Balance of Ration Nutrients and Efficiency of Feed Utilization by Ruminants. A Review.[1]

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Research work in animal nutrition has resulted in a better understanding of a balance of nutrients for optimum utilization of feeds in animal production. This knowledge, transferred to farm practice, has resulted in both increased livestock production and conservation of feed supplies.

Livestock producers and research men have long recognized that the quantity and quality of ration required is determined by the type of animal being fed, use to which feed is being put, and extent of animal response or level of production desired.

Axelsson and Eriksson (1953) in a recent review of the maintenance requirements of domestic animals point out that pregnant animals use only about 5 percent of the metabolizable energy of their ration for development of the fetus—95 percent being used for maintenance. During growth, about 66 percent of the ration is used for maintenance; while dairy cows producing 30 lb. of 4 percent milk use about 50 percent of the feed for maintenance. With so large a portion of the feed used for maintenance, the efficiency of use of the total ration assumes great importance.

Ritzman and Colovos (1943) characterized adult animals according to their use of excess food energy above maintenance, into three physiological types namely; (1) expenders, (2) conservers, and (3) secretors. The expenders are best represented by the horse at work and need not be considered here. The energy conservers are illustrated by good representatives of the meat breeds and are characterized by low basal metabolism rates. The secretors are best represented by high producing dairy cows characterized by high basal metabolism rates. The young of all three types are comparatively heavy spenders of energy and therefore correspondingly great consumers of energy. The data of Ritzman and Colovos are shown in Table 1 calculated to the basis of 500 kilograms empty weight.

A review of current research in animal feeding and nutrition, of interest to the technician and the practical feeder. Concepts are developed of the nature of a balanced ration and its relationship to efficient utilization of feed by ruminants.

Interest in the possibility of increasing the efficiency of energy conversion by genetic means recently received stimulation from the findings of Baird *et al.* (1952) that larger amounts of growth hormone (anterior pituitarius) apparently accounted for the more rapid rate of growth in swine. Animals selected for rapid gain required 2.76 lb. of feed per pound of gain while those selected for slow gain required 3.64 lb. feed.

Various committees of the National Research Council have prepared tables of recommended nutrient allowances for the various classes of domestic animals. Ellenberger *et al.* (1953) and Lofgreen *et al.* (1951) have shown these nutrient allowances to provide good animal response. The data for various classes of animals have been summarized in Table 2 as examples of near balanced rations for ruminants in the light of present knowledge. The data in Table 2 support the observations of Axelsson and Eriksson (1953) and Ritzman and Colovos (1943) and show a high degree of similarity for animals of the three types. Of interest are the high energy, protein and mineral requirements of the calf, somewhat higher feed requirement of sheep and the greater mineral requirement of cattle.

In this review only the interrelations of protein, energy and minerals in ration balance will be considered. Much useful information relative to ration balance has been obtained in recent years from work with "artificial rumens", but this review will be limited to findings from actual feeding trials. Data for sheep, dairy and beef cattle will be used interchangeably due to the similarity in their nutrient requirements.

Suitability of the individual components is the primary consideration in preparing a balanced ration. It is possible that a ration could be formulated which contained all nutrients in proper ratio and still be of no value for animal production. Some feeds contain toxic substances, some cause digestive disturbances and others possess nutrients which are unavailable due to their chemical makeup.

Many such feeds are known to the industry. The feeding of corn cobs and high protein supplements to dairy cows may result in good milk production and normal weight but the milk may be off-flavor and thus useless. A balanced ration for steers or lambs could be formulated using wheat and a protein supplement but the animals receiving the ration might have digestive disturbances from the heavy wheat feeding. Cottonseed meal could be used to

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Table 1. The use of energy by animals for growth, fattening and production (*from Ritzman and Colovos, 1943*)

	Body Deposit	Conservation	Expenditure—Basal Metabolism	Ratio of Expenditure to Conservation
	kg.	*cal.*	*cal.*	
Calf growth (1st. mo.).....	7.33	9,700	25,000	2.51 to 1
Cow fattening (adult).....	.72	6,270	9,810	1.57 to 1
Cow lactating (1st. mo.)...	(37 lbs. milk)	13,300	10,650	0.82 to 1
Cow lactating (6th. mo.)...	(28 lbs. milk)	7,500	9,600	1.28 to 1

provide a balanced ration for swine but the feed would result in a high mortality rate due to the substance gossypol which is frequently toxic to hogs. Thus the feeder must possess a knowledge of the extent to which a feed can be used, the suitability of the ingredient for the purpose for which it is to be fed and related problems encountered in the use of the feeds available for use.

Means of Effecting a Balanced Ration

A balanced ration is most frequently obtained from a combination of feeds, containing varying proportions of nutrients, to secure the level of each nutrient desired. Less frequently used methods include attempts to change the supply of nutrients available for metabolism by increasing the digestibility of certain ration components by use of special supplements. An example of the latter is the use of high protein and mineral supplements with such feeds as corn cobs. The supplement apparently increases the activity of rumen micro-organisms and results in the breakdown and use of the cellulose of the corn cob.

In recent years, much interest has been centered on the use of antibiotics to increase feed consumption and utilization. In general, their use in rations for ruminants has not been as advantageous as for animals such as swine and poultry.

Nutrient Interrelationships and Digestibility

Although Crampton and Jackson (1944), Baker *et al.* (1951), McCullough *et al.* (1953) and others have shown that the value of a ration cannot be accurately forecast on the basis of its digestibility alone, the ultimate value of a balanced ration is greatly influenced by the extent to which its various nutrients are digested. The factors affecting the digestibility of various ration components have been studied by several workers.

Swift *et al.* (1947) fed a basal ration of mixed hay, corn meal and linseed meal to sheep and added sources of crude fiber, ether extract, protein and carbohydrates to study their effect on digestibility. The addition of crude fiber (oat straw) reduced the amount of protein and ether extract digested, while the addition of carbohydrates (starch) reduced the digestibility of crude fiber and protein. Addition of protein (casein) increased protein, ether extract and energy digestibility and decreased crude fiber and nitrogen-free-extract digestibility.

Forbes *et al.* (1943) demonstrated the associative effects of certain combinations of feeds. Corn fed with alfalfa hay had a T.D.N. value 23.8 percent higher than when fed with an equal quantity of timothy hay. Corn was as efficiently digested in combination with one-third as much as with equal quantities of alfalfa. When added to alfalfa hay corn was more efficiently digested than when added to a basal ration of alfalfa hay, corn meal and linseed oil meal.

Titus (1926) fed alfalfa hay and a form of highly digestible cellulose in varying ratios to steers. The substitution of cellulose for hay resulted in a progressive decrease of crude protein in the ration from 13 to 5 percent and a decrease in protein digestibility from 71 to 42 percent. The substitution of a highly digestible carbohydrate increased dry matter digestibility of the ration from 60 to 69 percent.

Mitchell *et al.* (1940) fed timothy hay, corn and cottonseed meal to beef calves at various ratios to give protein levels of 7.5, 9.9, 15.6 and 22.4 percent. An increase in protein decreased crude fiber digestibility from 52 to 36 percent. The addition of glucose as 28 percent of the basal calories further reduced crude fiber digestibility about 10 percentage points in each ration. Hamilton (1942) fed 150–200 grams of glucose per sheep per day and also found a decrease in nitrogen and crude fiber digestibility.

The feeder is interested, of course, in taking advantage of changes in feeding value to increase the utilization of his feed. An example of such practice is the feeding of cottonseed meal with low quality hay. The cottonseed meal not only increases the digestibility of all ingredients but also adds needed protein and sometimes phosphorus.

Table 2. Comparative Nutritive Requirements*

Use of Ration	Type of Animal	Weight	Allowance per Day (1000 lbs live weight)				
			Total Feed	Dig. Prot.	TDN	Calcium	Phos.
		lbs.	*lbs.*	*lbs.*	*lbs.*	*gms.*	*gms.*
Normal growth	Dairy calf	100	20	4.00	20	80	60
	Dairy heifer	400	28	2.00	16	50	38
	Beef heifer or steer	400	30	2.25	17	50	38
	Lambs and yearlings	100	40	2.40	24	40	34
Production or fattening	Dairy cow (40 lb. milk)	1000	30	2.40	21	50	38
	Fattening yearlings (2.2 lb. daily gain)	600	30	2.16	20	34	29
	Fattening lambs (.25 lb. daily gain)	90	33	2.23	22	30	26

* From recommendations by National Research Council.

In recent years many experiments have shown the value of other feeds in increasing the utilization of low quality roughage. Work by Klosterman *et al.* (1953) has shown the value of adding small amounts of molasses, dehydrated alfalfa meal or good quality hay to rations composed largely of low quality feed.

At the same time it must be remembered that the value of a ration may also be impaired by feeding products which lower digestibility. While molasses fed in small amounts may increase feed utilization, the feeding of large amounts on good quality rations may lower digestibility and feed use. Brannon *et al.* (1954) showed that, by feeding 5 pounds of molasses per day to steers grazing good pasture, the digestibility of the ration and rate of gain were lower than when a similar quantity of corn was fed. Similar results were obtained by Myer *et al.* (1953) in California feeding trials with harvested green alfalfa. Properly balanced rations in suitable amounts at the proper time are essential in securing optimum utilization of feed.

Interrelationships in Nutrient Balance

For continuing growth and/or production, an animal must not make prolonged use of body stores of nutrients to satisfy its day-to-day requirements. Except for short periods during high milk production, best animal performance is ordinarily obtained when animals are in positive balance for all nutrients. Thus, the nutrient balance is a frequently used measure of the ability of a ration to supply adequate quantities of nutrients.

Moir and Williams (1950) fed rations of equal dry matter, crude fiber and gross energy content but varied the protein from 3.7 to 18 percent. The rations were fed to sheep. The animals had a negative nitrogen balance of 23.48 grams per day on the 3.7 percent protein ration due to an inadequate protein intake. At 14 percent protein, their nitrogen balance was a positive 13.3 grams per day but, at 18 percent protein, the animals exhibited a negative nitrogen balance of 1.6 grams per day apparently due to an inadequate supply of energy in the ration.

Lofgreen, *et al.* (1951), working with growing Holstein heifers, found that the addition of energy to low protein rations increased nitrogen retention but similar additions of energy to high protein rations were without effect.

In the studies of Titus (1926) the reduction in protein in an alfalfa-hay ration by the addition of cellulose increased the retention of nitrogen from 10.6 grams per day in animals fed on a 13 percent crude protein ration to 75.1 grams on a 7 percent ration. Further changes in protein percentage decreased the nitrogen retention.

These examples, while confined to protein alone, illustrate the relationships which exist in all balanced rations. Apparently, the law of "the limiting factor" operates in animal nutrition as in plant nutrition. For each nutrient there is a level too low for the animal's needs, an optimum level and a level which prevents other nutrients from being present in sufficient quantities or interferes with their utilization.

Interrelationships in Nutrient Utilization

The efficiency with which animals utilize feed for growth and production is determined by the quantity of intake and the balance of the nutrients supplied. Genetic aspects of efficiency of nutrient utilization should also be recognized.

Maximum feed utilization may not be obtained when maximum growth or production is the desired result. Within the limits of growth and production normally required in animal production, maximum feed utilization will usually result in maximum animal response when balanced rations are fed.

Titus (1926) found that increasing increments of cellulose, added to a ration of alfalfa hay for beef steers, resulted in increased dry matter digestibility, decreased protein percentage and decreased feed required per pound of gain.

The effects of phosphorus on feed utilization have been studied by many investigators. Kleiber, *et al.* (1936) fed two beef heifers rations containing .13 percent phosphorus and reported that the ration arrested growth, decreased the efficiency of energy utilization, interfered with protein use and decreased appetite. Eckles and Gullickson (1927) fed low phosphorus rations to dairy cows and found that 20 percent more digestible nutrients were required for the same level of animal response when phosphorus was the limiting nutrient.

Due to the vast importance of phosphorus in intermediary metabolism and the low availability of the element from the body stores during periods of deficiency, most workers agree that the most prevalent mineral deficiency in ruminants is phosphorus.

Efforts to study calcium deficiency in ruminants and its effect on feed utilization have not been too successful. Calcium deficiencies can be created only with considerable effort since the animal draws on its body stores during periods of deficiency and replacements occur when supplies are adequate.

Becker *et al.* (1934) fed dairy cows throughout entire lactation periods on rations supplying excess protein, energy and phosphorus but deficient in calcium. The addition of 2 percent bonemeal to the grain ration raised average milk production from 4,000 lbs. on the calcium-deficient ration to 6,425 lbs. on the ration with bonemeal.

Huffman *et al.* (1952) replaced 15 lbs. of the hay in a ration for dairy cows with 6 lbs. of corn and 9 lbs. of peanut hulls and obtained an average increase in FCM production. Cows on hay alone declined in production. In another experiment, Huffman and Duncan (1952) replaced part of the hay with grain and either wheat straw, oakwood meal or peanut hulls with the same effect. The workers interpreted their results as indicating that grain contained unidentified lactation factors(s) needed to improve the balance of roughages.

Saarinen *et al.* (1951) reviewed the experiments of Huffman and others and decided that the results obtained were not due to unidentified factors but to an increase in net energy. The results obtained by these workers are not too convincing when compared to those of Huffman but of greater importance is the fact that changing the ingredients in the ration improved milk production.

Many practical illustrations of the importance of nutrient interrelationships have appeared in research literature. At the Utah station, Whitcomb *et al.* (1951) fed various supplements to sheep on winter range. Previous work had shown the range forage to be low in energy, protein and phosphorus. Their work illustrated the necessity of both correcting all deficiencies and also feeding supplemental feeds at the optimum level. The feeding of soybean oil meal failed to increase percentage lamb crop while the feeding of soybean oil meal and monosodium phosphate together increased the percent lamb crop from 90 to 120 percent. A similar increase resulted when barley and soybean oil meal was fed.

It should be realized that in practical livestock feeding the addition of a feed to the ration may have effects other than the mere addition of extra nutrients. When poor quality hay is fed, animals frequently do not receive enough protein and TDN. Adding a high protein feed to the ration frequently results in an increase in hay consumption. Thus the animal not only receives supplemental protein but may consume enough extra hay to balance its ration for TDN.

Miscellaneous Factors

The effect of the plane of nutrition has been studied by several workers. The results obtained by Mitchell *et al.* (1932) are representative of the overall effect of feeding level. The essential details of their experiments are presented in Table 3. Increasing levels of intake from one-fifth full feed to full feed resulted in the lowering of both dry-matter digestibility and the percentage of metabolizable energy but increased body storage of nutrients as shown by the nitrogen balance.

Cox (1948) conducted seven experiments in which three lots of lambs in each experiment were fed rations consisting of concentrate to roughage ratios of 35:65, 45:55, and 55:45. It was concluded that an optimum physical balance in rations for lambs actually exists. Further, as bulky rations are increased in concentration, the gains made and the efficiency of feed utilization increase up to a certain level and then diminish with increasing concentration. Bailey (1952) has demonstrated a similar factor for dairy cattle.

Commercial dairymen and feeders have long suspected that certain feeds, particularly forages, contained certain factors which stimulated animal production. Evidence is gradually accumulating that such factors exist and are of great importance. Cheng *et al.* (1953) have recently extracted substances from clover and alfalfa hays which exhibit estrogenic activity. Estrogenic activity in the hay fed to lambs was regarded as circumstantial evidence that the level found contributed to the excellent gains made by the lambs.

McCullough (1953, 1954) has recently presented data on fescue vs. temporary winter pasture which strongly suggest the presence of such factors in the temporary forage.

Practical Considerations in Ration Balancing

The feeding of farm animals involves the use of feeds containing several nutrients rather than the more scientific approach of using single nutrients. With the exception of certain mineral deficient areas, the nutrient deficiencies are usually found to involve only protein and TDN. On a practical basis, therefore, attempts to balance rations usually involve only the decision of the relative quantities of the feeds to be fed. A knowledge of the problems encountered in the use of feeds available in a given area is indispensable to the formulation of good feeding practices.

Frequently the feeder has available large quantities of certain feeds and is more interested in using the feed available to best advantage than in feeding a ration that will give maximum returns. In such cases, emphasis should be placed on the purchase of feeds needed to insure livestock health and performance. The long history of the use of cottonseed cake on range is an outstanding example of a practical feeding program. Animal performance and feed utilization could be greatly improved by other feeding programs, but the range forage would be overlooked and a valuable part of the livestock program lost.

Mention should also be made of the pressure frequently exerted upon the feeder to use tonics, complex mineral mixtures and other "ration-improvers" which have no value in a good feeding program. Such products are seldom of any value

Table 3. Effects of Level of Feeding (*from Mitchell* et al., *1932*)

Level of Feeding	Dry Matter Digestibility	Nitrogen Balance	Metabolizable Energy
	percent	*gms.*	*percent*
Full	73.7	+43.71	60.61
4/5 full	74.4	+36.61	61.22
3/5 full	77.2	+7.73	64.13
2/5 full	80.9	+8.61	66.45
1/5 full	83.9	−5.59	70.14

and frequently do great harm since the feeder depends upon them when the actual need is for more feed or feed of a high quality.

Summary

In our present understanding of nutrition, the concept of a balanced ration has several implications:

1. Other things being equal, a ration is best balanced when it supplies all the nutrients required by the animal in the ratio in which they are required.
2. Properly balanced rations permit the best use by the animal of each nutrient for its specific body function and result in maximum efficiency of nutrient utilization.
3. In addition to balance between nutrients, evidence is accumulating that level of intake, relative concentration of dry matter, stimulating factors and other "non-nutrient" factors contribute to efficiency of utilization of feed by livestock.

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