser, Titus (1955) and Parnell (1957) report on experiments indicating the feed requirements of broilers from birth to market weight. These figures have been averaged and expressed as total feed consumed, feed consumed per week, and feed consumed per day. They are presented in Fig. 19 together with a curve of body weight versus age, for typical broilers.

Laying Flock Replacements

The main concern in this section is the feed required by the lighter laying breeds from the time they are born until they are incorporated into the laying flock. This occurs when the birds are approximately 24 weeks old and weigh from 3.5 to 4 lbs. (Schaible, 1957). Both Schaible and Heuser (1955) reported on experiments in which the total feed consumed at different stages of growth was presented. Their findings have been reproduced in graphic form in Fig. 20. The data presented by Heuser concern Leghorn pullets fed from birth, whereas

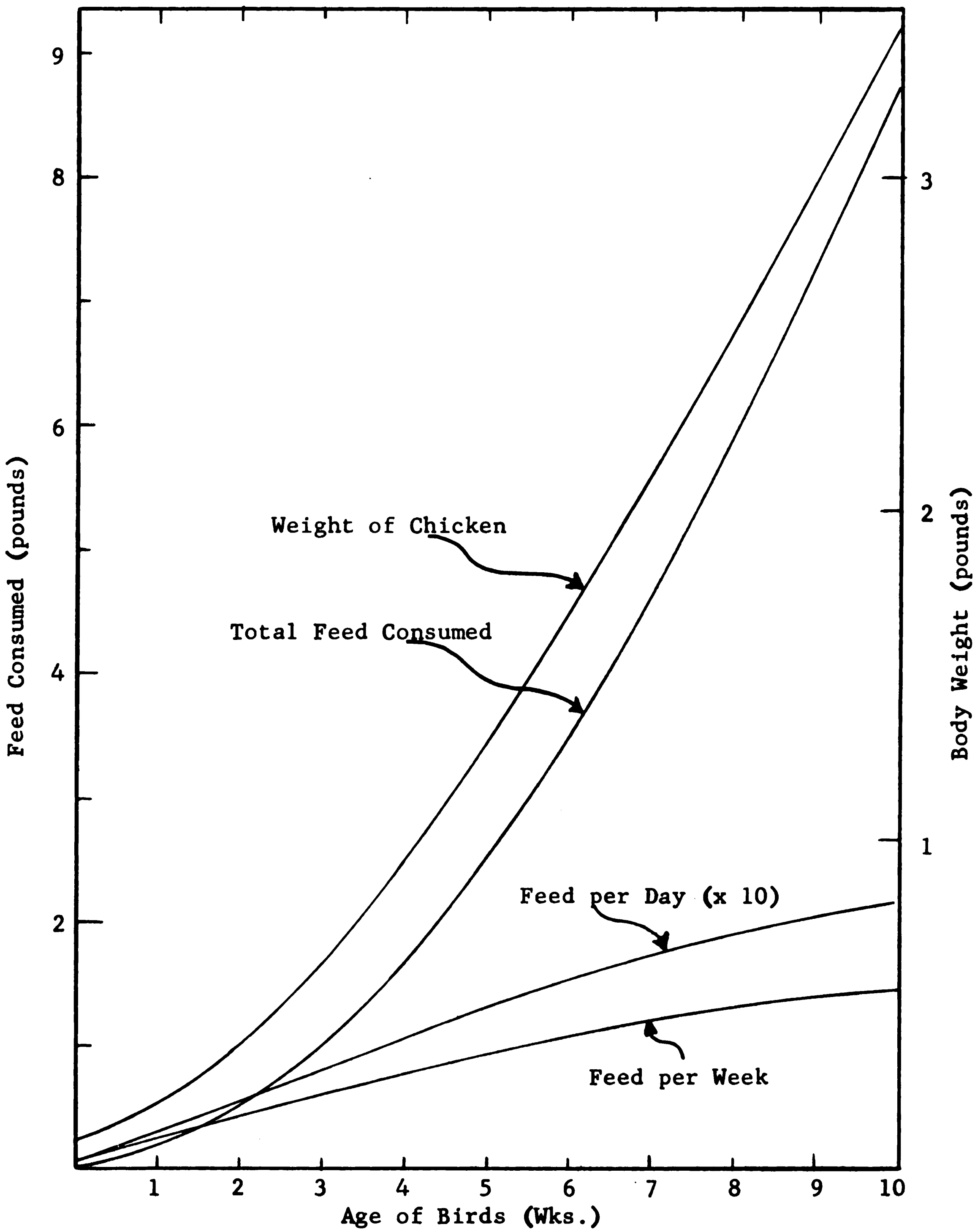

Fig. 19.--Body weight and feed consumption of broiler chickens at various ages.

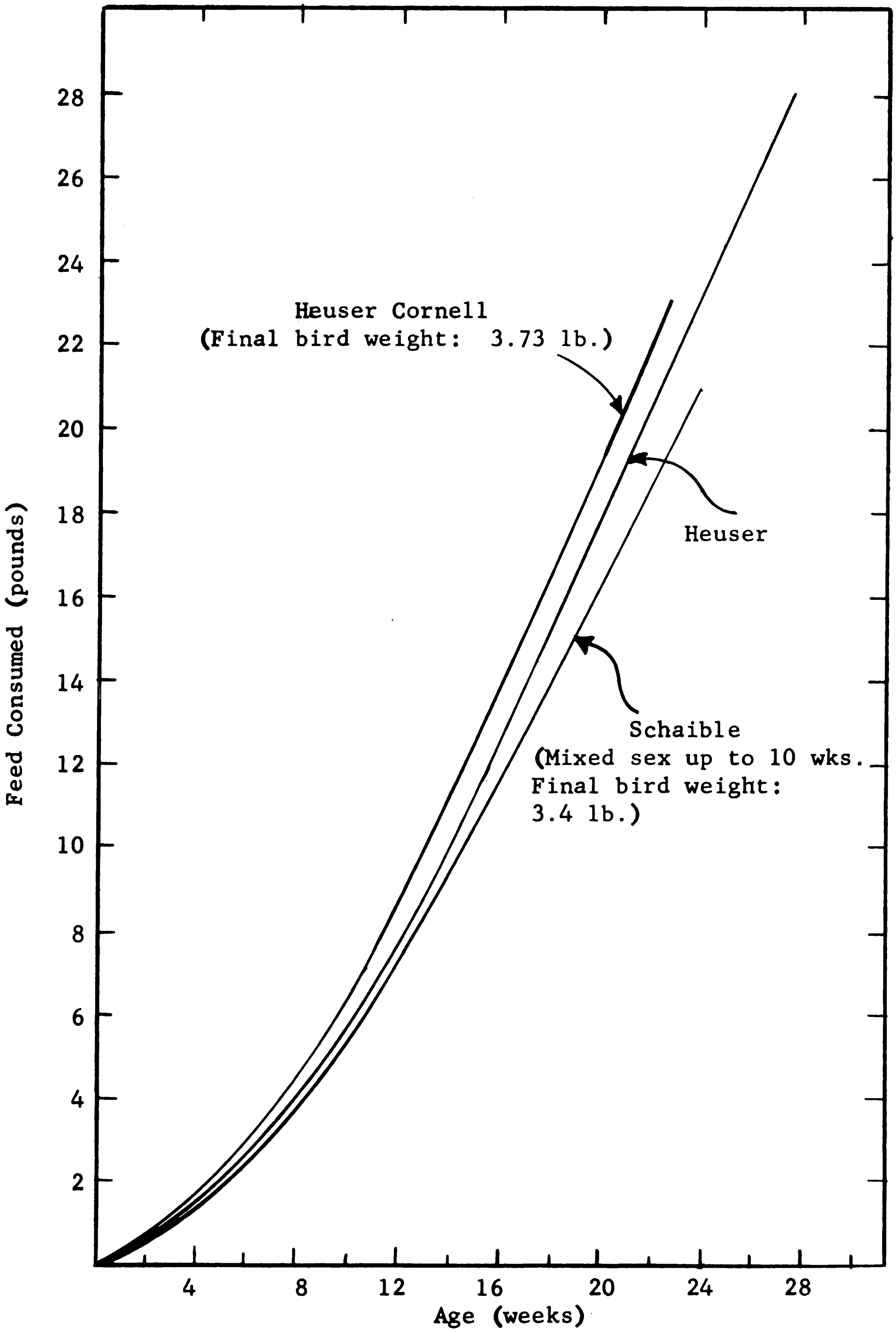

Fig. 20.--Cumulative feed consumption of laying-flock replacement chickens.

those by Schaible are for cockerels and pullets (50:50) up to the age of 10 weeks. The total feed consumption as indicated by these curves are well in accord with a further suggestion by Schaible that the normal feed requirement up to the start of egg production at 24 weeks is 22 to 25 lbs., and an additional experiment cited by Heuser in which the total feed consumed up to 26 weeks averaged 23.4 lbs. From these comments, it seems reasonable to assume that the upper and lower curves in Fig. 20 represent the maximum and minimum feed requirements of the lighter laying breeds. Other references quoted by Heuser indicate a slightly higher rate of feeding by which the birds reach 3.5 lbs. in 20 weeks. However, the total feed consumed in both cases is almost identical as the saving in time in one instance is just about offset by a reduction in daily feed intake in the other.

The total feed requirements for replacements of the larger breeds are somewhat greater. Schaible suggested a range of from 26 to 35 lb., while Heuser quoted experiments in which the total requirement for a bird to reach 5.7 lbs. body weight at 20 weeks was 27 lbs.

Turkeys

Two breeds of turkeys are worthy of consideration; the Broad Breasted Bronze representing the larger types and the Beltsville Small White representing the smaller types. Considerable agreement exists among workers as to amount of feed required to bring these birds to market condition. Most estimates of both total and per-day feed consumptions are based on feed efficiency factors. The accumulated feed efficiency is the average number of pounds of feed required to produce one pound of gain up to any given time; whereas the efficiency per period is the weight of feed required to produce a pound of gain within the given period. The former may be used to predict the total feed required from birth, while the latter is useful in estimating the average daily requirements for any period.

Heuser (1955), Winter and Funk (1960) and Schaible (1957) present data in which the overall efficiency for Broad Breasted Bronze turkeys, marketed at about 20 lbs. was 3.82 to 4.6 and those for

Beltsville Small Whites marketed at about 10 lbs. was 3.4 and 4.4. The corresponding means were 4.2 and 3.8. Figs. 21 and 22 have been prepared from data presented by Heuser and Winter and Funk respectively. These data have been used because they represent approximate average conditions. The figures on the right of the curves represent the accumulated efficiency to the end of that period while those on the left represent the average efficiency for the period on the curve opposite which they occur. The latter figures have been taken from a smoothed curve on the original data. Using these curves, it is possible to estimate the total feed required to reach any age and the average feed consumption over specified periods.

Example: In Fig. 21, when Beltsville White turkeys have reached the age of 12 weeks, they should weigh 5.1 lb., should have consumed 5.1 X 2.69 lb. feed, and average daily feed consumption for the previous two-week period should be $3.05 \times \frac{(5.1 - 3.8)}{14} = 0.283$ lb. per day.

Materials Handling Considerations in Poultry Production

In most cases where poultry is produced on a large scale the producer has a contract with a feed merchant to supply the feed at regular intervals throughout the year. Under this system, the only materials handling problems are providing sufficient storage for the feed required during the period between deliveries, and designing feeders to meet the maximum daily feed requirements of the birds. This system has the advantage that it relieves the farmer of some of the worries of providing long-term storage facilities and also fits in well with the general recommendation by nutritionists that mixed feeds should not be kept in storage for more than three weeks, due to deterioration of some of the ingredients (Schaible, 1957). The principle ingredients which deteriorate are carotene, vitamins A, D and B_{12} and trace elements. (American Feed Manufacturers Association-undated). In addition, the ration for growing birds must be changed as the birds grow older. This is not a particular problem in continuous enterprises such as broiler production, since birds at all stages are continually present. With seasonal enterprises such as

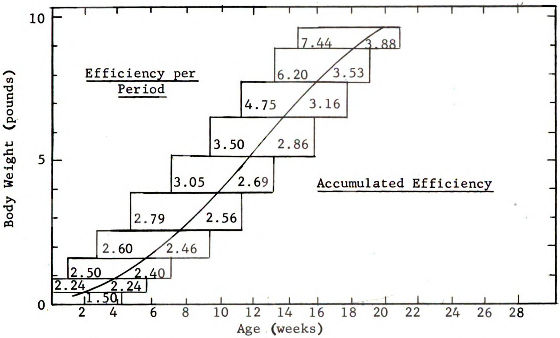

Fig. 21.--Efficiency of feed utilization of Beltsville Small White turkeys from birth to market.

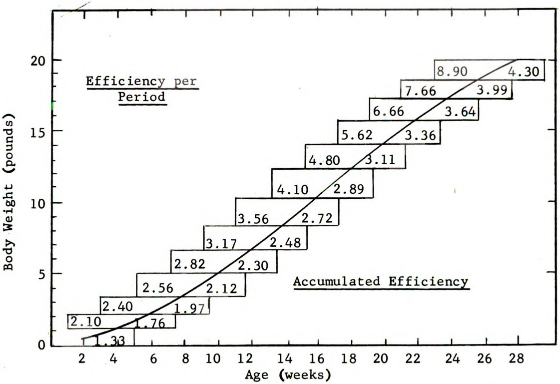

Fig. 22.--Efficiency of feed utilization of Broad Breasted Bronze turkeys from birth to market.

turkeys, frequent delivery of feed is a decided advantage in guarding against overstocking with one particular ration and the necessity of providing individual storages for different rations does not arise. On-the-farm mixing eliminates some of the obstacles just mentioned, but the problem still remains of estimating total requirements of individual feeds, and in view of changes in feed composition just mentioned, this would not be easy.

What Should be Known About Feed Requirements in Order to Design a Satisfactory Materials Handling System?

Feed requirements may be expressed in different ways depending on the type of enterprise being considered; (1) daily feed requirements, (2) yearly feed requirements, (3) total production requirements (less than one year). The latter concerns birds such as broilers, which are born and marketed in less than one year. Of these, the daily feed requirements are by far the most useful from a materials handling point-of-view. If the mean daily requirements for weekly of two-weekly periods throughout the bird's life are known, both the total and maximum daily feed requirements can be estimated. Feed efficiency factors are frequently quoted in enterprises where the emphasis is on meat production, and are used to estimate both daily and total feed consumption. A fuller discussion on efficiency factors may be found in the preceding sections dealing with the various poultry enterprises.

What Allowances Should be Made in Basing a Materials Handling System on Estimated Feed Requirements?

As pointed out in previous discussions, the estimates of feed consumption are for average conditions. It is essential, therefore, when designing storage and feeding facilities to make sufficient allowances to insure that the system is adequate under all conditions. In addition to the normal allowances necessary to cater for the less efficient birds which consume more than average amounts of feed, account must also be taken of other factors such as (1) feed wastage; Schaible, in a discussion on this problem presented data which show that wastage can go as high as 45 percent when the hoppers are overfilled and as low as 1.3 percent when the hoppers are filled about one third. In many enterprises a certain amount of feed is fed in the form of "scratch", that is, the grain is scattered on the litter and the birds allowed to forage for it. This invariably leads to feed losses and spoilage. Schaible estimates that feed wastage on most farms amounts to 200 lbs. per 100 birds per year (2-3%). (2) Feed shrinkage; when feeds are processed and mixed on the farm a certain amount of loss is inevitable. The American Feed Manufacturers Association, quoting a recent survey of seven feed mills, indicated that the losses in storing, handling, and grinding shelled corn and oats were 3 and 4.4 percent respectively. This is an important consideration on farms where home processing is practiced.

When all these factors must be taken into account, it is difficult to generalize on what should be considered a reasonable safety margin. Under the most extreme conditions, it seems necessary to allow a 20 percent margin in storage facilities and a 10 to 15 percent margin in feeding equipment.

Feeding Systems

Two systems are in common use in poultry feeding. (1) All mash and (2) mash-grain. A full discussion on the latter system has been excluded because of the infinite variety of combinations practiced. However, in individual cases the problem consists only of estimating what proportion of the feed is being fed as grain and designing storage and handling facilities accordingly.

SUMMARY

The design of materials handling equipment and systems is a relatively new area in Agricultural Engineering. In it the designer must combine his engineering skill with a thorough knowledge of animal feed requirements to produce a satisfactory system for conveying, processing, and storing feeds and other materials on the farm. A preliminary investigation into the nature of these requirements revealed that it was essential to know the yearly and maximum daily feed consumptions of the animals; this information was not available in a readily usable form. It was the object of the present investigation to extract information on these requirements from the available data on animal feeding and to add to it allowances for eventualities such as variations in feed composition and availability, changes in animal appetite, etc., so that a system, designed in accordance with the recommendations, would be adequate under all conditions, but not excessively large.

The feed requirements of dairy cows were first calculated on the basis of nutrient requirements and then compared with data obtained from feeding experiments. The latter were found to be considerably higher because the animal was not content to stop eating when it had taken in sufficient nutrients but continued until its appetite was satisfied. It was apparent from this that considerable underestimation of feed requirements was possible if estimates were based on nutrient requirements alone. The type of feed offered had a considerable effect on the quantity of feed consumed daily, as animals did not have the capacity to consume as much dry matter daily when the feeds were bulky. For animals producing less than 28 lb. of milk per day, a diet composed of all good quality roughage was adequate. If, however, she was producing more than 28 lb. daily some of the roughage had to be replaced by higher energy grain feeds. The method of grain feeding found most satisfactory for calculation purposes was to give one pound

of grain for every two pounds of milk produced in excess of what the roughage would support. Lactation curves were used to predict the month-to-month variations in daily milk production. The grain was balanced for protein according to the following formula:

$$\text{Percent protein in meal-mix} = \frac{(M + P - R)2}{Y - (W - 16)1.375} \times 100$$

Where

M = Daily protein requirement for maintenance (lb).
R = Pounds of protein supplied by roughages daily.
P = Pounds of milk produced per cow daily.
H = Weight of "Hay Equivalent" consumed daily.
Y = Daily milk yield (lb).

In normal feeding practice the roughage is fed ad libitum, while the grain is rationed. Under these conditions the quantity of grain consumed can be estimated with a fair degree of accuracy, but the estimated roughage requirement should be increased by not less than 15 percent to allow for feed wastage, and variations in animal appetite. Curves were prepared of the yearly feed requirements of cows with various milking capabilities, which incorporate these allowances. The point of entry on these curves is critical, as the quantity of grain fed must not exceed what is economically justifiable. In a review of recent literature the tendency seemed to be to feed one pound of grain for every 2.5 to 3 lb. of milk produced. The feed requirements for herd replacements were met by adding 200 lb. of milk, 275 to 700 lb. grain and 6.3 to 5.5 tons hay equivalent per cow per year depending on the quality of the roughage.

When designing a materials handling system for daily animals, one should make extra allowances for system flexibility and for deterioration and spoilage of feed. In addition the following points should be considered:

1. Method of preserving hay--loose, baled, or pelleted.
2. Possible unknown deterioration of some feeds in prolonged storage.
3. Allowances should be made for very large or very small cows.
4. The lactation period has been assumed to be one year, sometimes it is greater than this.
5. Silos should be designed so that at least 3 inches of silage is removed daily.

The most important phase in swine management is the production of slaughter pigs. The type of feed required is determined by the age of the animal and the type of carcase desired. Weaner pigs and those intended for the production of "bacon" type carcases need more protein in the ration than older pigs or those fed to produce "meat" type carcases. The amount of protein needed in the ration was governed by the type of animal and the composition of the energy feeds being offered. A table was prepared which gave the proportions of energy and protein feeds required for animals of different types and ages when fed various rations. Even where the energy feeds contained the required amount of protein, a minimum of 10 percent protein supplement, containing animal protein and carotene was added to supply essential nutrients. The total feed consumed by pigs from weaning at 40 lb. to slaughter at 215 lb. varied from 570 to 780 lb. depending on the type of management; the maximum daily feed consumption was 8 lb.

The quantity of feed consumed by pigs from birth to weaning depended on the size of litter and the milking capabilities of the sow. Under normal conditions this did not exceed 25 lb. of "creep" feed. The total feed consumed by breeding sows during gestation and lactation was about 1560 lb.

The following points should be taken into account when designing a materials handling system for swine:

1. Where possible it is better to arrange for periodic deliveries of protein supplement to avoid deterioration of ingredients.
2. Pigs of different sizes are usually grouped together for feeding, this will affect the size of feeding equipment needed.
3. A safety margin of at least 10 percent should be allowed when basing a materials handling system on feed requirement estimates.

Beef cattle are purchased for feeding as either calves, yearlings, or two-year-olds. It was noted that no matter which group was considered the total amount of air dry feed required to bring them to slaughter condition was about 4,400 lb. The maximum daily feed required by these groups was 22, 27, and 29 lb. of air-dry feed respectively. The amount of protein required was determined from the National Research Council recommendations on nutrient requirements of beef cattle.

In designing a materials handling system for beef cattle the following points should be considered:

1. Animals may be purchased as one group, hence feeding facilities should be designed to cater for all animals on maximum daily feed simultaneously.
2. Allow a safety margin of at least 15 percent when designing a materials handling system on feed requirement estimates.

In dealing with the feed requirements of sheep it was found that breeding animals needed little concentrate except for a time before lambing and during the lactation period. For breeding sheep kept in dry-lot the annual feed consumption for small animals was 915 lb. legume hay and 143 lb. grain, and for small animals was 1370 lb. legume hay and 240 lb. grain. When part of the hay was replaced by poor quality roughage the amount of grain had to be increased. When estimating the feed requirements of feeder lambs it was assumed that the lambs were purchased weighing 55 - 80 lb. and fed to slaughter condition at 90 - 100 lb. The amount of feed required to produce 100 lb. gain was 800 lb. of half and half grain and roughage. The maximum daily feed required was 4.4 lb. The amount of feed eaten by spring lambs to bring them to slaughter condition at 60 - 100 lb. varied according to the milking abilities of the ewe. One reference suggested that spring lambs should have consumed 67 lb. grain and 45 lb. legume hay by the time they were 90 days old.

In designing a materials handling system for feeder lambs the following points should be taken into account:

1. It is possible to have all lambs on maximum daily feed consumption simultaneously.
2. Animal deaths--normally a death rate of 3 - 4 percent should be expected.
3. If the operator is inexperienced he may select a type of sheep which will need more feed per pound of gain than anticipated.
4. Under good conditions of management allow a safety margin of at least 10 percent when designing a materials handling system on feed requirement estimates.

In dealing with poultry, the feed requirements of laying hens, broiler chickens, laying flock replacements, and turkeys were considered. The amount of feed required by laying hens depended on the size of the bird and its egg production. Under average feeding conditions it takes 10.5 lb. feed to produce a 3.5 lb. broiler. Laying flock replacements were treated as a separate entity until they began to lay at about 24 weeks. Up to that time they had consumed approximately 22 lb. of grain. In estimating feed requirements of turkeys it was found that the amount of feed required to produce one pound of gain were 3.9 and 4.3 lb. for small and large birds respectively. Small birds were usually fit for market at about 10 lb. and large birds at 20 lb. body weight.

The following factors should be taken into account when designing a materials handling system for poultry:

1. It may be economical in some instances to have the feed delivered periodically by a local feed merchant.
2. Birds waste considerable amounts of feed if the feeder is incorrectly designed.
3. In on-the-farm processing of feeds a 3 - 5 percent feed shrinkage can be expected.
4. Under good management conditions allow a safety margin of 10 - 15 percent in system design.

SUGGESTIONS FOR FUTURE STUDIES

(1) The design of a successful materials handling system for agriculture demands a thorough knowledge of both engineering and animal nutrition. Since most designs are executed by engineers it is essential that pertinent information on animal feeding capabilities be available to them in a readily understandable manner. It was found, when extracting this information, that many researchers, being interested in other facets of animal nutrition, omitted certain details which would be useful to a materials handling design engineer. This was particularly obvious in feeding trials on beef cattle, where the daily feed consumptions and weight gains were recorded, but only overall averages were given in the results. Valuable information of this kind exists in the files of animal nutritionists throughout the country and is available for the asking. It is suggested that such data be obtained and reassessed on the basis of materials handling design requirements.

(2) The data obtained in this investigation should be integrated with available information on feed lots and handling equipment to present a more complete picture of what is needed to insure a satisfactory system.

(3) The investigation just carried out is by no means complete. Much work remains to be done on animal requirements under specialized feeding and housing conditions.

(4) Similar data should be obtained for water requirements and animal manure.

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APPENDIX A

CALCULATING FEED MIXTURES[1]

Below is a simple method of determining how much grain and how much protein supplement to use to make a mixture with a certain protein content. In this example a mixture containing 16% protein is to be made from corn containing approximately 9% protein and supplement containing 40% protein.

Draw a square. In the center of the square put the protein content desired in the final mixture.

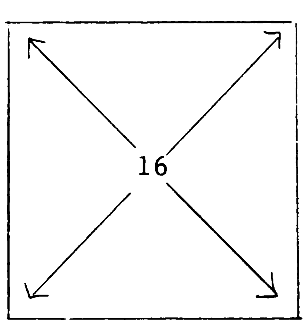
At the upper left-hand corner of the square write corn and its protein content (9); at the lower left-hand corner write supplement and its protein content (40).

Substract diagonally across the square (the smaller from the larger), and enter the results at the corners on right-hand side (16 - 9 = 7; 40 - 16 = 24).

The number at the upper right-hand corner gives the parts of corn and the number at the lower right-hand corner the parts of supplement needed to make a mixture with 16% protein.

Corn 9 — 24 parts corn or 77%

(24 ÷ 31 = .77 x 100 = 77%)



Supp. 40 — 7 parts supplement or 23%

(7 ÷ 31 = .23 x 100 = 23%)

—

31 parts

[1]From Animal Husbandry Publication AH 71. Michigan State University, East Lansing.

Therefore, a mixture of 77 pounds of corn and 23 pounds of protein supplement would make a ration containing 16% protein.

Calculating the Protein Content of a Ration (Example)

	% Protein in feed		
900 lb. Corn	times .09	=	81.00
500 lb. Oats	times .12	=	60.00
300 lb. Alfalfa Meal	times .17	=	51.00
280 lb. Soybean Meal	times .44	=	123.20
20 lb. Mineral			
2000			315.20

315.20 ÷ 2000 = .157 x 100 = 15.7% protein

APPENDIX B

BEEF FEEDING PROGRAMS--ANNUAL FEED REQUIREMENTS[1]

Feeding Systems

I. Good to Choice 400-pound Heifer Calves Fed to 900-pound Choice Slaughter Heifers	Estimated Feed Requirements (lb.)	
Feeds	Daily	Annual
Feeding Period 250 days		
Expected Daily Gain 2.0 lbs.		
A. Confined to Dry-Lot, Making Optimum Use of Corn Silage		
Corn silage, full fed	26.0	6,500
Corn, ground shelled (Corn and supplement limited to 1 lb. per cwt. of body weight daily)	5.0	1,288
44% protein supplement	1.5	375
Hay optional, if fed	2.0	500
(If hay is fed, reduce silage by 5 lbs. daily or 1250 lbs. annually)		
B. Confined to Dry-Lot, Making Optimum Use of Ground Ear Corn		
Corn, ground ear full-fed	13.0	3,290
Hay, limited to 1/2 lb. per cwt. of body weight daily	3.25	800
44% protein supplement	1.0	250

[1]From Fact Sheet 329, Cooperative Extension Service, Animal Husbandry Department, Michigan State University, East Lansing.

II. Good to Choice 400-pound Steer Calves Fed to 1000-pound Choice Slaughter Steers	Estimated Feed Requirements (lbs.)	
Feeds	Daily	Annual
Feeding Period 270 days		
Expected Daily Gain 2.25 lbs.		
A. Confined to Dry-Lot, Making Optimum Use of Corn Silage		
Corn silage, full-fed	28.0	8,000
Hay optional	2.0	600
(If hay is fed, reduce silage by 5 lbs. daily. 1500 lbs. yearly)		
Corn, ground shelled	5.5	1,680
(Corn and supplement limited to 1 lb. per cwt. of body weight daily.)		
44% protein supplement	1.5	450
B. Confined to Dry-Lot, Making Optimum Use of Ground Ear Corn		
Corn ground ear, full-fed	14.0	3,780
Hay, limited to 1/2 lb. per cwt. of body weight daily	3.5	1,000
44% supplement	1.0	270
III. Medium 400-pound Steer Calves Fed to 1000-pound Standard to Good Slaughter Steers		
Feeding Period 340 days		
Expected Daily Gain 1.75 lbs.		
A. Confined to Dry-Lot, Making Optimum Use of Hay		
Hay, full-fed	14.0	5,000
Corn, ground ear; limited to 3/4 lb. per cwt. of body weight daily	5.0	1,750
No protein supplement needed		
B. Confined to Dry-Lot, Making Optimum Use of Corn Silage		
Corn silage, full fed	42.0	14,000
44% protein supplement	2.0	700
(Limited to 2 lbs. daily)		

IV. Good to Choice 650-pound Yearling Steers Fed to 1100-pound Choice Slaughter Steers	Estimated Feed Requirements (lbs.)	
Feeds	Daily	Annual
Feeding Period 225 days		
Expected Daily Gain 2.25 lbs.		
A. Confined to Dry-Lot Making Optimum Use of Corn Silage		
Corn silage, full fed	35.0	8,000
Corn, ground, shelled	7.25	2,100
(Corn and supplement limited to 1 lb. per cwt. of body weight daily)		
44% protein supplement	1.5	340
(Limited to 1-1/2 lbs. daily)		
Hay optional, if fed	2.0	450
(If hay is fed reduce silage by 5 lbs. daily, 1125 lbs. yearly)		
B. Confined to Dry-Lot, Making Optimum Use of Ground Ear Corn		
Corn, ground ear, full-fed	17.0	3,850
Hay, limited to 1/2 lb. per cwt. of body weight daily	4.5	1,000
44% protein supplement	1.0	225
(Limited to 1 lb. daily)		
V. Medium 650-pound Yearling Steers Fed to 1000-pound Standard to Good Slaughter Steers		
Feeding Period 175 days		
Expected Daily Gain 2.0 lbs.		
A. Confined to Dry-Lot, Making Optimum Use of Corn Silage		
Corn silage, full-fed	55.0	9,500
44% protein supplement	2.0	350
(Limited to 2 lbs. daily)		
B. Confined to Dry-Lot, Making Optimum Use of Hay		
Hay, full-fed	17.0	3,000
Corn, ground ear (Limited to 3/4 lb. per cwt. of body weight daily)	6.0	1,050
No protein supplement needed		

Exchange Ratios Based on Digestible Energy or T.D.N.

In order to add more flexibility to the various feeding systems outlined above, some exchange ratios are listed below.

When one feed is substituted for another in the ration, it must be done on a digestible energy basis in order to maintain the desired rate of gain. Feeders must be careful not to exceed dry-matter intake capacity of the animal when a low-energy, density feed is substituted for a feed of higher energy density.

1. 1.2 bu. of 30% moisture shelled or ear corn replaces 1 bu. of 15% moisture corn.

2. 8 bu. of 15% moisture ground ear corn will replace 1 Ton of 70% moisture corn silage.

3. 9 bu. of 15% moisture ground shelled corn will replace 1 Ton of 70% moisture corn silage.

4. 1-1/2 Tons of 75% moisture alfalfa silage will replace 1 Ton of 70% moisture corn silage.

5. 1 Ton of 10% moisture alfalfa hay will replace 2-1/2 Tons of 70% moisture corn silage.

6. 1 lb. of 44% protein supplement plus .4 lb. of shelled corn will replace both the protein and energy contained in 1.4 lbs. of 32% protein supplement.

7. 1 lb. of ground shelled corn replaces 1.1 lbs. of ground ear corn.