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U. S. DEPARTMENT OF AGRICULTURE.

OFFICE OF EXPERIMENT STATIONS—BULLETIN NO. 125.

A. C. TRUE, Director.

A DIGEST

OF

RECENT EXPERIMENTS ON HORSE FEEDING.

BY

C. F. LANGWORTHY, Ph. D.,

OFFICE OF EXPERIMENT STATIONS.

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U. S. Department of Agriculture

WASHINGTON:
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THE
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OF
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EXPERIMENT STATIONS

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
OFFICE OF EXPERIMENT STATIONS,
Washington, D. C., January 29, 1903.

SIR: I have the honor to transmit herewith a bulletin prepared by C. F. Langworthy, Ph. D., of the Office of Experiment Stations, which summarizes and discusses the results of experiments on the feeding and care of horses, and especially the investigations of recent years. The attempt has been made to include all the work which has been carried on at the experiment stations in the United States as well as some of the more important foreign investigations. Statistics were also gathered regarding the rations fed horses used by express companies, cab companies, fire departments, packing houses, breweries, etc., in different regions of the United States, with a view to learning the nutrients supplied to horses performing different amounts of work. The data have been compared with similar values for horses fed at a number of the experiment stations under more or less definitely known conditions. The rations fed army horses in this and other countries, the horses of French and other cab companies, etc., have also been included for purposes of comparison.

Thanks are due to Director W. A. Henry of the Wisconsin Station, Director H. J. Patterson of the Maryland Station, and Mr. G. M. Rommel of the Bureau of Animal Industry of this Department, for valuable suggestions, and to Mr. H. A. Pratt of the Department of the Interior, for assistance in making the calculations involved in preparing the material.

Believing that the bulletin will prove a useful summary of the information at present available regarding the feeding of horses, I recommend that it be published as Bulletin No. 125 of this Office.

Respectfully,

A. C. TRUE,
Director.

Hon. JAMES WILSON,
Secretary of Agriculture.

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RECENT EXPERIMENTS IN HORSE FEEDING.

INTRODUCTION.

The scientific study of different problems connected with the feeding of farm animals has been followed for something over half a century. Some of the very early work was with horses, but more generally it was carried on with other domestic animals. Within the last few years this phase of the problem has received much more attention, and feeding tests, digestion experiments, and more complicated investigations have accumulated in considerable numbers. The bulk of this work has been carried on in France and Germany; a creditable amount, however, has been done in this country, notably by the agricultural experiment stations, and the results of these experiments and observations have been published from time to time, and are very useful. Mention must be made also of the work of practical feeders, which is of great value.

In the present bulletin the attempt is made to bring together some of the more important results and deductions which may be gathered from the American and foreign experimental work, especially that of recent years. It is not the purpose to provide practical feeders with directions for feeding according to a particular formula; indeed this is not necessary, if it were possible, for practical feeders understand the needs of their horses and how to meet them. The object is rather to summarize matter which seems interesting and valuable, and which in many cases may give the reason for something of which the wisdom has long been recognized in practice.

In addition to the bulletins, reports, and other works cited in the following pages, a large number of scientific and popular journals, treatises on horse feeding, and similar publications have been consulted, as well as reports issued by American and foreign experiment stations.

That a scientific study of the feeding of horses may not be without direct practical value is shown by the work of Grandeau, Leclerc, Lavallard, and others for the Paris Cab and 'Bus companies. By means of experimental studies of the food value and digestibility of different feeding stuffs, carried on under definite conditions, it was possible to so modify the ration fed to the thousands of horses belonging to one of these companies that an annual saving of 1,000,000 francs or over was effected, while at the same time the health and strength of the

horses were maintained at the usual standard. This was accomplished in the instance cited by demonstrating the value of Indian corn, against which there was a prejudice in France, and substituting it in part for oats.

The returns from scientific studies are not always so immediate, but the results are usually of use when the experiments have been well planned and carried out.

The problem of horse feeding is one which each feeder solves more or less for himself, the opinion regarding what is and what is not satisfactory feed varying more or less with the time and place. Opinions may differ as to the value of this food or that, but it is evident that the actual food requirements of a horse performing a given amount of work can not vary as a result of a change of opinion on the feeder's part. With horses, as with all animals, including man, the real problem is to supply sufficient nutritive material for building and repairing the body and furnishing it with the energy necessary for performing work, whether it be that which goes on inside the body (the beating of the heart, respiratory movements, etc.), or the work which is performed outside the body (hauling a load, etc.). The body temperature must also be maintained at the expense of the fuel ingredients, but whether material is burned in the body primarily for this purpose, or whether the necessary heat is a resultant of the internal muscular work, is not known with certainty.

The problem of successfully feeding horses differs somewhat from that encountered in feeding most domestic animals. Cattle, sheep, and pigs are fed to induce gains in weight, i. e., to fatten them, or in the case of milch cows to produce gains in the form of a body secretion (milk) rather than as fat in the body. In a similar way sheep are fed for the production of wool, and poultry for the production of eggs. Sometimes cattle are also fed as beasts of burden. Horses are fed almost universally as beasts of burden, whether the work consists in carrying a rider or drawing a load.

Mares with foal require food for the development of their young, and after birth the colt needs it for the growth and development of the body as well as for maintenance. Such demands for nutritive material are common to all classes of animals. Sometimes horses are fed to increase their weight; that is, to improve their condition. For instance, animals are often fattened by horse dealers before they are sold. However, generally speaking, the problem in horse feeding is to supply sufficient nutritive material for the production of the work required and at the same time to maintain the body weight. The almost universal experience of practical horse feeders, and the results of many carefully planned experiments, agree that there is no surer test of the fitness of any given ration than that it enables the horse fed to maintain a constant weight. If the animal loses weight it

is evident that the ration is insufficient, while if gains in weight are made and the animal becomes fat it is evident that more feed is given than is necessary. Provided the horse is in good condition, it is seldom desirable to induce any considerable gain in weight. Reference is not made to the small daily fluctuations in weight, but to gains or losses which extend over a considerable period. The most satisfactory ration must necessarily be made up of materials which are wholesome and are relished by the horse. It should also be reasonable in cost. It must be abundant enough to meet all body requirements, but not so abundant that the horse lays on an undesirable amount of flesh.

PRINCIPLES OF NUTRITION.

The foundation principles of nutrition are the same in the case of all animals, including man. A brief discussion of the properties of food and the general laws of nutrition follows.

The study of foods and feeding stuffs has shown that although they differ so much in texture and appearance they are in reality made up of a small number of chemical constituents, namely, protein, fat, carbohydrates, and ash, together with a larger or smaller amount of water. The latter can be often seen, as in the juice of fresh plants. In dry hay no water or juice is visible. A small amount is, however, contained in minute particles in the plant tissues.

Protein is a name given to the total group of nitrogenous materials present. The group is made up mainly of the true proteids and albumens, such as the gluten of wheat, and of nitrogenous materials such as amids, which are believed to have a lower feeding value than the albumens.

The group "fat" includes the true vegetable fats and oils, like the oil in cotton seed or corn, as well as vegetable wax, some chlorophyl (the green coloring matter in leaves, etc.), and other coloring matters; in brief, all the materials which are extracted by ether in the usual laboratory method of estimating fat. The name "ether extract" is often and very properly applied to this group. Chemically considered, the true fats are glycerids of the fatty acids, chiefly oleic, stearic, and palmitic.

The group "carbohydrates" includes starches, sugars, crude fiber, cellulose, pentosans, and other bodies of a similar chemical structure. This group is usually subdivided, according to the analytical methods followed in estimating it, into "nitrogen-free extract" and "crude fiber;" the former subdivision including principally sugar, starches, and most of the pentosans, and the latter cellulose, lignin, and other woody substances which very largely make up the rigid structure of plants.

The proteids contain nitrogen in addition to carbon, oxygen, hydrogen, and a little phosphorus and sulphur. The fats consist of carbon,

oxygen, and hydrogen, as do also carbohydrates. In the carbohydrates, however, the oxygen and hydrogen are always present in the proportions in which they occur in water, namely, two atoms of hydrogen to one of oxygen.

The group "mineral matter" includes the inorganic bodies present in the form of salts in the juices and tissue of the different feeding stuffs, the principal chemical elements found being sodium, potassium, calcium, chlorine, fluorine, phosphorus, and sulphur. The term "ash" is often and very properly used for this group, since the mineral matter represents the incombustible portion which remains when any given feeding stuff is burned.

As noted above, the functions of food are (1) to supply material to build and repair the body, and (2) to yield energy. The chemical composition of a feeding stuff serves as a basis for judging of its value for building and repairing body tissue. Its value as a source of energy must, however, be learned in another way. The most usual way of measuring energy is in terms of heat, the calorie being taken as a unit. This is the amount of heat which would raise the temperature of 1 kilogram of water 1° C., or 1 pound of water 1.8° F. Instead of this the unit of mechanical energy, the foot-ton (the force which would lift 1 ton 1 foot) may be used, but it is not as convenient. One calorie corresponds very nearly to 1.54 foot-tons. The heat of combustion of foods and feeding stuffs is ordinarily determined with the bomb calorimeter or other suitable devices. The fuel value of any food is equal to its heat of combustion less the energy of the excretory products derived from it and may be learned by taking into account the chemical composition of the food or feeding stuff, the proportions of the nutrients actually digested and oxidized in the body, and the proportion of the whole latent energy of each which becomes active and useful to the body for warmth and work. However, the fuel value may be and often is calculated from the composition of the food material supplied, since it has been found that 1 gram of protein furnishes 4.1 calories, 1 gram fat 9.3 calories, and 1 gram carbohydrates 4.1 calories, or 1 pound protein 1,860 calories, 1 pound fat 4,220 calories, and 1 pound carbohydrates 1,860 calories.^a

The relation between the quantities of nitrogenous and nitrogen-free nutrients in the ration is called the nutritive or nutrient ratio. In calculating this ratio 1 pound of fat is taken as equivalent to 2.25 pounds of carbohydrates—this being approximately the ratio of their fuel

^a These values, which have been often used in the past, are known to be unsatisfactory, but are retained because better and more generally accepted data, obtained in experiments with animals, are not available.

In discussions relating to human food later and more accurate values have been proposed, namely, 1,820 calories per pound for protein and carbohydrates and 4,040 calories per pound for fats.

values—so that the nutritive ratio is actually that of the protein to the carbohydrates plus 2.25 times the fat.

The body is necessarily made up of the same chemical elements as occur in food. Nitrogen is the characteristic element of body tissue and fluids. Carbon, oxygen, and hydrogen are also present, as well as the elements making up the various mineral matters of the body. Protein is the only nutrient which contains nitrogen, therefore this nutrient is essential for building and repairing body tissues. The carbon, oxygen, and hydrogen may be supplied theoretically by protein, fat, or carbohydrates; but a well-balanced diet or ration contains all in proper proportion. Protein, fat, and carbohydrates may be burned with the formation of carbon dioxid and water, and therefore all may serve as sources of energy.

The mineral matter in food is required for a number of different purposes, a considerable amount being needed for the formation of the skeleton. Some is also present in the organs and tissues. It can not, however, be regarded as a source of energy, according to commonly accepted theories, since it can not be burned with the formation of carbon dioxid and water. The water present in food is not a nutrient in the sense that it serves for building tissue or yielding energy, but it is essential, serving to carry the food in the digestive processes, to dilute the blood, and for many other physiological purposes. The oxygen of the air is required by all living animals for the combustion, or oxidation, of the fuel constituents of food.

When foods are burned in the body, i. e., oxidized, they give up the latent energy present in them. In determining the fuel value of protein, due allowance is made for the fact that combustion is not as complete in the body as in a furnace. In the latter, practically all organic materials are burned to carbon dioxid, water, and nitrogen; in the body, to carbon dioxid, water, and some cleavage product containing nitrogen, such as urea, uric acid, hippuric acid, and similar bodies which require further combustion before the free nitrogen is liberated. Combustion in a furnace and combustion in the body do not appear to be at all similar, but, generally speaking, they are the same from a chemical standpoint. The former takes place rapidly with the evolution of heat, and usually of light; the latter, more slowly and inconspicuously. If food is likened to fuel and the body to a furnace, the respiratory products given off from the lungs correspond to the combustion products which pass out through the flue. Ashes, in so far as they consist of material which will not burn (sand, bits of rock, etc.), and bits of coal which do not burn because they fall through the grate, or for some similar reason escape combustion, represent the feces (the indigestible and accidentally undigested material derived from the food). The bits of coal found in the ashes which are partially burned, but still contain some material valuable as fuel, correspond to the urea

and other incompletely oxidized nitrogenous bodies excreted in the urine. There is this difference, however, the furnace would have completed the combustion of the partly burned bits of coal if they had not been shaken out with the ashes, while the body can not burn the urea more completely. The body differs from a machine in a number of important ways; for instance, it is itself built up of the same materials which it utilizes as fuel, and further, if an excess of fuel, i. e., food, is supplied, it may be stored as a reserve material for future use, generally in the form of fat or glycogen.

The amount of work performed by a horse, for convenience in measurement, may be resolved into several factors, as follows: (1) The energy expended in chewing, swallowing, and digesting food, keeping up the beating of the heart, circulation of the blood, respiratory movements, and other vital processes;^a (2) the energy which is expended in moving the body, walking, trotting, etc., which is usually spoken of as energy required for forward progression; and (3) the energy which is expended in carrying a rider, as in the case of a saddle horse, or drawing a load, as in the case of a draft animal or carriage horse.

The character of the road, whether level or up or down hill, is an important factor in determining the amount of work. It is evident that more energy is required to lift the body at each step and move it forward when climbing an incline than when walking on a level. In the same way, when a load is drawn uphill it must be raised as well as drawn forward.

Work may be measured as foot-pounds or foot-tons, or by any other convenient unit. A foot-pound is the amount of energy expended in raising 1 pound 1 foot; a foot-ton, that expended in raising 1 ton 1 foot; a commonly used unit of force is the "ton power," equivalent to 550 foot-pounds per second. Work may also be measured in terms of heat, i. e., calories. This is especially convenient in discussing problems of nutrition, since the heat of combustion is one of the factors usually determined or calculated when foods are analyzed; and furthermore, the feeding standards which have been proposed for horses and other farm animals show the requirements per day in terms of nutrients and energy. One calorie corresponds, as stated above, very nearly to 1.54 foot-tons.

COMPOSITION OF FEEDING STUFFS.

The feeding stuffs of most importance for horses are cereal grains, such as oats and corn, either ground or unground; leguminous seeds, as beans and peas; cakes, and other commercial by-products, as oil-

^aThe heat of the body is closely connected with this kind of work, and may be derived either from the combustion of material directly for that purpose, or may be the result of the energy liberated when internal muscular work is performed, or may be due to both causes acting together.

cake, gluten feed, and so on; fodder crops, green or cured; and different roots, tubers, and green vegetables. In quite recent times cane molasses, beet molasses, and other beet-sugar by-products, have assumed more or less importance in this connection. The composition of a number of these different feeding stuffs may be seen by reference to the table below, which shows the average composition as determined by analysis, and when possible the digestible nutrients furnished for horses by each 100 pounds of the feeding stuffs, the latter data having been calculated, as explained elsewhere (p. 40), by the aid of figures obtained in digestion experiments with horses. In a number of cases such calculations have not been made, for the reason that experiments showing the digestibility of feeding stuffs had not been found, nor were results of experiments made with similar feeding stuffs available. The comparatively large number of feeding stuffs of which the digestibility has not been determined indicates one of the lines of work which might be profitably followed.

TABLE 1.—Average composition of a number of feeding stuffs.

Kind of food material.	Percentage composition.						Digestible materials in 100 pounds.				Energy in 100 lbs. digestible nutrients.
	Water.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Ash.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
GREEN FODDER.	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Calories.</i>
Corn fodder	79.3	1.8	0.5	12.2	5.0	1.2	.....	.....	.....	.....	.....
Corn leaves and husks	66.2	2.1	1.1	19.0	8.7	2.9	.....	.....	.....	.....	.....
Cornstalks stripped	76.1	.5	.5	14.9	7.3	.7	.....	.....	.....	.....	.....
Kafir corn	73.0	2.3	.7	15.1	6.9	2.0	.....	.....	.....	.....	.....
Rye fodder	76.6	2.6	.6	6.8	11.6	1.8	.....	.....	.....	.....	.....
Oat fodder	62.2	3.4	1.4	19.3	11.2	2.5	.....	.....	.....	.....	.....
Wheat fodder	77.3	2.3	.7	12.0	5.9	1.8	.....	.....	.....	.....	.....
Redtop in bloom	65.3	2.8	.9	17.7	11.0	2.3	.....	.....	.....	.....	.....
Tall oat grass in bloom	69.5	2.4	.9	15.8	9.4	2.0	.....	.....	.....	.....	.....
Orchard grass in bloom	73.0	2.6	.9	13.3	8.2	2.0	.....	.....	.....	.....	.....
Meadow fescue in bloom	69.9	2.4	.8	14.3	10.8	1.8	.....	.....	.....	.....	.....
Italian rye grass coming into bloom	73.2	3.1	1.3	13.1	6.8	2.5	.....	.....	.....	.....	.....
Timothy at different stages	61.6	3.1	1.2	20.2	11.8	2.1	.....	.....	.....	.....	.....
Kentucky blue grass at different stages	65.1	4.1	1.3	17.6	9.1	2.8	.....	.....	.....	.....	.....
Hungarian grass	71.1	3.1	.7	14.2	9.2	1.7	.....	.....	.....	.....	.....
Red clover at different stages	70.8	4.4	1.1	13.5	8.1	2.1	3.44	.....	10.94	3.79	33,796
Alsike clover in bloom ^a	74.8	3.9	.9	11.0	7.4	2.0	3.05	.....	8.91	3.46	28,681
Crimson clover ^a	80.9	3.1	.7	8.4	5.2	1.7	2.42	.....	6.80	2.43	21,669
Alfalfa at different stages	71.8	4.8	1.0	12.3	7.4	2.7	3.75	.....	9.96	3.46	31,936
Cowpea	83.6	2.4	.4	7.1	4.8	1.7	.....	.....	.....	.....	.....
Soy bean	75.1	4.0	1.0	10.6	6.7	2.6	.....	.....	.....	.....	.....
SILAGE.											
Corn silage	74.4	2.2	1.1	15.0	5.8	1.5	.....	.....	.....	.....	.....
Sorghum silage	76.1	.8	.3	15.3	6.4	1.1	.....	.....	.....	.....	.....
Red-clover silage	72.0	4.2	1.2	11.6	8.4	2.6	.....	.....	.....	.....	.....
Soy-bean silage	74.2	4.1	2.2	7.0	9.7	2.8	.....	.....	.....	.....	.....
Cowpea-vine silage	79.3	2.7	1.5	7.6	6.0	2.9	.....	.....	.....	.....	.....

^a Digestibility calculated from values obtained with green alfalfa.

TABLE 1.—Average composition of a number of feeding stuffs—Continued.

Kind of food material.	Percentage composition.						Digestible materials in 100 pounds.				Energy in 100 lbs. digestible nutrients.
	Water.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Ash.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
HAY AND DRY COARSE FODDER.	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Calories.</i>
Corn fodder, field cured	42.2	4.5	1.6	34.7	14.3	2.7	.....	.....	.....	.....	.....
Cornleaves, field cured	30.0	6.0	1.4	35.7	21.4	5.5	.....	.....	.....	.....	.....
Cornhusks, field cured	50.9	2.5	.7	28.3	15.8	1.8	.....	.....	.....	.....	.....
Cornstalks, field cured	68.4	1.9	.5	17.0	11.0	1.2	.....	.....	.....	.....	.....
Cornstover, field cured	40.5	3.8	1.1	31.5	19.7	3.4	.....	.....	.....	.....	.....
Kafir-cornstover, field cured	19.2	4.8	1.6	39.6	26.8	8.0	.....	.....	.....	.....	.....
Barley hay	10.6	9.3	2.5	48.7	23.6	5.3	.....	.....	.....	.....	.....
Oat hay	16.0	7.4	2.7	40.6	27.2	6.1	.....	.....	.....	.....	.....
Wheat hay	8.8	6.0	1.8	55.3	22.5	5.6	.....	.....	.....	.....	.....
Redtop cut at different stages ^a	8.9	7.9	1.9	47.5	28.6	5.2	4.51	0.39	26.98	11.35	81,234
Redtop cut in bloom ^a	8.7	8.0	2.1	46.4	29.9	4.9	4.57	.43	26.31	11.87	81,330
Orchard grass ^a	9.9	8.1	2.6	41.0	32.4	6.0	4.62	.54	23.25	12.86	78,036
Timothy	13.2	5.9	2.5	45.0	29.0	4.4	1.25	1.18	21.29	12.35	69,873
Kentucky bluegrass ^a	21.2	7.8	3.9	37.8	23.0	6.3	4.45	.81	21.43	9.13	68,536
Hungarian grass ^a	7.7	7.5	2.1	49.0	27.7	6.0	4.28	.43	27.78	11.00	81,905
Meadow fescue ^a	20.0	7.0	2.7	38.4	25.0	6.9	4.00	.56	21.77	10.28	69,415
Italian rye grass ^a	8.5	7.5	1.7	44.9	30.5	6.9	4.28	.35	25.51	12.11	79,410
Mixed grasses ^a	15.3	7.4	2.5	42.1	27.2	5.5	4.23	.52	23.87	10.80	74,554
Rowen (mixed) ^a	16.6	11.6	3.1	39.4	22.5	6.8	6.62	.64	22.34	8.93	73,175
Mixed grasses and clovers ^a	12.9	10.1	2.6	41.3	27.6	5.5	5.77	.54	23.42	10.96	76,957
Swamp hay ^a	11.6	7.2	2.0	45.9	26.6	6.7	4.11	.41	26.02	10.56	77,413
Salt-marsh hay	10.4	5.5	2.4	44.0	30.0	7.7	.....	.....	.....	.....	.....
Red clover	15.3	12.3	3.3	38.1	24.8	6.2	6.85	.95	24.19	9.27	78,984
Red clover in bloom ^b	20.8	12.4	4.5	33.8	21.9	6.6	6.91	1.29	21.46	8.19	73,450
Alsike clover ^b	9.7	12.8	2.9	40.7	25.6	8.3	7.13	.83	25.84	9.57	82,630
White clover ^b	9.7	15.7	2.9	39.3	24.1	8.3	8.74	.83	24.96	9.01	82,942
Crimson clover ^b	9.6	15.2	2.8	36.6	27.2	8.6	8.47	.80	23.24	10.17	81,272
Alfalfa	8.4	14.3	2.2	42.7	25.0	7.4	10.67	.42	29.98	9.75	95,520
Cowpea	10.7	16.6	2.9	42.2	20.1	7.5	.....	.....	.....	.....	.....
Soy bean	11.3	15.4	5.2	38.6	22.3	7.2	.....	.....	.....	.....	.....
Flat pea	8.4	22.9	3.2	31.4	26.2	7.9	.....	.....	.....	.....	.....
Soy-bean straw	10.1	4.6	1.7	37.4	40.4	5.8	.....	.....	.....	.....	.....
Wheat straw	9.6	3.4	1.3	43.4	38.1	4.2	.94	.85	12.20	6.74	40,544
Rye straw ^c	7.1	3.0	1.2	46.6	38.9	3.2	.83	.79	13.10	6.89	42,020
Oat straw ^c	9.2	4.0	2.3	42.4	37.0	5.1	1.11	1.51	11.91	6.55	42,770
Buckwheat straw	9.9	5.2	1.3	35.1	43.0	5.5	.....	.....	.....	.....	.....
ROOTS AND TUBERS.											
Potatoes	78.9	2.1	.1	17.3	.6	1.0	1.85	.....	17.20	.05	35,525
Carrots	88.6	1.1	.4	7.6	1.3	1.0	1.09	.....	7.13	.....	15,290
GRAINS AND OTHER SEEDS.											
Corn, dent	10.6	10.3	5.0	70.4	2.2	1.5	5.95	2.39	62.09	.....	136,636
Corn, flint	11.3	10.5	5.0	70.1	1.7	1.4	6.07	2.39	61.83	.....	136,376
Corn, all varieties	10.9	10.5	5.4	69.6	2.1	1.5	6.07	2.58	61.39	.....	136,363
Kafir corn	12.5	10.9	2.9	70.5	1.9	1.3	.....	.....	.....	.....	.....
Chicken corn	14.8	10.6	2.6	58.8	8.7	4.5	.....	.....	.....	.....	.....
Barley	10.9	12.4	1.8	69.8	2.7	2.4	.....	.....	.....	.....	.....
Oats	11.0	11.8	5.0	59.7	9.5	3.0	9.39	3.60	45.25	2.82	122,062
Rye	11.6	10.6	1.7	72.5	1.7	1.9	8.51	.72	63.29	1.70	139,747
Wheat, all varieties	10.5	11.9	2.1	71.9	1.8	1.8	.....	.....	.....	.....	.....
Cotton seed, whole, with hulls	9.1	19.6	20.1	28.3	18.9	4.0	.....	.....	.....	.....	.....
Cowpea	11.9	23.5	1.7	55.7	3.8	3.4	.....	.....	.....	.....	.....
MILL PRODUCTS.											
Corn meal	15.0	9.2	3.8	68.9	1.9	1.4	6.99	2.55	64.70	.38	144,454
Oats, ground	11.7	11.0	3.9	52.3	18.0	3.1	9.06	3.12	45.03	2.59	118,727
Corn and cob meal	15.1	8.5	3.5	64.8	6.6	1.5	.....	.....	.....	.....	.....
Barley meal	11.9	10.5	2.2	66.3	6.5	2.6	.....	.....	.....	.....	.....

^a Digestibility calculated from values obtained with meadow hay.^b Digestibility calculated from values obtained with red clover hay.^c Digestibility calculated from values obtained with wheat straw.

TABLE 1.—Average composition of a number of feeding stuffs—Continued.

Kind of food material.	Percentage composition.						Digestible materials in 100 pounds.				Energy in 100 lbs. digestible nutrients.
	Water.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Ash.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
MILL PRODUCTS—CON.	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Calories.</i>
Rye flour.....	13.1	6.7	0.8	78.3	0.4	0.7	.....	.....	.....	.....	.....
Pea meal.....	10.5	20.2	1.2	51.1	14.4	2.6	.....	.....	.....	.....	.....
Ground corn and oats (equal parts).....	11.9	9.6	4.4	71.9	2.2	.....	.....	.....	.....	.....	.....
WASTE PRODUCTS.											
Corn cob.....	10.7	2.4	.5	54.9	30.1	1.4	.....	.....	.....	.....	.....
Hominy chop.....	11.1	9.8	8.3	64.5	3.8	2.5	.....	.....	.....	.....	.....
Corn bran.....	8.7	9.8	6.2	62.6	11.2	1.5	.....	.....	.....	.....	.....
Gluten meal.....	8.6	30.0	8.8	49.2	2.6	.8	.....	.....	.....	.....	.....
Gluten feed.....	7.8	23.4	8.3	53.2	6.2	1.1	.....	.....	.....	.....	.....
Oat feed.....	7.7	16.0	7.1	59.4	6.1	3.7	.....	.....	.....	.....	.....
Barley screenings.....	12.2	12.3	2.8	61.8	7.3	3.6	.....	.....	.....	.....	.....
Brewers' grains, wet.....	75.7	5.4	1.6	12.5	3.8	1.0	.....	.....	.....	.....	.....
Brewers' grains, dried.....	8.0	24.1	6.7	44.8	13.0	3.4	.....	.....	.....	.....	.....
Rye bran.....	11.8	14.7	2.8	63.9	3.3	3.5	.....	.....	.....	.....	.....
Wheat bran.....	11.9	15.4	4.0	53.9	9.0	5.8	.....	.....	.....	.....	.....
Wheat middlings.....	12.1	15.6	4.0	60.4	4.6	3.3	.....	.....	.....	.....	.....
Wheat shorts.....	11.8	14.9	4.5	56.8	7.4	4.6	.....	.....	.....	.....	.....
Wheat screenings.....	11.6	12.5	3.0	65.1	4.9	2.9	.....	.....	.....	.....	.....
Cotton-seed meal.....	8.2	42.3	13.1	23.6	5.6	7.2	.....	.....	.....	.....	.....
Cotton-seed hulls.....	11.1	4.2	2.2	33.4	46.3	2.8	.....	.....	.....	.....	.....
Linseed meal, old process.....	9.2	32.9	7.9	35.4	8.9	5.7	.....	.....	.....	.....	.....
Linseed meal, new process.....	9.9	35.9	3.0	36.8	8.8	5.6	.....	.....	.....	.....	.....
Beet-sugar molasses.....	25.7	<i>a</i> 7.3	.....	<i>b</i> 58.2	.....	8.8	7.3	.....	58.2	.....	121,830
Cane-sugar molasses.....	25.1	<i>a</i> 2.4	.....	<i>b</i> 69.3	.....	3.2	7.3 2.4	.....	69.3	.....	133,362

a Largely nonalbuminoid nitrogenous materials.*b* Very largely sugars.

COMPARATIVE VALUE OF FEEDING STUFFS.

CEREAL GRAINS.

It will be seen that the cereal grains resemble each other quite closely in composition, being characterized by fairly low water content and a considerable amount of protein and nitrogen-free extract. Some crude fiber, derived from the outer or bran layer of the corn, is also present. The superiority of one grain over another must therefore depend, in large measure, if it exists at all, on some factor other than composition. It has been urged by many that oats possess a peculiar stimulating body called "avenin," and are on this account superior to other grains for horses. Oats undoubtedly possess a flavor or some such characteristic which makes them a favorite food with horses, but the most careful chemical study has failed to reveal any substance of the nature of the theoretical avenin. Recent experiments^a have shown that the fat of oats and oat straw is more thoroughly digested than that of other cereals. This is suggested as a possible explanation of the superior feeding value of oats.

^a Landw. Jahrb., 29 (1900), p. 483.

It is believed by many that horses show more spirit when oats form part of the ration. Discussing this subject, Director W. A. Henry,^a of the Wisconsin Experiment Station, says:

Horses nurtured on oats show mettle which can not be reached by the use of any other feeding stuff. Then, too, there is no grain so safe for horse feeding, the animal rarely being seriously injured if by accident or otherwise the groom deals out an oversupply. This safety is due in no small measure to the presence of the oat hull, which causes a given weight of grain to possess considerable volume, because of which there is less liability of mistake in measuring out the ration; further, the digestive tract can not hold a quantity of oat grains sufficient to produce serious disorders. Unless the horse is hard pressed for time or has poor teeth oats should be fed in the whole condition. Musty oats should be avoided.

Horsemen generally agree that new oats should not be used, though Boussingault, conducting extensive experiments with army horses, arrived at the conclusion that new oats do not possess the injurious qualities attributed to them.

In the opinion of Lavalard:^b

Not only may single grains and other single foods be substituted for oats, but more or less complex mixtures may be used as well. We believe that both from a hygienic and an economic standpoint our experiments have settled this matter, which has provoked so much discussion. An examination of the statistics we have gathered in the last thirty-five years show that, although a great saving has been effected, it has not been at the expense of the productive power of the horses.

Boussingault, perhaps, first suggested on the basis of experiments that other materials may be substituted for oats in the ration of horses. He prepared a table of nutritive equivalents, using hay as a unit of comparison. This was not very satisfactory, since the composition of hay varies within wide limits.

The grain most commonly substituted for oats in this country is Indian corn or maize. It is so commonly used, especially in the South and West, that it is difficult to realize the prejudice which has existed against it in other countries. It has been asserted that there are climatic and other conditions which render corn a suitable horse feed in America which do not exist elsewhere. This hardly seems reasonable, and has not been borne out by the numerous experiments undertaken in France, Germany, and other countries. Such experiments have demonstrated the value of corn and shown the truth of the opinions generally held in this country, namely, that it is a safe and satisfactory feeding stuff for horses.

Barley, rye, and wheat are sometimes fed to horses. Their resemblance to oats will be seen by reference to the table. All these grains should be substituted on the basis of chemical composition, and not pound for pound. As would be expected, the ground grains differ little from the same varieties before grinding.

Bran, shorts, middlings, and other by-products vary in composition, but all have a low water content, while the crude fiber content is gen-

^a Feeds and Feeding, Madison, Wis., 1898.

^b Experiment Station Record, 12 (1900-1901), p. 4.

erally rather high. Their nutritive ingredients are principally protein and carbohydrates. The high crude fiber content is due to the fact that these products represent the outer layers of the grain, which are more hard and firm in construction than the interior portion, which consists largely of starch.

The total number of tests to compare different feeding stuffs for horses which have been undertaken by the agricultural experiment stations in the United States is not large compared with the tests made with other farm animals. The results obtained are, however, interesting. Some of those which have to do with grain, whole and ground, follow:

At the Maine Station Jordan^a made a comparison with oats and a mixture of one-third pea meal and two-thirds middlings for Percheron colts. No advantage was observed for the oats over the mixture. A comparison of oats with mixed grains (middlings, gluten meal, and linseed meal), also made with colts, showed that considerably larger gains were made on the mixed grain ration, which was also the more nitrogenous.

At the Utah Station J. W. Sanborn^b tested the effect of feeding grains (rye, oats, and bran) and cut hay, mixed and separately. So far as the test showed, the two methods of feeding were equally satisfactory. No regular variation in the weight of the two lots of horses was observed when the comparative value of the whole and cut hay (alfalfa and clover mixed) was tested.

The comparative value of corn and oats supplementing bran and hay was also tested at the Utah Station.^c The grains were ground and mixed before feeding. In these and other tests referred to above it appears that during the summer corn and timothy were not as good as oats, wheat, and clover for maintaining horses. During the winter corn and timothy were as satisfactory as oats, clover, and timothy in maintaining weight. During the spring and summer wheat or bran and mixed hay produced greater gains in weight than oats, wheat, or bran and mixed hay. In another trial^d corn meal and timothy hay did not sustain work horses as well as oats, wheat, and clover hay.

The value of oats versus bran and shorts, the feeding value of wheat, wheat versus bran and ground wheat, were tested with horses and mules by J. H. Shepperd^e at the North Dakota Station. Bran and shorts were found to have practically the same feeding value as oats. Unground wheat was poorly digested, and it was therefore believed undesirable to feed it as a sole grain ration. When wheat was added to a ration of bran and shorts 1:1 no advantage was gained. On the basis of tests reported, bran and ground wheat 1:2 was considered

^a Maine Station Rpt. 1890, p. 68.

^d Utah Station Rpt. 1892, p. 30.

^b Utah Station Bul. 13.

^e North Dakota Station Bul. 20.

^c Utah Station Bul. 36.

a more satisfactory grain ration for horses at light work than whole oats.

The New Hampshire Station^a studied the value of different grain mixtures for horses with the view to determining whether the cost of a ration could not be diminished by lessening the amount of oats fed. The rations consisted of different mixtures of oats, bran, corn, gluten feed, linseed-oil meal, and cotton-seed meal. Fairly good results were obtained with all the grain mixtures, the mixture containing cotton-seed meal being least satisfactory, as it was not relished at first by the horses. It is stated by C. W. Burkett, who carried on the tests, that the oats proved no more satisfactory than the other concentrated feeding stuffs, either in respect to the general condition of the animal or the efficiency for work, and the conclusion was drawn that a combination of feeding stuffs, furnishing the desired nutriment at a reasonable cost, should be considered in preparing rations for horses. A mixture of bran and corn, half and half, is regarded as a good substitute for corn and oats for work horses.

In a study of alfalfa hay and timothy hay for horses at the Utah Station^b the comparative merits of oats and a mixture of bran and shorts were also tested. The conclusion was drawn that the mixed grain could be satisfactorily substituted for oats.

The barley grown on the Pacific coast is extensively used in the feeding of horses, and its use for this purpose is old in other countries. Elsewhere barley is not extensively used as a feed in the United States, doubtless owing to the fact that it is in such demand for brewing purposes that it is usually high in price. Wherever it is grown, however, it is frequently possible to secure at a low cost grain which is off color owing to rain or fog during harvest, and which, for this or some other reason, is unfit for brewing, but valuable as feed.

Barley may be fed whole to horses having good teeth and not required to do severe work. Since ground barley, like wheat, forms a pasty mass when mixed with saliva it is regarded as more satisfactory to crush than to grind it, if for any reason it is considered undesirable to feed the grain whole.

At the North Dakota Station J. H. Shepperd^c has recently studied the value of barley as a feed for work horses and mules. For some months this grain was fed with timothy hay to three horses and two mules. The mules did not eat the barley with marked relish at any time, but for two months, during which time they were performing light work, they ate enough to keep them in condition. The work was then increased, but they would not eat a correspondingly greater quantity of barley, and soon began to refuse it altogether for a day or so

^a New Hampshire Station Bul. 82.

^c North Dakota Station Bul. 45.

^b Utah Station Bul. 77.

at a time. The mules were then given oats on alternate months. This grain was eaten with relish, and gains in weight were made. Although the trial lasted nine months, the mules persistently refused barley.

Of the horses mentioned above, two were work horses. They were fed alternately barley and oats with timothy hay for nine periods of twenty-eight days each. They ate the barley without regard to the amount of work required of them. On the oat ration there was an average daily gain of 0.38 pound per horse. On the barley ration there was an average daily gain per horse of 0.15 pound. In both cases the horses averaged 5.50 hours' work per day.

This trial indicates that horses, when taxed to the limit by hard work, can not be supported upon barley quite so well as upon oats, and that it is worth slightly less per pound than oats with stock which is given a medium amount of work. It indicates further that mules take less kindly to barley than do horses, and that horses which are inclined to be "dainty" will not eat barley so readily as oats.

Malted barley was compared with oats in a trial made with four work horses. The two grains were alternated in different periods. Oat hay was supplied as coarse fodder. The malted barley was prepared as follows: After soaking in water for twenty-four hours the grain was spread on the floor in a layer 6 inches or less in depth and allowed to remain until the sprouts were 0.5 to 0.75 inch long; it was then fed. On the oat ration there was a daily gain of 0.49 pound, and on the malted barley there was an average daily loss of 0.76 pound per horse. When fed malted barley the horses ate 0.1 pound more grain than when fed oats. In this test the horses worked between five and six hours per day on an average.

A mixture of malted barley and bran was also compared with oats, the two rations being alternated as above. The grains were mixed in the proportion of two parts of barley (before malting) to one part of bran. As in the above test, oat hay was fed with the grain. The horses worked some seven hours per day. When fed a barley and bran ration they ate an amount equivalent to about 17.4 pounds of dry grain per day. There was an average daily loss of 0.8 pound per horse. When fed the oat ration an average of 16.2 pounds was consumed per day, and there was an average daily gain per horse of 0.22 pound. In other words, the horses did not maintain their weight on the bran and malted barley, although they ate a larger quantity than when the oat ration was fed.

These trials indicate that malted barley is not an economical feed for work horses, and that the addition of 1 part bran to 2 parts of malt, as measured by the dry barley, from which it was produced, is neither a cheap nor satisfactory feed for hard-worked horses.

Few experiments have been reported on the feeding value of Kafir corn for horses. At the Oklahoma Station, according to Morrow and

Bone,^a 41 bushels of ground Kafir corn were fed during a year to a pair of work horses in addition to other grain and coarse fodder. From this test and others made with different farm animals the conclusion was drawn that Kafir corn is a healthful, palatable, and nutritious feed with a feeding value somewhat less than that of corn. This grain is very flinty, and to secure the best results should be ground. According to information recently received from the station, Kafir corn is highly esteemed locally as a feed for horses, many being kept throughout the year on this grain and prairie hay. The unthrashed heads are commonly fed, a head of Kafir corn being regarded as equivalent to an ear of corn.

At the Mississippi Station^b chicken corn, a variety of Kafir corn, was compared with corn meal as a feed for mules doing heavy work, mixed hay being fed in addition to the grain ration. The mules fed the chicken corn lost in weight a little more than those fed corn meal. According to those making the test "the feeding value of the chicken corn is about as high as that of the corn."

LEGUMINOUS SEEDS.

Beans and other leguminous seed resemble the cereal grains in having a low water content. In Europe horse beans are common feeding stuff for horses. Lavalard says:^c

The experiments made many years ago for the Paris cab companies warrant the statement that when beans replace oats, only half the quantity should be used. Tests made with army horses have confirmed this conclusion. The chemical composition of beans shows why they are regarded as more nutritious than oats alone. Beans may be advantageously fed to horses required to perform long continued, sudden, or severe labor. The opinion is prevalent in England that in hunting it is always possible to recognize horses fed with beans by their great endurance. In accord with the practice of the leading racing stables, we used a large proportion of beans in the ration of young horses which were being trained. The results obtained were most satisfactory.

OIL CAKES AND OTHER COMMERCIAL BY-PRODUCTS.

The various cakes, gluten materials, and similar feeding stuffs are, generally speaking, commercial by-products. Thus, cotton-seed cake is the material left after the oil has been expressed from the cotton seed. In the same way, linseed cake is the residue obtained in the manufacture of linseed oil. If this cake is ground it becomes linseed meal. In the manufacture of beer the malted grain is known as brewers' grain and is best fed after drying. When starch is manufactured from corn, the nitrogenous portion of the grain is rejected and constitutes gluten feed and gluten meal. The cereal breakfast food companies have placed many feeding stuffs upon the market made up of

^aOklahoma Station Rpt. 1899, p. 31.

^cLoc. cit.

^bMississippi Station Bul. 8.

various by-products obtained in the manufacture of their breakfast foods and similar products. These feeding stuffs vary in value, but may generally be said to represent the branny portion of the grains from which they are derived.

A comparison was made by E. B. and L. A. Voorhees^a of dried brewers' grains when substituted for oats, pound for pound, at the New Jersey stations, eight horses heavily worked during the summer being used. As shown by weight and general condition of the animals, the brewers' grains were fully equal to the oats, pound for pound, while their cost was considerably less. In a second trial, dried brewers' grains were compared with a mixture of wheat bran and linseed meal 5 : 1.5 when fed in addition to timothy hay and corn. The uniformity in the amount of feed consumed and the weight of the animals, taken in connection with the work performed, indicates that there was no material difference in the value of the two rations. According to calculations made (timothy hay at the time being worth \$18, wheat bran \$17.50, corn meal \$22, dried brewers' grain \$17, and linseed meal \$29 per ton), a farm horse weighing 1,000 pounds can be fed for \$30.84 during the six months of the year when the most work is performed if dried brewers' grain furnishes the bulk of the necessary protein, and for \$33.49 if wheat bran and linseed meal are the chief sources of this nutrient. If the fertilizing value of the feeding stuffs is taken into account the difference in favor of the brewers' grains is less marked.

In tests made by Emery^b at the North Carolina Station horses were satisfactorily fed 2 pounds of cotton-seed meal per head daily as part of the mixed ration. When the amount was increased to 3.5 pounds the results were not as favorable. It is stated that neither of the horses used in the test showed any symptoms which indicated that cotton-seed meal disagreed with them. It is also stated that at the Biltmore estate 2 pounds of cotton-seed meal per head daily were fed to the horses and mules with 13 to 15 pounds of cut hay and finely cut corn feed, 4 pounds of wheat bran, and 6 pounds of corn meal. On Sundays the ration was made up of whole corn and oats and uncut hay. According to later information the feeding of cotton-seed meal has not been found satisfactory at Biltmore. In the tests with mixed rations, carried on at the New Hampshire Station (p. 18), the cotton-seed mixture was least satisfactory.

In the opinion of Director Stubbs,^c of the Louisiana stations, cotton-seed meal may be fed with satisfactory results to horses and mules. At the Louisiana stations 1 or 2 pounds per mule per day have been fed with success. Six pounds is regarded as the maximum quantity

^a New Jersey Stations Bul. 92, Rpt. 1893, p. 179.

^b North Carolina Station Bul. 109.

^c Louisiana Planter, 28 (1902), p. 178.

which it is desirable to feed, and, in Director Stubbs's opinion, this amount should be led up to gradually. He notes that only bright yellow cotton-seed meal of a nutty, pleasant odor and taste should be used, and that no reddish or musty meal should be fed. It is stated that excessive quantities of cotton-seed meal should be avoided, since it is a very concentrated feed. It should be gradually added to a ration, carefully mixed with other feeds, until mules learn to relish it, and no uneaten residues should be allowed to ferment in the feed boxes.

The cereal grains, ground and unground, commercial by-products, leguminous seeds, oil cakes, and similar products are very frequently called concentrated feeds, the name being suggested by the fact that, generally speaking, the food value, especially the protein content, is high in comparison with the bulk. So far as the general experience and the results of American and foreign feeding experiments go, most of the common feeding stuffs in the group are wholesome and valuable for horses. If any one of these feeding stuffs is substituted for oats, which may be taken for a standard, the substitution should be proportional to the composition of the two feeds and not pound for pound.

FORAGE CROPS, FRESH AND CURED.

The various forage crops—grass, clover, Kafir corn, corn, etc.—all have a high water content; that is, they are more or less succulent and juicy. They contain, however, considerable nutritive material, usually protein and carbohydrates, and are valuable feeding stuffs.

The leguminous forage crops—alfalfa, clover, cowpeas, soy beans, vetch, etc.—are richer in protein than the grasses. When the forage crops are dried and cured the resulting hay is richer in proportion to its bulk than the green material; in other words, it has been concentrated by the evaporation of the greater part of the water present. However, this is not the only change which has taken place. When hay is properly cured it undergoes a peculiar sort of fermentation or oxidation which materially affects its composition.

As shown by Holdefleis's^a recent investigations, fermentation improves the hay by diminishing the quantity of crude fiber and by increasing the relative amount of other nutrients, especially nitrogen-free extract. The greater the fermentation the more the crude fiber is diminished, and this is especially marked when hay is dried on racks. Hay which has undergone proper fermentation has a better flavor and agrees better with animals and is apparently more digestible than hay which has dried quickly in the sun without fermentation. Fermentation apparently diminishes the amount of pentosans in hay, especially in the case of hay from grasses. It also seems that the relative amount of true protein is increased.

^a Mitt. Landw. Inst. Univ. Breslau, 1899, p. 59.

The feeding value of different forage crops, fresh and cured, depends in considerable degree upon the stage of growth, as has been shown by a number of chemical studies of the composition of different crops and cuttings of alfalfa, young and more matured corn forage, etc. Generally speaking, the nutritive value of the crop increases until growth is complete and diminishes somewhat as the plants mature or become overripe. Straw, the fully ripened stalk of cereal grains, contains some nutritive material, but is less nutritious than the same portion of the plant cut before ripening. In the perfectly ripe condition the nutritive material, elaborated in different portions of the ordinary forage plants, has been conveyed to the seed and used for its development or stored as reserve material.

Green forage crops are frequently preserved by ensiling. In this process the material undergoes a peculiar oxidation which correspondingly changes it in composition and food value. Some of the carbohydrates are changed into alcohol, acetic and other acids, and crude fiber is undoubtedly softened somewhat, and possibly the silage is thus rendered more digestible. Bodies having peculiar flavor and odor are also formed.

The green crops, hay, straw, other cured crops, and silage are frequently called "coarse fodder" or "roughage." This term is due to the fact that they contain a comparatively small amount of nutritive material and a high proportion of crude fiber as compared with their total bulk. Although inferior to concentrated feeds in composition, they are an essential part of the ration of horses and other farm animals, serving to give the required bulk to the food and being useful in other ways.

It is believed that unless the food, when taken into the stomach, is comparatively bulky and the mass is more or less loose in structure, it is not readily acted on by the digestive juices. The intestinal tract of the horse is long in proportion to the size of the animal, and food remains in it for several days. Experiments indicate that crude fiber, which is only slightly digestible by man, is quite thoroughly digested by horses, and even more thoroughly digested by ruminants, owing its digestibility to the fact that it is fermented for a comparatively long period by micro-organisms in the intestines.

Regarding the need of straw in a ration to supply the necessary bulk, Lavalard's^a opinion follows:

The statement is often made that horses can not do without straw [to supply coarse fodder]. This is an error, for we have fed horses hay and oats during very long periods, and have never noticed that they suffered any inconvenience or detriment. This is a matter of importance, since it is often inconvenient to obtain straw [even for bedding], and in such cases peat, sawdust, sand, etc., may be profitably used as bedding in place of straw.

^aLoc. cit.

This does not mean that crude fiber, one of the important constituents of coarse fodder, is not required, but rather that a sufficient amount of crude fiber was supplied by the hay and oats in the cases cited by the author. As part of a series comprising some fifteen experiments carried on at the Maryland Station,^a an attempt was made to feed the horses on oats alone. At the beginning of the trial one horse consumed 6,000 grams (13.2 pounds) and the other 6,750 grams (14.9 pounds) of oats per day, but after a few days refused to eat. The experiment could not be continued long enough to permit the determination of the coefficients of digestibility. Under the experimental conditions it was regarded as impossible to maintain horses on a grain ration alone; it seemed certain that they required some coarse fodder in addition. From such experiments the general deduction is obvious that the common practice of feeding horses on a ration of grain and coarse fodder is reasonable and based on the actual physiological requirements of the animal.

A number of feeding experiments have been made on the comparative value for horses of different forage crops, fresh and cured. The American experiment stations have studied the more important coarse fodders in use in this country. A summary of their work follows.

D. O. Nourse^b of the Virginia Station reported a number of trials of the value of corn silage for horses and mules. Gradually increasing amounts were fed until they were given all the silage they could eat, with hay and grain in addition. Provided animals are gradually accustomed to it, as shown by these tests, silage is a satisfactory feed for horses and mules.

In tests carried on by J. H. Shepperd^c at the North Dakota Station oat straw and prairie hay were compared. Oat straw was found to be a cheaper horse fodder than hay, but when it was used more careful feeding was necessary to keep the horses in good condition. In a subsequent test^d brome grass hay gave as good results when fed to work horses as timothy hay.

In a study of different grain mixtures for work horses, carried on at the New Hampshire Station,^e the relative merits of timothy hay and corn stover were also studied. The rations consisted of 12 pounds of hay and corn stover alone or mixed, fed with 14 pounds of mixed grain. During the test, which covered nearly three months, the two sorts of coarse fodder were found equally satisfactory. Although the corn stover cost only one-third as much as the timothy hay, the conclusion was drawn that it has a feeding value equal to timothy hay fed with suitable mixtures of either corn and oats or corn and bran, and that when corn stover or timothy hay supplied the coarse fodder in a

^aMaryland Station Bul. 51.

^dNorth Dakota Station Bul. 45.

^bVirginia Station Bul. 80.

^eNew Hampshire Station Bul. 82.

^cNorth Dakota Station Bul. 20.

ration, oats and corn, half and half, and bran and corn, half and half, have generally equivalent feeding values.

Bermuda grass hay and timothy hay, fed in addition to corn, were compared with working mules at the Mississippi Station.^a No marked differences in the cost of the rations nor in the gains made by the mules were observed.

The Oklahoma Station^b reports a test in which Kafir corn stover was fed to horses and mules, the amount eaten by the horses averaging some 32 pounds per day and by the mules some 41 pounds. From this and tests of other farm animals the conclusion was drawn that Kafir corn stover is about equal in feeding value to corn stover, and that running stalks through a thrashing machine is a satisfactory method of preparing this feeding stuff.

At the Utah Station^c a ration of timothy hay and grain was compared with one consisting of clover, oats, and wheat, two lots of work horses being used. The nutritive ratio of the first ration was 1:14.8; of the second, 1:5.5. For more than half the test the grains were fed unground. Somewhat better results were obtained with a ration having the narrower nutritive ratio. However, in a second test,^d the ration having a wide nutritive ratio (1:15.2) gave results as satisfactory as the one having a narrower ratio (1:7.8).

Later, at the Utah Station, the comparative merits of alfalfa hay and timothy hay were investigated by L. A. Merrill^e in tests with work horses and driving horses, which extended over four years. In some of the tests as much as 25 pounds of alfalfa or timothy hay with 10 pounds of bran and shorts was fed per head daily. In other tests the amount of hay was considerably smaller and the amount of grain larger. In some cases oats were fed instead of bran and shorts. Generally speaking, the timothy ration was the more expensive and the horses did not maintain their weight on it as well as on the alfalfa ration.

Tests were also made in which the feeding value of an alfalfa ration without grain was studied. It was found that 20 pounds of this material was sufficient to maintain the weight of a horse weighing nearly 1,400 pounds, provided no work was performed. When at hard work some 33 pounds of alfalfa hay was barely sufficient to maintain the weight. When the work was very severe 40 pounds of alfalfa hay was not an adequate ration, although it was about the limit which could be eaten. Regarding the experiments, the statement was made in effect that it is doubtful if there is any economy in feeding a horse 40 pounds of alfalfa per day. It is certain that better results can be secured by limiting the amount of hay to 20 pounds and substituting for the extra 20 pounds enough grain to make up the cost. This would secure at

^aMississippi Station Bul. 15.

^bOklahoma Station Rpt. 1899, p. 18.

^cUtah Station Rpt. 1892, p. 30.

^dUtah Station Bul. 30.

^eUtah Station Bul. 77.

current prices [1902] 8 pounds of bran and shorts or 3.6 pounds of oats per day, and this amount with 20 pounds of alfalfa will make a better maintenance ration than 40 pounds of alfalfa. Aside from the financial consideration it should be emphasized that if digestive disorders are to be entirely avoided concentrated foods must make up part of the diet of the horse.

Considered as a whole the experiments are very favorable to the use of alfalfa hay as a coarse fodder for horses. The fact is recognized that, like other leguminous crops, it contains a larger amount of protein in proportion to its bulk than timothy. Feeding alfalfa did not exercise any bad effects on the health of the horses. It is stated that attacks of colic and other digestive disorders can be prevented by a judicious system of feeding. The amount of hay fed on most Utah farms, it is believed, could be reduced at least one-half. It may be economical to reduce the amount of hay and increase the amount of grain fed to horses. In this connection the author says:

It is folly to claim that a horse will not eat more than is necessary if allowed the liberty of the stack and the grain bin. The argument is sometimes made that a horse under natural conditions, on pasture, never eats more than is necessary, and that under these conditions he is never subject to digestive disorders. While this is undoubtedly true, it must be kept in mind that as soon as we stable the horse and require work of him, we have taken him away from his natural condition and placed him under unnatural environments.

It was observed that larger amounts of water were consumed on the alfalfa ration and that the amount of urine excreted was also larger and had a higher specific gravity. The excess, however, was never found great enough to cause any inconvenience. These experiments at the Utah Station are especially interesting since they confirm the results of twelve years' practical tests of the feeding value of alfalfa. During this period the station horses have always received this material as a coarse fodder, except when they were fed other rations for experimental purposes.

From a study of the comparative digestibility of alfalfa hay and meadow hay by horses, Müntz and Girard^a concluded that the former is superior as regards nitrogenous constituents and the latter as regards carbohydrates.

In studies at the Wyoming Station, undertaken by F. E. Emery^b to determine what constituted maintenance rations for horses performing little work, alfalfa hay constituted the principal feed, no grain being supplied. It was found that farm horses required to perform very little work maintained their weight on an average daily ration, per 1,000 pounds live weight, of 13.75 pounds alfalfa hay and 2.25 pounds oat straw. A driving horse maintained his weight on a daily ration of 17.71 pounds alfalfa hay and 2.83 pounds oat straw per 1,000 pounds live weight.

^a Ann. Agron., 24 (1898), p. 5.

^b Wyoming Station Press Buls. n. ser. 5, 10.

In discussing the subject of alfalfa for horses, the California Station^a says in effect that in regions where it is a staple crop the quantity of protein which can be supplied in green and cured alfalfa is so great that much less grain is required than when the coarse fodder consists of cereal hays only. For the Pacific coast, where cereal hays replace so largely those from meadow grasses, the station recommends a ration of alfalfa hay with wheat hay or barley hay and grain.

In a recent discussion of the problem of horse feeding under local conditions, Director Stubbs,^b of the Louisiana stations, emphasizes the value of cowpea vine hay.

The outcome of the different experiments is in accord with the observation of careful feeders, viz, that the various common coarse fodders may be fed to horses as circumstances demand. Although timothy hay is in many regions regarded as the preferable coarse feed, yet experience has shown that corn fodder, hay from wheat, barley, and other cereal grains, and from clover, and alfalfa may be substituted for it. That this is what might be expected is shown by a study of the composition of these feeding stuffs. As will be seen by reference to the table above (p. 13), they resemble each other very closely in the character and amount of nutrients which they contain—alfalfa, clover, and other leguminous hays being richer in protein than the cured grasses and cereal forage. Straw is not much fed to horses in the United States, but is a common feeding stuff in Europe. As shown by its composition and digestibility (pp. 14, 41), it compares quite favorably with other coarse fodders. The substitution of one coarse fodder for another in a ration should always be made on the basis of composition and digestibility, rather than pound for pound.

Very few tests have been made on the comparative value of different uncured feeds or different sorts of pasturage in horse feeding, though all the common forage crops are regarded as wholesome if properly fed. In discussing green crops for horses, ^c Lavalard says:

Such feed is very dependent upon the fertilizer used for the crop, the method of harvesting, and the condition of the animal fed. Green fodder does not contain sufficient nutritive material to make it in any real sense a feeding stuff for horses performing much work. The same may be said of certain plants which have been much advertised from time to time, such as furze, couch grass [sacchaline], etc.

ROOTS AND TUBERS.

Carrots, Swedish turnips or ruta-bagas, and other roots and tubers, green vegetables, and fruits contain a high percentage of water and small amounts of the different classes of nutrients. Generally speaking, the percentage of crude fiber is smaller than in the green forage crops; but since the proportion of nutritive material is small in comparison with the total bulk, they are ordinarily referred to as coarse

^aCalifornia Station Bul. 132.

^b Loc. cit.

^c Experiment Station Record, 12 (1900-1901), p. 4.

fodder. The use of these materials as food for horses has been attempted at different times with varying success, but it is not followed to any great extent in this country. In the opinion of a recent German writer, about 12 pounds of raw potatoes per 1,000 pounds live weight may be fed to horses with advantage and, if supplemented with proper feed, there need be no fear of physiological disturbances. When fed in this amount the potatoes should be mixed with hay or cut straw to insure their being properly chewed. If small, they may be fed whole; if large, they should be sliced. In any case only healthy, ripe, unsprouted tubers should be used. It is said that horses should not be watered immediately after a ration containing potatoes.

MOLASSES AND OTHER BY-PRODUCTS OF SUGAR MAKING.

The beet chips, diffusion residue, and other by-products obtained in the manufacture of beet sugar, consist of the sugar beet from which a considerable portion of the carbohydrates has been removed. The total amount of nutritive material present, however, is fairly large. These products, properly speaking, are also coarse fodders. Molasses, which consists almost entirely of carbohydrates (sugars), was used as early as 1830 as a feed for horses, and has recently attracted considerable attention in this connection. When used for this purpose it is usually sprinkled on dry feed, being first diluted with water, or it is mixed with some material which absorbs it and renders it easy to handle, such as peat dust, or with some material rich in nitrogen, as dried blood. In the latter case the mixture more nearly represents a concentrated feed than the molasses alone, or molasses mixed with an absorbent material only. Cane-sugar molasses is also used as a feeding stuff. It differs from beet molasses in that it contains glucose in addition to cane sugar, and has a much smaller percentage of salts.

In this connection the experiments reporting the successful feeding of cane molasses to over 400 work horses at a sugar plantation in the Fiji Islands^a are of interest. As high as 30 pounds of molasses was fed per head daily at different times, but the ration finally adopted consisted of 15 pounds of molasses, 3 pounds of bran, and 4 pounds of maize. In addition, green sugar cane tops were fed. The health of the horses remained excellent. Molasses did not cause diarrhea, but rather constipation, which was counteracted by feeding bran. Feeding molasses effected a saving of over \$45 per head per annum. However, it was believed that such a saving was possible only by reason of large quantities of waste molasses and valueless cane tops available on the spot. In discussing these experiments the following statements were made:

For working horses the sugar in cane molasses is a satisfactory substitute for starchy food, being readily digested * * * and 15 pounds can be given to a 1,270-pound working horse with advantage to the health of the animal and to the efficiency of its

^a Agr. Gaz. New South Wales, 9 (1898), p. 169.

work. It produces no undue fattening, softness, nor injury to the wind. The high proportion of salts in it has no injurious effect. An albuminoid ratio as low as 1:11.8 has proved highly suitable for heavy continuous work when a sufficient quantity of digestible matter is given.

According to W. C. Stubbs,^a of the Louisiana stations, cane-sugar molasses has been used extensively with success for a number of years for feeding horses and mules in Louisiana, many feeders keeping mules exclusively on a ration of rice bran and molasses in addition to cowpea hay. The general custom is to feed the molasses from a large trough, allowing the mules to eat it ad libitum. It is said they will consume with apparent relish from 8 to 12 pounds per head daily. The mules at the Louisiana stations have been fed molasses daily ad libitum for eight or ten years, and, according to Director Stubbs, show its good effects "in their splendid condition, lively action, and endurance of work."

In this connection it is interesting to note the results obtained by G. E. Griffin^b in the experimental feeding of cane-sugar molasses to army horses in Porto Rico. In accordance with the local custom, this material was fed with chopped grass, the ration being gradually substituted for the usual ration of oats and hay. The molasses was diluted with 25 per cent of water, and as much as possible was mixed with the chopped grass. The remainder was added to the drinking water. The test reported continued some five months and led to the deduction that 35 pounds of grass and 13 to 15 pounds of molasses daily per 1,000 pounds live weight is sufficient to maintain a horse in good condition in a climate like that of Porto Rico. This method of feeding, it was believed, had some disadvantages, which were as follows:

Molasses attracts insects, notably flies and ants; it sticks to the animal's coat, smears his face and breast, halter and halter strap, soils the clothing and equipment of the men, and causes some trouble and delay in mixing it with the grass, which must be cut fine.

G. H. Berns^c reports the successful feeding of molasses to 100 draft horses working ten hours a day hauling very heavy loads usually at a walk. The horses averaged 1,700 pounds in weight and were fed per head, night and morning, 1 quart of molasses diluted with 3 quarts of water and thoroughly mixed with 6 pounds of cut hay of good quality, 1.5 quarts of corn meal, and 2.5 quarts of coarse bran. In addition they were fed 5 quarts of dry oats in the middle of the day and 11 pounds of long hay at night. It is stated that the horses gradually improved in condition and gained in weight during the fourteen months covered by the test, their coats becoming sleek and glossy, while the amount of work performed was the same as before the molasses ration was adopted. In the meantime their general health is said to have

^a Loc. cit.

^c Amer. Vet. Rev., 26 (1902-3), p. 615.

^b Amer. Vet. Rev., 25 (1901-2), p. 894.

been excellent, and cases of acute indigestion or spasmodic colic very rare, although formerly quite frequent. The molasses ration was decided upon after its value had been demonstrated in a test with two horses. A ration similar to the above was also fed with success to a number of driving horses.

In general, no disturbance was observed in changing from an ordinary to a molasses ration. As part of a mixed ration, the author calculates that 1 quart of molasses will replace 3 to 4 quarts of oats of good quality. He believes that "molasses of a good quality is a most nutritious food for horses, easily digested and assimilated, and will in many cases correct faulty digestive processes," and that "molasses-fed horses will do fully as much work and at the same time remain, as a rule, in much better general condition than animals fed on dry food, while the cost of feeding is reduced from 25 to 33 per cent."

As an outgrowth of this work Dr. Berns states that molasses has been successfully fed, under his direction, to 2,500 or 3,000 horses.

The value of beet-sugar molasses as a part of a ration for horses and other farm animals was tested several years ago by Dickson and Malpeaux^a in France. The test with horses was made with four animals fed a total ration of 15.4 pounds of oats, 11 pounds of alfalfa hay, and 11 pounds of wheat straw. Molasses was gradually substituted for part of the oats, until 13.2 pounds of the latter and 2 of the former were fed. The molasses was mixed with the drinking water. The feeding was continued for about six weeks, and all the horses gained slightly in weight. The authors regard the substitution of molasses for part of the oats as entirely satisfactory, since it was readily eaten and the vigor and weight of the horses were maintained.

Grandeau^b has very recently described a number of practical tests in which molasses mixtures were added to the rations of horses. The cost of the ration was diminished and the health and condition of the animals maintained. Similar results have been reported by other investigators in France and by Wibbens^c in Holland. From all these investigations it seems fair to conclude that molasses can be safely fed to horses when its cost in comparison with other feeding stuffs warrants its use. Apart from the nutritive material it supplies, it has a value as an appetizer and frequently renders poor hay or other feed more palatable.

The feeding value of blood molasses (a mixed feed containing dried blood and beet-sugar molasses) was studied in Denmark^d with 23 horses belonging to a Copenhagen milk company. The horses were divided into two lots. One lot was fed a ration of barley and oats 1:2

^a Ann. Agron., 24 (1898), p. 353.

^b Jour. Agr. Prat., n. ser., 4 (1902), pp. 569, 599, 697.

^c Cultura, 14 (1902), p. 520.

^d Landmandsblade, 32 (1899), p. 349.

during part of the test, and later of oats and hay. Lot 2 was fed the same ration except that blood molasses was substituted for part of the grain in the ratio of 1 pound to 2 pounds; 2.5 pounds to 3 pounds, and, later, of 3 pounds to 4 pounds. This latter ratio represents about what was considered the comparative value of the molasses feed. In earlier Scandinavian experiments^a the successful feeding of 2.2 pounds of beet-sugar molasses per head daily to work horses was observed; other similar tests might be cited.

FRUITS, FRESH AND DRIED.

Although horses are often given apples as they are given lumps of sugar, fruit is not generally thought of as a feeding stuff, yet its use for this purpose is by no means novel. The Arabs, according to E. Daumas,^b commonly feed their horses fresh dates. In such dates the pits are soft and are eaten with the pulp. Sometimes 3 or 4 pounds of fresh dates are mixed with water to a sort of mush before feeding. It is believed that dates are fattening, but that they do not produce muscle.

In California and possibly in other regions fruit, especially prunes and other dried fruit, is sometimes fed when the market is overstocked or when for some other reason it can not be profitably sold. According to a recent statement,^c small prunes of low market value have been successfully fed to horses for a long period. It is stated that the horses eat them with relish. The pits should be crushed before feeding.

The California Station^d has reported analyses of a number of fresh and dried fruits and discussed their value as stock feed. A recent report of the Arizona Station^e gives the composition of almond hulls or pericarps, the portion of the almond removed before the nut is marketed, and states that this material has been found to be a fattening feed for horses.

All common fruits when fresh are very succulent, containing on an average 80 to 90 per cent water, the nutritive material consisting almost entirely of carbohydrates. When dried—i. e., concentrated by evaporation—they are much more nutritious. Raisins, prunes, dried peaches, etc., contain about 25 per cent water and about 70 per cent carbohydrates, of which a considerable part is sugar. The value of sugar as a nutrient is recognized, and it is not surprising, therefore, that fruits, especially after drying, should have a considerable feeding value.

^aK. Landt. Akad. Handl. Tidskr., 34 (1895), p. 246.

^bLes Chevaux du Sahara. Paris: Calmann Lévy, 1887, p. 134.

^cPacific Rural Press, 60 (1900), p. 402.

^dCalifornia Station Bul. 132.

^eArizona Station Rpt. 1902, p. 269.

INJURIOUS FEEDING STUFFS.

In feeding horses precautions should always be taken to avoid materials harmful in themselves, or those which have become harmful. Dirt, small stones, etc., should be removed from grain by proper screening, and all feeding stuffs should be clean. On this subject Lavalard^a says:

Some of our recent experiments have had to do with the methods of feeding. They cover a number of points. The first and perhaps the most important is the advantage of cleaning the grain. Grandeau showed in his experiments that oats could be satisfactorily freed of foreign grains and impurities by some of the well-known screening devices. He studied the composition of the impurities, and found that some of them were injurious to the health of the horses.

The importance of proper cleaning is illustrated by a point in our own experience. A few years ago, after a very severe drought, we were compelled to feed oats containing tares and leguminous seeds, some of which were those of the species of *Lathyrus*. Symptoms of *Lathyrus* poisoning were noted in a number of horses. The attacks were frequently severe and sometimes fatal. When oats were properly cleaned this trouble was entirely obviated. Cleaning also increases the density of the oats by removing mineral matter and dust, which may sometimes induce attacks of intestinal obstruction, colic, etc.

There are a number of plants which are poisonous to horses when eaten in any considerable amount. The loco plants, mostly species of *Astragalus*, are ordinarily regarded as of this class. These plants have been studied by the Colorado, Kansas, South Dakota, Montana, and Oklahoma stations among others, and by this Department, but the results obtained are not entirely conclusive. The poisonous properties of rattlebox (*Crotalaria sagittalis*) were demonstrated by the South Dakota Station, and those of some lupines by the Montana Station. According to recent experiments at the Vermont Station^b the common horsetail (*Equisetum arvense*) may cause poisoning when present in hay. It was found that when horses were fed cured horsetail equal in amount to not more than one-fourth of their coarse fodder ration, symptoms of poisoning were noticed, and if the feeding was continued the horses died. The symptoms of poisoning were less noticeable with young than with old horses, and also when a liberal grain ration was supplied. It was also observed that the green plant was less harmful than the dry, possibly owing to the fact that green fodder is somewhat laxative.

Feeds which are ordinarily wholesome may under certain conditions be harmful. Thus there is a widespread and apparently justifiable prejudice against moldy or decomposing feeding stuffs. Experiments carried on at the Kansas and Indiana stations showed that the continued feeding of moldy corn induced intestinal and nervous disorders of a serious nature. It is a matter of common observation that food which has been wet will ferment or sour readily and cause intestinal disorders. This has to be guarded against especially in warm

^aLoc. cit.

^bVermont Station Bul. 95.

climates. Plants which are ordinarily wholesome may become harmful if infested with ergot. The effect of ergot on horses has been studied by the Iowa, Kansas, and Montana stations and others. It is generally conceded that the presence of ergot is a cause of rheumatism. Some feeds which are regarded as wholesome when properly fed may sometimes prove injurious if fed for a long time, or in improper quantities. Thus, millet hay, in many sections of the Western United States, is believed to cause the so-called millet disease of horses. This question was studied by the North Dakota Station.^a It was found that long-continued feeding of millet hay caused lameness and other symptoms of poisoning. From the experiments and observations the conclusion was drawn that feeding millet alone as a coarse fodder is injurious to horses, since it produces an increased action of the kidneys and causes lameness and swelling of the joints and an infusion of blood into the joints. It may also injure the texture of the bones, rendering them soft and less tenacious. The bad effects due to long-continued feeding of millet were observed whether the crop was cut just when the heads were fully ripe or earlier, although there is a popular belief that the trouble is due to harvesting the crop before the heads are fully ripe. The investigation seemed to show conclusively that feeding millet produced millet disease, but the specific cause to which the dangerous properties of millet are due was not learned, though later work at the station indicates that it is a glucosid.

An explanation of the poisoning of stock by young sorghum and some other forage plants is offered by the discovery by Dunstan and Henry^b of a cyanogenetic glucosid in a number of varieties of sorghum (*Sorghum vulgare*), which under the influence of a special ferment present in the plant liberates prussic acid. It is thought probable that this acid may be likewise liberated in the digestive tract of animals feeding on the young plants. They did not find the glucosid in the mature sorghum. For a number of years Peters, Avery, and Slade,^c at the Nebraska Experiment Station, have studied sorghum poisoning, and have recently demonstrated the presence of cyanic acid in the green leaves of young and old sorghum plants and Kafir corn.

METHOD OF FEEDING.

The method of feeding is a subject which is often discussed, the questions of especial interest being the comparative merits of cooked and raw feed, dry and soaked grain, ground and unground grain, and cut or chaffed and uncut coarse fodder. The number of experiments which have to do with these topics is not numerous.

^a North Dakota Station Buls. 7, 26, and 35.

^b Proc. Roy. Soc. [London], 70 (1902), p. 153.

^c Nebraska Station Rpt. 1902, pp. 50, 55; Jour. Comp. Med. and Vet. Arch., 23 (1902), p. 704; Jour. Amer. Chem. Soc., 25 (1903), No. 1, p. 55.

COOKED AND RAW FEED.

Boussingault compared oats and an equal volume of rye boiled until the grain burst. The results were not favorable to cooking the feed. According to another of his tests 30.8 pounds of mashed steam potatoes could not replace 11 pounds of hay. The potatoes were mixed with cut straw and fed cold.

It is often claimed that cooking feed increases its palatability and digestibility. The general conclusion drawn from tests with farm animals is that this belief is not warranted and that the cost of cooking is not made up for by the increased value of the ration. Prof. W. A. Henry^a states that boiled feed is useful for colts, brood mares, and stallions if fed two or three times per week, and that draft horses which are being prepared for sale or for exhibition may be given cooked feed once a day. In his opinion an excellent feed for horses is made by boiling barley and oats in a kettle with considerable water and pouring the mass over chaffed hay, allowing the whole to stand until the hay is well softened. Bran, roots, and a small quantity of oil meal may be added also.

DRY AND SOAKED FEED.

It is often said that soaking feed, especially hard grain, renders it more easily masticated and improves its digestibility. It is doubtful if the matter is as important with horses as some other classes of farm animals. According to Wolff^b healthy horses with good teeth digested dry beans and corn as well as the same materials which had been soaked in water for 24 hours.

Soaking or wetting feed may sometimes be of importance as regards the health of horses. According to the experience of an English feeder^c chaffed straw, which was fed on account of a shortage in the hay crop, gave better results when soaked than when dry. The dry material caused colic and constipation. It was also observed that the horses relished soaked grain (corn and oats 1:1).

It is believed that the dust in hay causes heaves, and to avoid such trouble both long and cut hay, especially clover, is very often dampened before feeding to lay the dust.

GROUND AND UNGROUND FEED.

Opinions differ as regards the advantages of grinding grain. In Professor Henry's^a opinion, for horses which are out of the stable during the day and worked hard, all grains, with the possible exception of oats, should be ground, and for those at extremely hard work, all grain should be ground and mixed with chaffed hay. For idle

^a Loc. cit.

^c Live Stock Jour., 39 (1894), p. 30.

^b See footnote, p. 60.

horses, oats or grain should not be ground, nor should hay or straw be chaffed. In other words, provided the animals have time to masticate their ration thoroughly, grinding is not necessary. When this is not the case, grinding takes the place of thorough mastication to some extent and increases the assimilation of the ration.

When whole oats were compared with ground wheat and bran by Shepperd^a at the North Dakota Station the horses fed the former ration ate somewhat more, and showed a slight loss in weight, while doing a little less work than those fed the ground grain.

In a test of the comparative merits of timothy hay and corn and clover, oats, and wheat made with two lots of work horses at the Utah Station^b the grains were fed unground for somewhat more than one-half of the experimental period and ground during the remainder of the period. The ground and unground grains were regarded as equally satisfactory.

At the Iowa Station Wilson and Curtiss^c compared whole and ground grains (oats, corn, and barley) for colts, and found that somewhat larger gains were made on the ground feed.

In the study of the digestibility of the different feeding stuffs carried on at the Maryland Experiment Station Patterson^d compared a number of whole and ground feeds. His results show that ground oats and corn were more thoroughly digested than the unground grain. In this connection it should be noted that similar results have been obtained in tests with other farm animals, but it is commonly believed that the difference in digestibility is often not sufficient to pay for the additional cost of grinding.

From the American tests and those which have been made in Europe it appears fair to say that there is no very marked advantage in grinding grain for healthy horses with good teeth. Lavalard says:

Contrary to the opinion of some experts, the writer believes it is not necessary to grind grain for horses. This is especially true in the case of oats. In some of our earlier experiments, where ground grain was fed, it was noticed after a few months that the horses preferred to crush it themselves. Of course this does not refer to old horses [i. e., horses having poor teeth]. They can be fed ground grain to advantage.

CUT AND UNCUT COARSE FODDER.

It is perhaps the general opinion that when horses have ample time for chewing and digesting their feed there is no necessity for chaffing or cutting hay and straw. When the time for feeding is limited chaffing and cutting coarse fodder is regarded as advantageous. This is an item of special importance with hard-worked horses kept in the stable only at night. Furthermore, chaffed feed occupies less space for storage than uncut hay or straw and can be readily handled.

^aNorth Dakota Station Bul. 20.

^bUtah Station Bul. 30.

^cIowa Station Bul. 18, p. 470.

^dMaryland Station Bul. 51.

Shredding corn fodder is regarded as an economical practice, but apparently few experiments on the comparative merits of shredded and whole corn fodder for horses have yet been reported. No marked variation was observed in the weights of two lots of horses fed whole and cut timothy or whole and cut alfalfa and clover hay mixed in a test carried on at the Utah Station.^a

At the Maryland Station Patterson,^b who studied the digestibility of a number of whole and ground feeds, found that grinding corn shives—i. e., cornstalks from which the blades, husks, and pith are removed—until the material resembled coarse bran did not destroy its value as a coarse fodder and that the finely ground material supplied the necessary bulk to the ration as well as the same material unground. It was further claimed that the finely ground coarse fodder possessed an advantage over the unground material in that it could be mixed with grain to form a well-balanced ration and fed to horses on ship-board, or under similar conditions, more readily than unground fodder and grain.

COST OF A RATION.

The cost of a ration made up of the ordinary grains and coarse fodders has been investigated by at least three of the American experiment stations. The Massachusetts Hatch Station^c recorded the kinds and amounts of foods consumed by three farm horses for five years, with a view to learning the average cost of the daily feed. In the different years the cost of the ration, which consisted of hay, corn, oats, and other common feeding stuffs, varied from 18.5 to 24.8 cents per head daily.

At the Oklahoma Station^d statistics of the cost of feed of work horses were also recorded in tests of the comparative value of Kafir corn and maize. Red Kafir corn and maize at 20 cents per bushel, oats at 25 cents per bushel, and bran at 25 cents per hundredweight were used. The average cost per horse of a day's labor was estimated to be 17 cents.

Using mixed-grain rations, according to the New Hampshire Station,^e the average cost of feed per horse per year was \$74.32. The average cost for feed per hour's work performed during the two years covered by the test was 3.4 cents.

The data recorded above are too limited for general deduction.

FATTENING HORSES FOR MARKET.

Fattening horses so that they will reach market in good condition for sale is quite an important industry in some regions. For instance, in Iowa there are a number of feeders who thus prepare large num-

^a Utah Station Bul. 13.

^d Oklahoma Station Rpt. 1899, p. 31.

^b Maryland Station Bul. 51.

^c New Hampshire Station Bul. 82.

^e Massachusetts Hatch Station Rpt. 1893, p. 179.

bers of horses for the Chicago market. Though few, if any, experiments have been carried on at the stations to show the feed required per pound of gain, the relative cost of gain, etc., J. A. Craig and H. W. Brettell,^a of the Iowa Station, have described this industry on the basis of data gathered from local feeders extensively engaged in it.

The horses are usually purchased in the fall, after the farm work is over, and are stabled and fed an abundant ration, care being taken to accustom them gradually to full feed in order to avoid colic. When on full feed the horses studied were given, per head, 10 to 14 ears of corn in the morning, at noon, and again at night, with 3 quarts of oats and bran 1:2 and hay ad libitum in the middle of the forenoon and also in the middle of the afternoon. Recognizing the importance of a long period of rest, no feed was given from 6 or 7 at night until 5 o'clock in the morning. The horses were watered twice a day and were given all they would drink. On account of the large number fed, the horses could not be exercised, but as a rule were kept idle in the stable until a few days before they were marketed. To insure good condition it was found advantageous to give 0.5–0.75 pint Glauber salts per head twice a week. Oil meal, it is stated, may also be given to good advantage, as it aids greatly in putting on flesh and also makes the skin soft.

The importance of keeping mangers and feed boxes clean is insisted upon, and attention is especially directed to the need of examining the horses' teeth and removing with a float any sharp points which would make the gums sore and thus prevent the horses from masticating their feed properly.

With such feeding and care satisfactory gains were generally realized. In one instance, it is stated, a horse fed in this manner made a gain of 5.5 pounds per day for a period of fifty days, or 550 pounds in one hundred days. In several instances, with as many as a dozen horses, a gain of 3.75 pounds per head per day was obtained throughout a period of ninety days.

WATERING HORSES.

A discussion of the subject of watering horses should take into account the reasons why water is needed, the amounts required, the proper time for watering, and related topics.

Horses, like other animals, require water to moisten their food so that the digestive juices may permeate it readily, to dilute the blood and other fluids of the body, and for other physiological uses. It may be assumed that under any given normal condition the body contains a definite amount of water. When any considerable amount of water is lost from the body, a sensation of thirst is experienced, showing that more water is needed to take its place. Practically all

^aBreeders' Gaz., 35 (1899), p. 781.

the water excreted leaves the body in the feces, urine, perspiration, and breath. The amount eliminated in each, according to Wolff,^a increases with the amount of water consumed, the largest amount being excreted in the feces. In experiments which he carried on, the total amount of water consumed ranged from 17.363 kilograms to 34.272 kilograms (38.3 to 75.6 pounds). The feces contained from 40.3 to 47.3 per cent of the total amount excreted; the urine from 21.2 to 34.9 per cent.

In addition to the water drunk by horses, a considerable amount is obtained in the more or less succulent food eaten. The amount of water required is influenced by a number of factors, including the season of the year, temperature of the surrounding air, character of the feed, the individual peculiarities of the horse, the amount and character of the work performed, and probably others. The amount of water needed increases with the temperature and with the amount of work performed, since it is very evident that both of these factors increase the amount which is given off from the body in the form of perspiration. Muscular work also increases the amount of water vapor excreted in the breath. According to Grandeau and Leclerc,^b a horse used in one of their experiments, when at rest, evaporated 6.4 pounds of water per day; when walking, 8.6 pounds; when walking and drawing a load, 12.7 pounds; when trotting, 13.4 pounds, and when trotting and drawing a load, 20.6 pounds. It is evident from these figures that the amount of water excreted, and hence the amount required, varies with the work performed.

It has been found that less water is required when the ration consists largely of concentrated feed than when large amounts of coarse fodder are consumed, and it is a matter of common observation that less water is consumed when green, succulent feeds form a considerable part of the ration than when it consists of dry feed. That the amount of water taken, even in dry feed, may be considerable is shown by the fact that a ration of 12.1 pounds oats and 15.4 pounds hay, according to Wolff's^a calculation, furnishes some 4.1 pounds water. A succulent ration would furnish much more. In Grandeau and Leclerc's experiments with the Paris Cab Company's horses it was found that with a mixed ration the average proportion of water drunk to dry matter supplied was 2.1:1 when the horses were at rest, and 3.6:1 when they were used for cab work. In some of Wolff's experiments the proportions varied from 2.35:1 to 3.5:1. The effect of the amount of work performed and of individual peculiarities on the amount of water required is illustrated by the following figures obtained by Grandeau and Leclerc: Two horses consumed respectively 24.9 and 30.7 pounds of water per day when their work consisted only

^a Landw. Jahrb., 1887, Sup. 3.

^b Ann. Sci. Agron., 1888, II, p. 276.

of walking; when the horses walked and in addition drew a load, the amounts of water consumed were 28.9 and 35.4 pounds; when trotting without a load, 31.3 and 27.6 pounds, and when trotting and drawing a load, 52 and 50.7 pounds, respectively.

In a number of feeding experiments carried on with horses at the experiment stations in the United States the amount of water consumed has been recorded. In tests at the New Hampshire Station,^a in which the ration consisted of different grain mixtures, with timothy hay and corn fodder, it was found that the quantity of water consumed varied from 70.94 pounds to 90.4 pounds per horse per day. It was observed that both the ration consumed and the amount of work performed influenced the quantity of water drunk, although the individuality of the horse had the most marked effect.

The amount of water consumed by horses on rations of timothy hay and alfalfa hay (with oats) was studied at the Utah Station.^b It was found that on an average larger amounts were consumed with the latter than with the former, the average amounts per day being some 78.51 and 88.85 pounds, respectively. The greater consumption of water on the alfalfa ration induced a greater elimination by the kidneys, but so far as could be observed this was not attended by any bad results nor was it found inconvenient.

At the Oklahoma Station^c a pair of mules, during hot summer weather, drank 113 pounds of water per head daily, and on one day the pair drank 350 pounds. On an average a pair of mules and horses, each weighing 2,130 pounds, drank 107 pounds of water per head per day while at moderate work. In these tests the grain ration consisted of Kafir corn, maize, oats, and bran.

The proper time to water horses is a matter concerning which opinions differ. Many feeders believe that they should be watered before feeding, while others are equally certain that feeding should precede watering. Experiments made on this subject at the Utah Station did not lead to definite conclusions.

The subject was recently investigated by Tangl^d at Budapest. The rations fed consisted of different mixtures of corn, oats, hay, and straw, and a number of experiments were made in which the only condition which varied was the time of watering. In some of the tests the horses drank before and in some after eating, and in others after the grain portion of the ration was eaten but before the hay.

Regarding these experiments Professor Tangl makes in effect the following statement: So far as was observed the time of drinking had

^a New Hampshire Station Bul. 82.

^b Utah Station Bul. 77.

^c Oklahoma Station Rpt. 1899, p. 31.

^d Landw. Vers. Stat., 57 (1902), p. 329; Twentieth Century Farmer, 1892, No. 82, p. 1.

no effect on the digestibility of a ration of grain and hay. When hay only was fed there seemed to be a slight advantage in watering before feeding. In general, horses may be watered before, during, or after meals without interfering with the digestion and absorption of food. All these methods of watering are equally good for the horse, and each of them may be employed, according to circumstances. It is obvious that certain circumstances may make it necessary to adopt one or other method. For instance, after severe loss of water, such as occurs in consequence of long-continued, severe exertion, the animal should always be allowed to drink before he is fed, as otherwise he will not feed well. Although all methods of watering are equally good for the horse, it is not desirable to change unnecessarily from one method to another. Animals, or at least some of them, appear to be not altogether indifferent to such a change. In the experiments referred to above it was found that whenever a change was made from the plan of watering after feeding to that of watering before, the appetite fell off for some days; not that the horses did not consume the whole of the food given to them, but for some days together they did not eat with the same avidity as before, and took a longer time to consume their rations completely. A similar effect was not observed when the change was from watering before to watering after feeding, or from watering after to watering during meals, or when the change was in the opposite direction to the last. It is possible that the method of watering before feeding, until the animal has become accustomed to it, produces a certain feeling of satiety. The time of drinking exercised a marked effect on the amount of water consumed and upon the amount of water excreted. The horses drank the greatest amount of water when it was given after feeding and the least when it was supplied before feeding. This was especially noticeable in the morning when water was sometimes refused if offered before feeding. The excretion of urine was directly proportional to the amount of water consumed. When it is desired to increase the excretion, the author recommends watering after feeding. The method of watering had no effect upon the amount or qualitative composition of the feces. Body weight varied with the amount of water consumed.

DIGESTIBILITY OF FEEDING STUFFS.

In the preceding pages reference has been made to the composition of different feeding stuffs and to the tests of the comparative value of different concentrated feeds and coarse fodders. The real value of any feeding stuff is determined, not alone by its composition, but also by its digestibility; that is, by the amount of material which it gives up to the body in its passage through the digestive tract. It is evident that if two feeding stuffs have practically the same composition, but

one gives up more material to the body than the other, that is, is more thoroughly digested, it must actually be more valuable than the other material. The bulk of the substance of almost all feeding stuffs is insoluble when eaten. Only material in solution can pass through the walls of the stomach and intestines into the circulation and be utilized by the body, therefore digestibility consists chiefly in rendering insoluble materials soluble. This is effected by the aid of digestive ferments and also by bacteria.

Digestion experiments are frequently made to learn how thoroughly a given feeding stuff or ration is assimilated. The usual method is to feed the material under consideration for a longer or shorter time, the amount and composition being determined. From the total nutrients consumed, the amount excreted and undigested in the feces is deducted, showing the amount of each retained in the body. It is the usual custom to express the amounts digested in percentages, the results thus obtained being termed coefficients of digestibility.

The digestibility of a number of different feeding stuffs has been tested with horses in this country and in Europe, although the number of such experiments is much smaller than in the case of cattle and sheep. The most extended series of American experiments with horses was carried on by Patterson^a at the Maryland Experiment Station. In the table below the American and foreign digestion experiments with horses are summarized. In a few cases values obtained with ruminants are also included in the table, since no coefficients of digestibility, obtained with horses, were available, and the data were needed in computing the value of rations discussed later (p. 48).

TABLE 2.—*Summary of coefficients of digestibility obtained in experiments with horses.*

Kinds of fodder.	Coefficients of digestibility.			
	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Alfalfa, uncured.....	78.2	.....	81.0	46.8
Alfalfa hay.....	74.6	19.1	70.2	39.0
Alfalfa (hay) stalks.....	72.6	.....	63.9	40.3
Alfalfa (hay) leaves.....	75.5	.....	76.6	52.1
Red clover hay.....	55.7	28.7	63.5	37.4
Meadow hay, best quality.....	63.5	22.0	65.5	48.2
Meadow hay, medium quality.....	57.5	18.0	58.1	39.0
Meadow hay, poor quality.....	54.6	23.6	52.2	37.6
Meadow hay, average.....	57.1	20.7	56.7	39.7
Timothy hay.....	21.2	47.3	47.3	42.6
Corn stover ^b	64.1	73.6	68.2	73.8
Ground corn shives.....	67.5	59.8	47.0	54.6
Wheat straw.....	27.7	65.7	28.1	17.7
Spelt straw.....	22.9	20.2	17.9	30.0
Corn silage ^c	49.3	80.0	68.6	66.7
Carrots.....	99.3	.....	93.8	.....
Potatoes.....	88.0	.....	99.4	9.1
Shelled corn.....	57.8	47.7	88.2	.....

^a Maryland Station Bul. 51.

^b Coefficients of digestibility of corn fodder as fed to ruminants.

^c Coefficients of digestibility as fed to ruminants.

TABLE 2.—Summary of coefficients of digestibility obtained in experiments with horses—Continued.

Kinds of fodder.	Coefficients of digestibility.			
	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
Corn meal	76.0	67.1	93.9	20.2
Oats.....	79.6	72.1	75.8	29.7
Ground oats.....	82.4	79.9	86.1	14.4
Wheat ^a	79.6	72.1	75.8	29.7
Rye.....	80.3	42.4	87.3	^b 100.0
Cotton-seed meal ^c	88.4	93.3	60.6	55.5
Field beans.....	85.9	13.2	93.6	65.4
Lupine seeds.....	94.2	27.3	50.8	50.8
Peas.....	83.0	6.9	89.0	8.0
Wheat bran ^c	77.8	68.0	69.4	28.6
Wheat shorts ^d	77.8	68.0	69.4	28.6
Dried brewers' grains ^c	79.3	91.1	57.8	52.6
Gluten meal ^c	88.2	94.4	89.8	.....
Linseed meal ^c	85.2	96.6	86.1	80.4
Molasses	100.0	.....	100.0	.....

^a As oats, no coefficients of digestibility of wheat having been found.

^b This value is without doubt much too high.

^c Coefficients of digestibility as fed to ruminants.

^d As bran, no coefficients of digestibility of shorts having been found.

In addition to the experiments reported above, a number have been found on record which show the digestibility of a mixed ration, but, generally speaking, the total number of digestion experiments with horses is small and, as will be seen, the tests are limited to a comparatively small number of feeding stuffs. Some 36 experiments were found on the digestibility of oats and 30 on the digestibility of meadow hay. The total number reported with alfalfa hay was 12, and in all other cases the number was very small. It is evident that more digestion experiments are needed with some of the common feeding stuffs, and that the digestibility of many additional materials should be studied.

As will be seen in the majority of feeding stuffs, the percentage of protein digested is fairly high, greater in grains and seeds than in hay and grasses, and least in the case of timothy hay and spelt straw. The high values reported in the table for protein of carrots and molasses need some explanation. The percentage of protein in the former is comparatively small, and it is doubtful if the figures reported show the actual digestibility, as it is difficult to determine in the case of a nutrient present in small quantities. In the case of molasses, the greater part of the nitrogenous material consists of amids or other nonalbuminoid bodies. It should be remembered that neither carrots nor molasses is fed for protein, but rather for the carbohydrates which they contain.

Generally speaking, the values obtained for the digestibility of fat are rather low, the fat of oats being most digestible and that of peas least digestible. In general it has been found that the determination of the coefficients of the digestibility of fat presents more difficulty than that of other nutrients.

It will be seen that nitrogen-free extract is quite thoroughly assimilated, the values ranging from 100 per cent in the case of molasses to 17.9 per cent in the case of spelt straw. The high value obtained for the digestibility of this nutrient in molasses is doubtless due to the fact that carbohydrates exist in it in soluble forms and hence in a condition very favorable for assimilation. Possibly the comparatively small amount of crude fiber present in carrots and potatoes accounts for the high digestibility of the starch which makes up the greater part of the nitrogen-free extract of the feeds. The principal sources of nitrogen-free extract in the ration are the cereal grains and their by-products, and it is interesting to note that the coefficients of digestibility of nitrogen-free extract of these materials is high. In the majority of feeding stuffs the crude fiber is not very thoroughly digested, the coefficients of digestibility being on an average less than 50 per cent. The high value given in the above table for the crude fiber of rye is unusual, and should be confirmed by further experiments before it can be accepted.

The digestibility of the different materials which make up the carbohydrate group has been recently studied by Weiser and Zalischek^a with horses and other farm animals. The following table shows the results obtained with a horse fed different combinations of meadow hay, broom-corn seed, and oats.

TABLE 3.—*Digestibility of different carbohydrates by a horse.*

Rations.	Cellulose or crude fiber.	Starch.	Pento- sans.	Undeter- mined constitu- ents.	Total ni- trogen- free extract.
	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>	<i>Per cent.</i>
8.1 pounds meadow hay and 10.8 pounds broom-corn seed.....	45.6	84.9	53.2	35.8	70.3
7 pounds meadow hay, 6.6 pounds broom-corn seed, and 6.6 pounds oats.....	30.5	97.7	33.8	34.0	70.9
8.3 pounds meadow hay and 7.7 pounds oats.....	48.7	96.7	49.7	57.0	72.0

As will be observed, the starch is much more thoroughly digested than the other carbohydrates. In all the experiments the values obtained for digestibility of the group, "nitrogen-free extract," were comparatively low. The authors attribute this to the presence of the material called "undetermined constituents," and advance the opinion that this material does not consist of carbohydrates though included in this group by the ordinary analytical methods. The thoroughness with which the different members of the carbohydrate group were digested by the horse and other farm animals is discussed in the following section.

^a Arch. Physiol. [Pflüger], 93 (1902), p. 98.

COMPARATIVE DIGESTIBILITY BY HORSES AND RUMINANTS.

In computing the digestible nutrients furnished by different feeding stuffs, it has been a common custom to use available data obtained from digestion experiments with farm animals without distinguishing between ruminants and nonruminants, although differences had been pointed out by a number of observers. The extended investigations of Wolff^a and his associates on the comparative digestive power of horses and sheep furnished much information on the subject. Dietrich and König^b summarized the available data regarding the question and discussed it. The matter was also considered in the summary prepared by Jordan and Hall.^c

The following table compares the coefficients of digestibility obtained with ruminants (chiefly sheep) and horses, the values given being the average of a large number of European and American experiments.

TABLE 4.—Comparison of digestibility of a number of different feeding stuffs by ruminants and horses.

Feeding stuffs.	Number of experiments.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.
		<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
Meadow hay:					
Ruminants	178	58.6	53.6	63.5	60.9
Horses	30	57.1	20.7	56.7	39.7
Difference in favor of ruminants		1.5	32.9	6.8	21.2
Timothy hay:					
Ruminants	6	48.1	52.7	64.0	46.6
Horses	2	21.2	47.3	47.3	42.6
Difference		26.9	5.4	16.7	4.0
Red-clover hay:					
Ruminants	56	58.6	57.2	65.7	50.0
Horses	5	55.7	28.7	63.5	37.4
Difference		2.9	28.5	2.2	12.6
Alfalfa hay:					
Ruminants	32	72.7	48.8	66.6	43.7
Horses	12	74.6	19.1	70.2	39.0
Difference		-1.9	29.7	-3.6	4.7
Wheat straw:					
Ruminants	3	23.4	35.6	38.7	55.5
Horses	6	27.7	65.7	28.1	17.7
Difference		-4.3	-30.1	10.6	37.8
Ground corn shives:					
Ruminants	9	46.7	78.2	60.4	57.0
Horses	2	67.5	59.8	47.0	54.6
Difference		-20.8	18.4	13.4	2.4
Oats:					
Ruminants	19	79.0	84.9	76.3	30.2
Horses	36	79.6	72.1	75.8	29.7
Difference		-0.6	12.8	0.5	0.5

^a Loc. cit., p. 60.

^b Zusammensetzung und Verdaulichkeit der Futtermittel, 2. ed., vol. 2, pp. 1070, 1128.

^c U. S. Dept. Agr., Office of Experimental Stations Bul. 77.

TABLE 4.—*Comparison of digestibility of a number of different feeding stuffs by ruminants and horses—Continued.*

Feeding stuffs.	Num- ber of experi- ments.	Protein.	Fat.	Nitro- gen- free ex- tract.	Crude fiber.
Corn meal:		<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>	<i>Per ct.</i>
Ruminants	13	71.1	92.4	94.3	53.8
Horses	4	76.0	67.1	93.9	20.2
Difference		-4.9	25.3	0.4	33.6
Field beans:					
Ruminants	18	88.1	86.7	91.6	71.9
Horses	5	85.9	13.2	93.6	65.4
Difference		2.2	73.5	-2.0	6.5
Potatoes:					
Ruminants	11	56.1	2.4	90.3	.....
Horses	1	88.0	.....	99.4	9.1
Difference		-31.9	2.4	-9.1	-9.1

As it will be seen in nearly every case the ruminants digested a larger percentage of fat, carbohydrates, and crude fiber than horses, the differences being most marked in the case of the crude fiber. These results, are, it seems fair to say, in accord with what might be expected from differences in the digestive organs of the different classes of animals. The ruminants have an opportunity to chew their food more thoroughly than horses and retain it longer in the digestive tract. It is said that on an average horses retain their food 4 days or less; cattle, 3 or 4 to 7 or 8 days; sheep or goats from 3 or 4 days with ordinary rations to 7 or 8 days when straw is eaten. That the food is actually more finely divided by ruminants in chewing and digesting is indicated by the mechanical condition of the feces; those from horses containing an abundance of fairly large fragments of hay and other coarse fodders, etc., while the feces of cattle commonly contain undigested residue in a finer state of division. In the case of sheep the feces contain the undigested residue in still smaller fragments. It is well known that fineness of division is an important factor in considering the thoroughness of digestion. The length of time any given food material remains in the digestive tract is also important. It is perhaps generally believed that crude fiber is chiefly digested by the action of bacteria in the intestine and it is obvious that the longer materials remain in the intestine the greater the opportunity for the action of such micro-organisms.

Weiser and Zalischek,^a in their investigation of the digestibility of the different constituents of the carbohydrate group, report results obtained with a horse and other farm animals. In nearly every case the rations were made up of different combinations of meadow hay, broom-corn seed, and oats. It is interesting to compare the average digestibility by different farm animals of the constituents into which

^aLoc. cit.

the carbohydrate group was divided. In the case of pentosans a steer digested on an average 63.4, sheep 53.6, horse 45.5, and swine 47.9 per cent. In the case of crude fiber the values were, steer 56, sheep 55.1, horse 40.6, and swine 22.8 per cent. The values for starch were, for a steer 96.6, sheep 89.4, horse 93.1, and swine 98.3. The values for the undetermined constituents were, for a steer 44.8, sheep 32.9, horse 42.3, and swine 28 per cent, and for total nitrogen-free extract, steer 74.7, sheep 68.5, horse 71.1, and swine 85.6 per cent. As will be observed the horse, generally speaking, digested different carbohydrates less thoroughly than the ruminants but more thoroughly than the swine.

The fact that, other things being equal, horses digest their feed less thoroughly than cattle, i. e., retain less nutritive material from any given ration when it passes through the digestive tract, has been long recognized. For this reason horse manure is richer than manure from cattle. In other words, the horse manure contains a larger proportion of the ration than cow manure, and hence, more of the nitrogen and mineral matter, especially phosphoric acid and potash, originally present in the ration. Investigations carried on by I. P. Roberts, G. C. Watson, and others at the New York Cornell Station^a have to do with this subject.

The value of the manure produced by horses was studied by Armsby^b at the Pennsylvania Station. Observations made with a number of horses indicate that a horse produces annually about 12,700 pounds of fresh manure, not including the amount dropped while at work. This quantity, which would be worth about \$13.50 as fertilizer, would require the use of about 2,500 pounds of straw for bedding. According to the author's calculations a ton of wheat straw economically used for bedding horses may result in 6 tons of fresh manure, although in general practice the amount is not likely to exceed 5 tons and may be much less if few animals are kept or the manure is infrequently removed.

RATIONS ACTUALLY FED AND FEEDING STANDARDS.

The amount of the different feeding stuffs required and hence the quantity of nutrients supplied to horses may be learned by observation or experiment or a combination of the two methods. Doubtless all practical horse feeders supply rations which they believe are suited to their horses' needs, and in stables where horses are fed in any considerable number economy demands that the amount fed shall be fixed and not vary according to the wishes of the feeder. When the feeding stuffs used are weighed and the condition of the horses is noted, a

^a See especially New York Cornell Station Bul. 56, p. 169.

^b Pennsylvania Station Rpt. 1892, p. 79.

feeding experiment results. Using average values obtained from many more or less complicated feeding experiments and other investigations, so-called feeding standards have been devised which are designed to show the amount of the different nutrients required per day for various conditions of work and rest. For the sake of uniformity, the standards are usually calculated on the uniform basis of 1,000 pounds live weight. The feeding standards show the amount of protein, fat, and carbohydrates required daily, and often the nutritive ratio also; that is, the ratio of protein to the sum of the carbohydrates and 2.25 times the fat. It is also possible to express the feeding standards in terms of protein and energy, since the functions of food, as previously stated, are to build and repair tissue and supply energy, protein alone serving for the former purpose, while all the nutrients yield energy. The best known feeding standards for horses and other farm animals are those computed by Wolff and revised by Lehmann.

Very frequently so-called standards for horses have been proposed which have shown the quantities of feeding stuffs required; for instance, the pounds of oats and hay needed per day per 1,000 pounds live weight. Such standards, or more properly standard rations, have been adopted in many countries for army horses, and in other cases where large numbers of horses are fed under uniform conditions. The digestible nutrients furnished by such standard rations can be calculated by the aid of figures showing the average composition and digestibility of the feeding stuffs. Such calculations have been often made, especially by earlier investigators, on the basis of data secured by digestion experiments with ruminants. However, this method can not give the most satisfactory results. If possible, coefficients of digestibility obtained in experiments with horses should be used.

Standard rations and feeding standards have been proposed by Grandeau and Leclerc, Lavalard, and others. These French investigators based their recommendations chiefly on investigations with the horses of the Paris cab companies and the French army. The work extended over a number of years and thousands of horses were included. In connection with the work the digestibility of the ration was determined.

In compiling this bulletin letters were addressed to express companies, cab companies, fire companies, and other organizations in different cities of the United States using large numbers of horses, requesting information regarding the rations fed. Information was also secured regarding the average weight of the horses. Similar values regarding horses fed by a number of cab companies, etc., in foreign countries were compiled from available published data. The rations fed army horses in the United States and other countries were also learned by correspondence and by compilation from various

sources and included for purposes of comparison as were also data regarding the rations fed in a large number of experiments carried on at the experiment stations in this country, only those tests being selected in which the horses maintained their weight.

No attempt has been made to gather statistics regarding race horses, hunters, fancy coach and driving horses, and similar animals, as the main purpose of the table was to learn the value of the rations fed farm and other work horses in this country. The table below shows the nutrients furnished per 1,000 pounds live weight by these rations and also the calculated digestible nutrients and the total energy supplied by them. In most cases the values for digestible nutrients were calculated by the aid of coefficients of digestibility obtained in experiments with horses and referred to on a preceding page (41). From the data thus collected the average quantities of nutrients furnished by the rations of horses performing like amounts of work were calculated. For purposes of comparison the Wolff-Lehmann feeding standards are also included in the table as well as standards or averages proposed by Lavalard and a number of other investigators.

TABLE 5.—*Rations actually fed to horses and digestible nutrients and energy in rations calculated to basis of 1,000 pounds live weight.*

	Weight of horses.	Rations actually fed.	Nutrients in ration per 1,000 pounds live weight.				Digestible nutrients in ration per 1,000 pounds live weight.				Energy in digestible nutrients.
			Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
ARMY HORSES.	Lbs.	Pounds.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Calo- ries.
United States:											
Cavalry	1,050	{Oats, 12..... Hay, 14.....	2.14	0.90	12.82	4.95	1.25	0.57	8.00	1.97	23,300
Artillery	1,125	{Oats, 12..... Hay, 14.....	2.00	.84	11.96	4.62	1.16	.53	7.48	1.84	21,750
Mules	1,025	{Oats, 9..... Hay, 14.....	1.84	.78	11.39	4.80	1.00	.48	6.88	1.94	20,250
Great Britain:											
In quarters	1,125	{Oats, 10..... Hay, 12..... Straw, 8.....	2.16	.84	12.42	6.23	1.38	.44	7.32	1.79	21,400
In camp	1,125	{Oats, 12..... Hay, 12.....	2.11	.80	10.76	3.80	1.47	.43	7.35	1.38	20,750
Cabs.....	1,125	{Oats, 10..... Hay, 12.....	1.92	.71	9.72	3.61	1.32	.36	6.57	1.32	18,650
With extra issue...	1,125	{Oats, 12..... Hay, 12..... Straw, 8.....	2.35	.92	13.46	6.42	1.53	.51	8.11	1.84	23,500
Mules (heavy work).	1,025	{Oats, 10..... Hay, 12..... Straw, 8.....	2.37	.92	13.63	6.84	1.51	.49	8.04	1.96	23,450
Mules in camp ...	1,025	{Oats, 12..... Hay, 12.....	2.31	.88	11.81	4.17	1.61	.47	8.27	1.51	22,750
Small mules.....	850	{Oats, 5..... Hay, 10..... Straw, 13.....	2.22	.86	14.24	9.21	1.26	.44	7.14	2.33	21,800
Small mules in camp.	850	{Oats, 6..... Hay, 12.....	2.04	.71	10.12	4.28	1.34	.32	6.60	1.60	19,050
Registered horses..	1,125	{Oats, 18..... Hay, 10.....	2.52	1.02	13.12	3.92	1.83	.61	9.28	1.37	25,800

TABLE 5.—*Rations actually fed to horses and digestible nutrients and energy in rations calculated to basis of 1,000 pounds live weight—Continued.*

	Weight of horses.	Rations actually fed.	Nutrients in ration per 1,000 pounds live weight.				Digestible nutrients in ration per 1,000 pounds live weight.				Energy in digestible nutrients.
			Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
ARMY HORSES—cont'd.											
France:											
Peace footing, maintenance ration—	Lbs.	Pounds.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Calo-ries.
Reserve	1,050	{Oats, 13.01 Hay, 8.82	2.09	0.83	10.81	3.41	1.50	0.49	7.56	1.21	21,150
Line	1,050	{Oats, 11.46 Hay, 7.72	1.84	.73	9.50	2.99	1.31	.43	6.65	1.06	18,550
Light cavalry .	850	{Oats, 10.36 Hay, 6.61	2.01	.80	10.42	3.24	1.45	.47	7.32	1.14	20,400
Artillery and train.	1,075	{Oats, 12.35 Hay, 8.49	1.94	.77	10.07	3.19	1.39	.45	7.03	1.13	19,650
Mules	950	{Oats, 10.8 Hay, 7.5	1.94	.77	9.99	3.18	1.38	.44	6.98	1.13	19,500
Warfooting, maintenance ration—											
Reserve	1,050	{Oats, 14.7 Hay, 8.82	2.27	.90	11.75	3.58	1.63	.54	8.28	1.26	23,050
Line	1,050	{Oats, 13.54 Hay, 7.72	2.05	.83	10.65	3.20	1.48	.50	7.52	1.12	20,900
Light cavalry .	850	{Oats, 11.76 Hay, 6.61	2.19	.88	11.39	3.41	1.59	.54	8.05	1.19	22,400
Artillery and train.	1,075	{Oats, 14.2 Hay, 8.49	2.13	.86	11.07	3.38	1.53	.51	7.80	1.18	21,700
Germany:											
Heavy ration—											
Garrison	1,050	{Oats, 11.16 Hay, 5.58 Straw, 7.81	1.88	.80	11.29	5.19	1.25	.50	6.81	1.33	19,550
March	1,050	{Oats, 12.27 Hay, 3.34 Straw, 3.9	1.66	.72	9.59	3.41	1.19	.48	6.36	.93	17,800
Field	1,050	{Oats, 12.61 Hay, 3.34 Straw, 3.9	1.70	.74	9.77	3.45	1.22	.49	6.50	.94	18,150
Light cavalry in garrison.	1,050	{Oats, 10.6 Hay, 5.58 Straw, 7.81	1.83	.77	10.97	5.13	1.21	.48	6.57	1.31	18,950
Light cavalry on march.	1,050	{Oats, 11.5 Hay, 3.34 Straw, 3.9	1.58	.70	9.15	3.33	1.13	.46	6.04	.90	16,950
Light cavalry in field.	1,050	{Oats, 12.61 Hay, 3.34 Straw, 3.39	1.69	.73	9.58	3.27	1.21	.49	6.45	.90	17,950
Light ration—											
Garrison	1,050	{Oats, 9.48 Hay, 5.58 Straw, 7.81	1.70	.71	10.35	5.03	1.10	.44	6.11	1.29	17,650
March	1,050	{Oats, 10.6 Hay, 3.34 Straw, 3.9	1.50	.65	8.66	3.24	1.07	.42	5.66	.88	15,900
Field	1,050	{Oats, 11.16 Hay, 3.34 Straw, 3.9	1.54	.68	8.97	3.30	1.10	.44	5.90	.89	16,550
OMNIBUS HORSES.											
France:											
Paris, 1879	1,240	{Beans, 1.4 Corn, 6.9 Oats, 10.1 Hay, 9.1 Straw, 10.5	2.61	.81	16.44	5.19	1.73	.44	10.55	1.43	27,350
Paris, 1880	1,240	{Beans, 1.4 Corn, 8.3 Oats, 8.8 Hay, 7.8 Straw, 11.1	2.52	.76	16.41	4.97	1.65	.42	10.60	1.31	27,000

TABLE 5.—*Rations actually fed to horses and digestible nutrients and energy in rations calculated to basis of 1,000 pounds live weight—Continued.*

	Weight of horses.	Rations actually fed.	Nutrients in ration per 1,000 pounds live weight.				Digestible nutrients in ration per 1,000 pounds live weight.				Energy in digestible nutrients.
			Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
STREET CAR HORSES—continued.											
Various European cities—Continued.	Lbs.	Pounds.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Calories.
Munich.....	1,150	{Corn, 6.6..... Oats, 11..... Hay, 5.5..... Straw, 4.4.....	1.64	0.58	10.59	2.64	1.11	0.35	7.46	0.74	18,800
Vienna.....	1,150	{Oats, 15.4..... Hay, 11..... Straw, 2.2.....	1.84	.73	10.02	3.39	1.29	.43	6.55	1.13	18,490
Average.....			1.86	.54	11.05	2.54	1.18	.23	8.22	.85	20,075
HORSES WITH LIGHT WORK.											
Driving horse, Wyoming station.	1,200	{Alfalfa, 21.25..... Straw, 3.2.....	2.38	.18	5.87	2.34	1.76	.05	3.58	.92	11,855
Carriage horse.....	1,050	{Oats, 10..... Hay, 12.....	2.06	.76	10.42	3.87	1.40	.40	6.97	1.44	19,935
Average.....			2.22	.47	8.15	3.10	1.58	.22	5.27	1.18	15,895
Fire company horses:											
Boston, Mass.....	1,400	{Groundgrain, 9.38..... Hay, 18.....	1.65	.68	9.57	4.57	.87	.41	6.14	1.73	18,000
Chicago, Ill.....	1,350	{Oats, 4..... Hay, 15.....	1.00	.43	6.77	3.50	.42	.24	3.70	1.45	11,365
Portland, Me.....	1,350	{Oats, 6..... Hay, 10.....	.96	.41	5.99	2.57	.52	.25	3.59	1.04	10,650
Albany, N. Y.....	1,350	{Oats, 12..... Hay, 12..... Straw, 10.....	1.58	.67	9.30	3.42	.95	.42	5.91	1.35	17,050
St. Louis, Mo.....	1,350	{Oats, 10..... Bran, 2.5..... Hay, 7.....	1.46	.58	7.76	2.38	.99	.39	5.16	.90	14,700
New York, N. Y.....	1,350	{Oats, 12..... Hay, 9.....	1.44	.62	8.30	2.78	.92	.40	5.45	1.07	15,550
Average.....			1.35	.56	7.95	3.20	.78	.35	4.99	1.26	14,555
General average for light work.			1.57	.54	8.00	3.18	.99	.32	5.06	1.24	14,890
HORSES WITH MODERATE WORK.											
Express horses:											
Richmond, Va., summer.	1,400	{Corn, 4.67..... Oats, 5.33..... Bran, 0.83..... Corn meal, 4.16..... Hay, 15.....	1.79	.78	11.78	3.64	.97	.45	8.19	1.46	21,650
Richmond, Va., winter.	1,400	{Corn, 4.38..... Oats, 7.5..... Bran, 0.83..... Corn meal, 1.64..... Hay, 16.....	2.00	.86	12.88	3.99	1.12	.50	8.93	1.59	23,750
Jersey City.....	1,325	{Corn, 2..... Oats, 19..... Bran, 1.5..... Hay, 9.5.....	2.45	1.03	13.45	3.57	1.66	.67	9.37	1.32	25,800
Boston.....	1,325	{Corn, 12..... Oats, 5.25..... Hay, 20.....	2.38	1.04	14.96	5.32	1.28	.60	9.75	2.12	27,000
Average.....			2.15	.93	13.27	4.13	1.26	.55	9.06	1.62	24,550

TABLE 5.—*Rations actually fed to horses and digestible nutrients and energy in rations calculated to basis of 1,000 pounds live weight—Continued.*

	Weight of horses.	Rations actually fed.	Nutrients in ration per 1,000 pounds live weight.				Digestible nutrients in ration per 1,000 pounds live weight.				Energy in digestible nutrients,
			Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
HORSES WITH MODERATE WORK—cont'd.											
Cab horses, United States.	<i>Lbs.</i>	<i>Pounds.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Lbs.</i>	<i>Calories.</i>
New York, N. Y.	1,200	Oats, 14 Hay, 10	1.87	0.79	10.72	3.53	1.20	0.53	7.06	1.37	20,100
Philadelphia, Pa.	1,200	Corn, 17 Oats, 9.28 Groundgrain, 4.40, ^a Hay, 13.50 Straw, 7.10	2.01	.82	12.13	4.13	1.19	.50	8.05	1.64	22,350
Washington, D.C.	1,200	Oats, 10 Corn, 5	2.56	1.12	16.50	6.43	1.28	.63	10.42	2.60	29,250
Do.	1,350	Hay, 23 Oats, 12 Hay, 12	1.58	.67	9.30	3.42	.95	.42	5.91	1.35	17,050
San Francisco, Cal.	1,350	Oats, 8 Hay, 16	1.39	.59	8.87	4.00	.70	.36	5.21	1.64	15,550
Average			1.88	.80	11.51	4.30	1.06	.49	7.33	1.72	20,860
Farm horses:											
Wyoming Station.	1,000	Alfalfa, 13.75 Straw, 2.25	1.85	.14	6.27	.....	1.37	.03	4.03	.....	8,240
New Hampshire Station.	1,235	Bran, 2 Corn, 6 Gluten meal, 6 Hay, 10	2.37	.93	10.49	2.90	1.59	.64	7.47	1.03	21,465
Do.	1,220	Bran, 2 Corn, 6 Oats, 8 Hay, 10	2.03	.86	11.92	3.26	1.21	.50	8.18	1.24	21,880
Do.	1,230	Hay, 10 Bran, 7 Corn, 8	2.03	.78	11.21	3.00	1.18	.41	7.65	1.14	20,275
Do.	1,220	Corn, 8 Linseed meal, 4 Hay, 10	2.35	.66	9.46	2.80	1.52	.36	6.64	1.24	19,000
Do.	1,250	Bran, 2 Corn, 8 Cotton-seed meal, 1 Hay, 10	1.73	.71	9.11	2.65	.98	.39	6.18	1.05	16,915
Do.	1,170	Bran, 2 Corn, 6 Oats, 8 Hay, 10	2.11	.90	12.43	3.41	1.27	.44	8.53	1.29	22,485
Do.	1,280	Bran, 7 Corn, 8 Hay, 10 Corn stover, 6	1.96	.75	10.80	2.89	1.14	.40	7.36	1.10	19,545
Do.	1,290	Hay, 6 Corn, 7 Oats, 4 Bran, 3	1.74	.71	10.44	2.88	1.05	.40	7.59	1.40	20,360
Do.	1,230	Hay, 12 Oats, 7 Corn, 7	1.85	.84	11.75	3.50	1.01	.46	8.14	1.37	21,510
Do.	1,300	Corn stover, 12 Oats, 7 Corn, 7	1.56	.66	9.87	2.45	1.04	.40	7.72	1.49	21,005
Do.	1,175	Corn stover, 12 Bran, 7 Corn, 7	1.94	.67	10.57	2.67	1.30	.39	8.07	1.63	22,105
Do.	1,280	Hay, 12 Bran, 7 Corn, 7	1.98	.75	10.97	3.33	1.11	.40	7.38	1.30	19,900

^a Corn meal and bran, 3.07:1.33.

TABLE 5.—*Rations actually fed to horses and digestible nutrients and energy in rations calculated to basis of 1,000 pounds live weight—Continued.*

	Weight of horses.	Rations actually fed.	Nutrients in ration per 1,000 pounds live weight.				Digestible nutrients in ration per 1,000 pounds live weight.				Energy in digestible nutrients.
			Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
HORSES WITH MODERATE WORK—cont'd.	Lbs.	Pounds.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Calo-ries.
Farm horses—cont'd.											
New Hampshire Station.	1,275	Hay, 12 Corn, 7 Oats, 4 Bran, 3	1.87	0.78	11.20	3.36	1.03	0.42	7.66	1.31	20,370
Do.....	1,340	Hay, 12 Corn, 7 Oats, 7 Hay, 6 Bran, 2½	1.70	.77	10.78	3.21	.93	.42	7.47	1.25	19,620
New Jersey Station	1,000	Corn, 4½ Dried brewers' grain, 8¾	3.21	.89	10.81	3.09	2.22	.65	6.99	1.38	22,440
Do.....	1,000	Hay, 6 Bran, 2½ Corn, 4½ Oats, 8¾	2.23	.89	12.11	2.68	1.45	.56	8.65	1.00	23,010
Do.....	1,150	Hay, 8 Corn meal, 6.25 Dried brewers' grain, 6.15	2.24	.65	9.55	2.82	1.49	.48	6.53	1.24	19,250
Do.....	1,180	Hay, 8 Corn meal, 6.55 Linseed meal, 5.40	2.61	.49	8.81	2.45	1.88	.35	6.60	1.17	19,425
Massachusetts Station.	1,100	Hay, 18 Wheat bran, 2 Provender, 6=crushed corn, 2.73; oats, 3.27	1.85	.76	11.85	5.25	.85	.41	7.04	2.14	20,385
Do.....	1,100	Hay, 20 Wheat bran, 2 Provender, 6=crushed corn, 2.73; oats, 3.27	1.96	.81	12.66	5.77	.87	.44	7.43	2.37	21,705
Do.....	1,080	Hay, 15 Wheat bran, 2 Provender, 4=crushed corn, 1.73; oats, 2.27	1.53	.60	9.62	4.43	.70	.32	5.58	1.81	16,200
Do.....	1,090	Hay, 15 Wheat bran, 3 Provender, 6=crushed corn, 2.73; oats, 3.27	1.85	.73	11.21	4.58	.94	.41	6.85	1.85	19,660
Utah Station	1,125	Timothy hay, 25.8 Corn, 23.7 Clover hay, 26.1	3.12	1.30	26.06	7.05	1.43	.61	18.60	2.68	44,815
Do.....	1,200	Oats, 11.8 Wheat, 11.8 Clover hay, 22.4	4.96	1.10	21.67	7.03	3.35	.60	15.36	2.53	42,040
Do.....	1,125	Oats, 9.7 Wheat, 9.7 Timothy hay, 22.4	4.44	.98	19.33	6.39	3.00	.53	13.67	2.30	36,520
Do.....	1,200	Corn, 19.4 Alfalfa hay, 24.5	2.44	1.01	20.50	5.70	1.10	.48	14.51	2.18	35,115
Do.....	1,400	Bran and shorts (1:1), 10	3.59	.69	11.43	4.96	2.71	.28	7.99	1.88	24,580

TABLE 5.—*Rations actually fed to horses and digestible nutrients and energy in rations calculated to basis of 1,000 pounds live weight—Continued.*

	Weight of horses.	Rations actually fed.	Nutrients in ration per 1,000 pounds live weight.				Digestible nutrients in ration per 1,000 pounds live weight.				Energy in digestible nutrients.
			Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
HORSES WITH MODERATE WORK—cont'd.	Lbs.	Pounds.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Calo-ries.
Farm horses—cont'd.											
Utah Station	1,370	Alfalfa hay, 25. Bran and shorts (1:1), 10.	3.72	0.71	11.83	5.16	2.81	0.29	8.27	1.96	25,480
Do.....	1,325	Timothy hay, 22.8. Bran and shorts (1:1), 10.	2.17	.75	11.93	5.61	1.11	.42	6.56	2.31	20,345
Do.....	1,420	Timothy hay, 23.5. Bran and shorts (1:1), 12.2.	2.28	.78	12.20	5.51	1.23	.44	6.82	2.25	21,015
Do.....	1,400	Alfalfa hay, 24.5. Bran and shorts (1:1), 12.2.	3.82	.75	12.29	5.09	2.89	.31	8.58	1.91	26,615
Do.....	1,400	Alfalfa hay, 25. Bran and shorts (1:1), 14.6.	4.14	.83	13.39	5.32	3.14	.38	9.36	1.99	28,555
Do.....	1,120	Alfalfa hay, 16. Bran and shorts (1:1), 12.6.	3.75	.79	12.32	3.96	2.86	.38	8.60	1.45	25,615
Do.....	1,230	Timothy hay, 13.7. Oats, 12.....	1.81	.76	10.84	4.15	1.06	.48	6.79	1.65	19,700
Do.....	1,235	Alfalfa hay, 14.7. Oats, 11.5.....	2.80	.72	10.65	4.66	2.15	.38	7.79	1.42	22,715
Do.....	1,385	Alfalfa hay, 19.7.	2.04	.31	6.07	3.56	1.52	.06	4.26	1.39	16,435
Do.....	1,385	Alfalfa hay, 19.9.	2.06	.32	6.14	3.59	1.54	.06	4.31	1.40	13,740
Do.....	1,420	Alfalfa hay, 32.6.	3.28	.51	9.80	5.74	2.45	.10	6.88	2.24	21,940
Virginia Station...	1,460	(Hay, 19.3 Corn, 11.3 Corn silage, 23.1.	1.95	.92	13.70	4.92	.81	.49	9.18	2.25	24,815
Do.....	1,155	(Hay, 16 Corn, 14.1.....	2.10	1.00	14.73	4.28	.92	.48	10.44	1.71	26,335
Average			2.46	.75	11.92	4.05	1.57	.40	8.09	1.62	22,760
General average for moderate work.			2.38	.77	11.99	4.08	1.49	.42	8.09	1.63	22,710
Farm mules, Virginia Station.	1,310	(Hay, 15.2 Corn, 10.5 Corn silage, 10.5.	1.70	.82	12.00	4.00	.72	.42	8.22	1.75	21,655
Do.....	1,190	(Hay, 14.5 Corn, 9.2 Hay, 9.8 Corn, 6.1.....	1.54	.72	10.86	3.70	.62	.34	7.34	1.50	19,030
Do.....	1,020	Corn silage, 12.2.	1.46	.69	10.29	3.61	.61	.36	6.96	1.65	18,670

TABLE 5.—*Rations actually fed to horses and digestible nutrients and energy in rations calculated to basis of 1,000 pounds live weight—Continued.*

	Weight of horses.	Rations actually fed.	Nutrients in ration per 1,000 pounds live weight.				Digestible nutrients in ration per 1,000 pounds live weight.				Energy in digestible nutrients.
			Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
HORSES WITH MODERATE WORK—cont'd.	Lbs.	Pounds.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Calories.
Farm mules, Virginia Station.	1,080	{ Hay, 13.4 Corn, 11.8 }	1.88	0.90	13.18	3.83	0.82	0.44	9.34	1.54	23,510
Do.....	1,275	{ Hay, 15.6 Corn, 10.5 Corn silage, 14.6 }	1.84	.88	12.96	4.38	.78	.46	8.84	1.96	23,480
Do.....	1,225	{ Hay, 11.7 Corn, 9.9 }	1.41	.67	9.93	2.94	.61	.32	7.00	1.18	17,700
Average			1.64	.78	11.54	3.74	.69	.39	7.95	1.60	20,675
HORSES WITH SEVERE WORK.											
Truck and draft horses: Chicago, Ill., daily ration.	1,500	{ Oats, 7.5 Hay, 20 }	1.38	.58	8.99	4.34	.64	.34	5.11	1.79	15,450
Chicago, Ill., holiday ration.	1,500	{ Oats, 2 Bran, 2.5 Oil meal, 0.2 Hay, 20 }	1.25	.47	7.74	4.16	.53	.26	4.11	1.75	13,000
South Omaha, Nebr.	1,500	{ Oats, 15 Hay, 12 }	1.65	.70	9.57	3.27	1.04	.45	6.23	1.27	17,800
New York, N. Y....	1,600	{ Oats, 23 Hay, 12 }	2.14	.91	11.96	3.54	1.44	.61	8.10	1.33	22,800
Washington, D. C., summer.	1,600	{ Oats, 19 Hay, 13 }	1.88	.79	10.74	3.49	1.21	.53	7.11	1.34	20,200
Washington, D. C., winter.	1,600	{ Oats, 12.5 Corn, 6.75 Ground grain, a 4 Hay, 10 }	1.93	.81	11.19	2.83	1.25	.51	8.16	1.03	21,550
Average (omitting holiday ration).			1.80	.76	10.49	3.49	1.12	.49	6.94	1.35	19,560
Draft horses, heavy, hard work. Sidney's estimate.	2,000	{ Beans, 6 Oats, 13 Corn, 3 Clover, 15 }	3.87	.75	11.72	3.11	1.94	.28	5.86	1.56	18,590
FARM HORSES, SETTEGAST'S ESTIMATE.											
Light work.....	1,250	{ Oats, 8 Hay, 7.5 Straw, 3 }	1.29	.50	7.45	2.83	.87	.29	4.61	.91	13,103
Moderate work.....	1,250	{ Oats, 10 Hay, 10 Straw, 3 }	1.64	.63	9.23	3.50	1.11	.35	5.80	1.17	16,500
Heavy work.....	1,250	{ Oats, 13 Hay, 12 Straw, 3 }	2.04	.79	11.31	4.16	1.40	.45	7.24	1.40	20,550
FEEDING STANDARDS AND AVERAGE RATIONS.											
Light work, Wolff-Lehmann.							1.5	.40		9.5	22,150
Medium work, Wolff-Lehmann.							2.0	.60		11.0	26,700
Heavy work, Wolff-Lehmann.							2.5	.80		13.3	32,750

a Bran, cornmeal, and cut hay 2:1.6:4.

TABLE 5.—*Rations actually fed to horses and digestible nutrients and energy in rations calculated to basis of 1,000 pounds live weight—Continued.*

	Weight of horses.	Rations actually fed.	Nutrients in ration per 1,000 pounds live weight.				Digestible nutrients in ration per 1,000 pounds live weight.				Energy in digestible nutrients.
			Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	Protein.	Fat.	Nitrogen-free extract.	Crude fiber.	
FEEDING STANDARDS AND AVERAGE RATIONS—continued.	Lbs.	Pounds.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Calo-ries.
Maintenance, moderate work, original, Grandeau.							2.14	.52	11.15	.....	26,900
Maintenance, moderate work, modified, Grandeau.							1.95	.44	9.93	.....	23,950
Paris Bus Co., horses, Lawes & Gilbert's computation.							1.60	.40	12.14	.....	27,200
Ordinary work, Lavalard.							1.10	a 11.0	.....	.....	22,510
Severe work, Lavalard.							1.30	a 11.0	.....	.....	22,880
AMERICAN EXPERIMENTS.											
Horses with light work:											
Driving horses.....							1.58	.22	5.27	1.18	15,895
General average.....							.99	.32	5.06	1.24	14,890
Horses with moderate work:											
Express and cab horses.....							1.06	.49	7.33	1.72	20,860
Farm horses.....							1.57	.40	8.09	1.62	22,760
General average.....							1.49	.42	8.09	1.63	22,710
Mules with moderate work: Farm mules.							.69	.39	7.95	1.60	20,675
Horses with severe work: Truck and draft horses.							1.12	.49	6.94	1.35	19,560

a This value represents total carbohydrates plus 2.25 times the fat.

The figures in the above table, showing the amounts eaten by army horses in the United States and other countries and by horses belonging to cab companies, etc., in foreign countries, were compiled from various sources, though in many cases the data have been recalculated, using, as previously noted, the values for composition and digestibility included in Tables 1 and 2. These figures are included chiefly for purposes of comparison with those showing the nutrients and energy in the ration of American work horses, especially those used by cab companies, express companies, and other private firms, and by farmers in different regions of the United States.

It will be noticed that the number of feeding stuffs used in making up the rations fed is not large, oats and corn being the common grains, and hay, usually timothy, the common coarse fodder. The amounts of nutrients and energy in the different rations of the horses making up the different groups varied within rather wide limits, which is not surprising when it is remembered that the horses were fed under many

different conditions and by a large number of feeders whose opinions regarding what constituted a proper ration naturally differed. Taken as a whole it does not seem unfair to assume that the figures are reasonably trustworthy, since it is highly probable that the private firms fed their horses rations which experience had shown were satisfactory and in the case of the farm horses, which were without exception fed at the experiment stations under controlled conditions, the rations were undoubtedly adequate, since the only results included are those of feeding tests in which the horses maintained their weight. As will be seen, the average values for the protein and energy in the rations of the horses performing light work are considerably less than similar values for horses performing moderate work. The data for the former group is much more limited than for the latter, but the relation is in accord with the commonly accepted theories. The farm mules consumed a ration furnishing less protein and practically the same amount of energy as horses performing similar work, though the tests with mules are too few for general deductions. The rations of the truck and draft horses performing severe muscular work furnished less protein and energy on an average than the rations of the horses with moderate work. This is not in accord with commonly accepted theories and may be explained in part perhaps by the fact that the data for the group performing severe work is much less extended than that for the group performing moderate work. There is every reason to suppose that the truck and draft horses received rations sufficient for their needs, as the firms owning them are known to make the effort to maintain their horses in good condition. Such truck and draft animals are often employed at work which is performed at a slow pace, and undoubtedly this has a bearing on the fact that they were able to perform a large amount of work on a comparatively small ration, as the speed at which work is performed has a marked effect upon the food requirements.

It will be seen that the average values, representing the amounts which were fed to American horses performing light, moderate, and severe work, differ somewhat from the commonly accepted feeding standards. The average values for horses at moderate work (express horses, cab horses, and farm horses), namely, 1.49 pounds digestible protein and 22,710 calories per 1,000 pounds live weight per day are considerably less than those called for by the Wolff-Lehmann standard or by Grandeau's estimates. The agreement with Lavalard's figures is much closer, the protein being a little larger and the energy very nearly the same. The average values for horses at light work, namely, 0.99 pound digestible protein and 14,890 calories per 1,000 pounds live weight, are also less than the values called for by the Wolff standard. The greatest difference, however, is observed in the values for horses with severe work, the American average being 1.12 pounds

digestible protein and 19,560 calories. It would be going too far to propose the adoption of these average values as standards in the place of those which have been commonly accepted. It is undoubtedly true that a feeding standard should be based on other data than the results of feeding experiments; however, in so far as the results represent the average practice of successful feeders they are worthy of consideration, and certainly emphasize the importance of undertaking investigations with a view to revising the standards. It should be remembered that the amounts of digestible nutrients in the rations actually fed were calculated with the aid of coefficients of digestibility obtained with horses and are, therefore, considerably lower than would be the case if average values obtained with ruminants had been used, a method of calculation which has been often followed in the past, but which does not seem desirable.

METHOD OF CALCULATING RATIONS.

The feeding value of any ration may be readily calculated and compared with the standards. Suppose a horse at moderate work and weighing 1,200 pounds is fed 11 pounds of oats and 10 pounds of timothy hay daily. The Wolff-Lehmann feeding standard for horses at moderate work calls for 1.8 pounds of protein and 26,700 calories per thousand pounds live weight. A horse weighing 1,200 pounds would therefore require 1.2 times as much, or 2.2 pounds protein and 32,000 calories. Oats contain 9.39 pounds of digestible protein and 122,100 calories per hundred pounds. Eleven pounds would therefore furnish 1.03 pounds of protein ($9.39 \times 0.11 = 1.03$), and 13,430 calories ($122,100 \times 0.11 = 13,430$). Timothy hay furnishes 1.25 pounds protein and 69,850 calories per hundred pounds. Ten pounds would therefore furnish 0.13 pounds protein ($1.25 \times 0.10 = 0.13$) and 6,985 calories ($69,850 \times 0.10 = 6,985$). The sum of the nutrients furnished by 11 pounds of oats and 10 pounds of hay would therefore be 1.16 pounds protein and 20,415 calories, or 1.04 pounds protein and 11,585 calories less than the standard calls for. This may be made up by adding more oats, hay, or other feeding stuff. The amount of oats required to furnish the necessary protein may be learned from the proportion $100 : 9.39 :: x : 1.04$; or, in other words, by dividing 1.04 by .0939, which gives 11.07. This quantity of oats would also furnish 13,517 calories, making the total protein of the ration 2.2 pounds and the total fuel value 33,932 calories. The fuel value of the ration is in excess of the standard, though the agreement is close enough for all practical purposes.

As previously stated, it is not necessary that the amounts furnished in a ration shall exactly equal those called for by the standard, but rather that they approximate them, being greater rather than less through a long period. Rations which will furnish the amounts called

for by other feeding standards, or by the average values deduced from American rations, can, of course, be calculated in the same way. As will be noted, the amount of feeding stuffs necessary to provide nutrients equal to the amount called for by the Wolff standard for a horse at moderate work is large compared with the amounts ordinarily used in this country. (See discussion on pages 57, 58.)

MUSCULAR WORK AND ITS EFFECT ON FOOD REQUIREMENTS.

It is commonly said that the amount of food required by horses is proportionate to their weight; it being self-evident that a large horse would require more material than a small horse to build and repair the body and to carry on all the vital processes which constitute internal muscular work. Investigations have shown that the requirements are more nearly proportional to the surface areas than to the body weight. Individual peculiarity is, of course, a factor which must be reckoned with, but the general statement is justified. The factor which has the greatest influence on the ration required is the amount of work performed, the ration increasing with the work. When horses which have been consuming a large ration and performing work are compelled to rest, even for a few days, the ration should be diminished. Girard^a found that the horses at the Meaux farm, doing hard work, were well nourished with a maximum ration of 16–20 liters (15–19 quarts) oats, 6.5 kilograms (14 pounds) hay, and straw ad libitum. If the work stopped for three days and the ration was not diminished the horses were subject to paralysis, resulting in death. It was therefore recommended that on Sundays and holidays the ration consist of 6 liters (5.7 quarts) oats at noon, and 6 liters (5.7 quarts) of bran mash night and morning, with the same amount of hay and straw as before. The disease practically ceased after this practice was followed. The facts brought out above are quite generally recognized by large feeders and it is a common custom to diminish the rations on Sundays and holidays.

In order to study the effects of work upon the amount of food required it is necessary to have some means of measuring and comparing the different kinds of work done.

MEASURING MUSCULAR WORK.

It has been said already that the total work performed by a horse consists of internal and external muscular exertion. The former includes the force expended in the digesting of food, the beating of the heart, etc.; the latter that expended in moving the body, i. e., in the motion of forward progression, and in drawing or carrying a load. The latter factor is the one of most importance in considering the horse as a

^aQuoted by Lavalard, loc. cit.

beast of burden. The amount of such muscular work has been calculated or measured in various ways. The methods of calculation are often complex and need not be discussed in detail. The amount of muscular work performed has usually been measured with some form of dynamometer. An extended series of experiments in which such an instrument was employed was conducted by Wolff.^a The dynamometer which he used consisted of a revolving arm, turning on a base, which could be weighted so as to increase the friction and hence the amount of work required to turn it. There were special devices for recording the number of revolutions made.

According to the classic experiments of James Watts, a horse can exert a power equal to 33,000 foot-pounds per minute, i. e., in 1 minute can exert a force sufficient to raise 33,000 pounds 1 foot. This value has been termed 1-horse power and has been accepted as a common unit for the measurement of force. In countries where the metric system is employed the more common unit is the kilogrammeter. This unit is equal to 7.2 foot-pounds. According to Watts's values, a horse working eight hours per day would perform work represented by $33,000 \times 60 \times 8 = 15,840,000$ foot-pounds. Later estimates give lower values. It has been calculated that an average horse will produce only about 22,000 foot-pounds per minute, which would be equivalent to 10,560,000 foot-pounds in a working day of eight hours.

According to Wolff's experiments,^a the day's work of a horse hauling a load eight hours on a level road amounted to 7,999,800 foot-pounds. Working the same length of time with a dynamometer the work amounted to 12,996,000 foot-pounds. As will be seen by the figures given below (p. 61), Lavalard obtained larger values in his calculations representing the amount of work performed daily by army horses.

Mention should be made in this connection of some comparatively recent investigations carried on at the American experiment stations and other institutions. At the Utah, New York (Cornell), Michigan, and Missouri stations and at the University of Tennessee, Sanborn, Roberts, Fulton, Waters, and Carson have studied the draft of different kinds of wagons under different road conditions and related topics, thus securing data for estimating the work done by horses under the conditions studied although the experiments were not made from this standpoint. A number of the experiment stations have also devoted considerable attention to testing the draft of plows and other agricultural implements.

^aFor full accounts of the extended experiments of Wolff and his associates concerning the digestibility of different feeds, the production of muscular work, etc., see *Landw. Vers. Stat.*, 20 (1876-77), p. 125; 21 (1877-78), p. 19. *Landw. Jahrb.*, 8 (1879), Sup. I; 13 (1884), p. 257; 16 (1887), Sup. III; 24 (1895), p. 125; also *Grundlagen für die rationelle Fütterung des Pferdes*, Berlin, 1885.

When a horse does road work it is evident that a large animal must expend more energy than a small one for the motion of forward progression. Lavalard ^a made weighings in experiments with some 30,000 horses belonging to the Paris cab companies and to the French army. He gives the average weight of horses of different kinds and of mules as follows:

TABLE 6.—*Average weight of horses.*

	Weight.	
	Kilograms.	Pounds.
Heavy draft horses	700-800	1,540-1,760
Light draft horses	500-600	1,100-1,320
Fancy horses, reserve cavalry horses, and horses of the line	450-510	990-1,120
Carriage horses and light cavalry horses	380-400	835-880
Artillery and train horses	480-495	1,055-1,090
Mules	430	945

Taking into account the average amount of muscular work expressed in foot-pounds, the speed at which work is performed, the duration of the work, and the amount of work done at a walk and trotting, the total work done per day by army horses carrying a rider weighing 80 kilograms (175 pounds) without a pack, and 120 kilograms (265 pounds) with a pack, and 90 kilograms (200 pounds) with accouterment for maneuvers, was calculated to be as follows:

TABLE 7.—*Work performed by army horses per day.*

Work per day.	Weight carried.	Velocity per second.	Work per second.	Duration of daily work.	Amount of work at different gaits.
ORDINARY WORK (RIDER WITHOUT PACK).	<i>Pounds.</i>	<i>Feet.</i>	<i>Foot-lbs.</i>	<i>Hrs. Min.</i>	<i>Foot-lbs.</i>
Walking.....	176	5.446	958.5	2 30	8,626,500
Trotting.....	176	9.022	1,587.9	1 30	8,574,660
Total					17,201,160
ROAD WORK (RIDER WITH PACK).					
Walking.....	265	5.446	1,443.2	1 30	7,793,280
Trotting.....	265	9.022	2,390.8	1 30	12,910,320
Total					20,703,600
MILITARY MANEUVERS (RIDER WITH LIGHT PACK).					
Walking.....	198	5.446	1,078.3	2 00	7,762,760
Trotting.....	198	9.022	1,786.4	3 00	19,293,120
Total					27,055,880

According to the calculation of an English army officer, Maj. F. Smith,^b the mean ratio of carrying power to body weight is 1:5.757; that is to say, it takes, roughly speaking, 5.75 pounds of body weight to carry 1 pound on the back during severe exertion (racing excepted). The rule he gives for ascertaining the carrying power of a horse is to

^a Loc. cit.^b Queensland Agr. Jour., 4 (1899), p. 493.

divide his body weight by 5.757, and if intended for only moderate work to add to the product 28 pounds. It has to be noted that the observations were made upon military horses. It is doubtful if it would work out so accurately if applied to all horses used for the saddle.

According to Lavalard^a the general opinion of cavalry officers who have studied the question is that measuring the distance covered and the rate of speed is practically the only method for determining the work done by a saddle horse. He states that Marcy computes that the work accomplished in a given time is proportional to the square of the velocity, his coefficients being 3.42 for walking or pacing, 16 for trotting, 28.62 for cantering, and 68.39 for a full gallop. In other words, 4.5 times as much work is performed when trotting as when walking, 1.75 times as much when galloping as trotting, and 2.5 times as much at a full gallop as on an ordinary trot or canter. These values are calculations rather than results obtained by experiments.

According to Poncelet^b a horse carrying a weight of 120 kilograms (265 pounds) and traveling at a speed of 1.1 meters (3.6 feet) per second for 10 hours per day performs 4,752,000 kilogrammeters (34,214,400 foot-pounds) of work. If the weight carried equals 80 kilograms (363 pounds) and the speed is 2.2 meters (7.3 feet) per second, 4,435,000 kilogrammeters (31,932,000 foot-pounds) of work will be performed in 7 hours.

The Prussian cavalry horses, according to Ellenberger's^b estimation, perform 1,500,000 kilogrammeters (10,800,000 foot-pounds) of useful work daily during the winter months. In the spring and summer months extra military duties increase this amount by 200,000 kilogrammeters (1,440,000 foot-pounds) daily. Different values have been proposed by other investigators for saddle horses of various kinds.

The speed at which the horse travels, the way in which the load is distributed, the external temperature, and other conditions evidently have an effect upon the work performed.

According to Colin's^b figures a horse walking 1 kilometer (0.63 mile) in 10 minutes travels at a speed of 1.66 meters (5.4 feet) per second. Trotting the same distance in 4.25 minutes the distance covered is 3.92 meters (12.9 feet) per second. The average speed of a trotting horse was calculated to be 2.72 meters (8.9 feet) per second. These values refer especially to army horses.

MUSCULAR WORK IN ITS RELATION TO THE RATION.

Many experiments have been made, chiefly in Europe, to determine the exact relation between the amount of muscular work performed and the amount of the different nutrients required per day. It is the opinion of Wolff and Muntz, and others who have been especially

^a Experiment Station Record, 12 (1900-1901), p. 4.

^b Quoted by Lavalard, loc. cit.

active in the study of these problems, that provided a sufficient amount of protein is supplied for physiological maintenance, i. e., to replace the wear and tear of body tissue, it is immaterial which of the three classes of nutrients (protein, fat, and carbohydrates) furnishes the energy necessary for external muscular work performed by horses. The opinion of these investigators, which is quite generally accepted, has been summarized as follows by Warington: ^a

The doctrine laid down by Wolff and his fellow workers at Hohenheim is a very simple one. He distinguishes between the food necessary to maintain the horse at rest without loss of weight and the extra food which must be given when work is performed, if the horse is again to be maintained, without its weight suffering loss. Between the weight of digestible matter in this extra food and the quantity of work accomplished there is a tolerably uniform relation. Wolff reckons that digested nutritive matter equivalent to 100 grams of starch is capable of producing 85,400 kilogrammeters of work, or, expressed in English terms, 1 pound of starch digested by a horse will accomplish 1,232 foot-tons of work. This is 48 per cent of the full work which the starch could accomplish if burned outside the body. The result is the average of many experiments with different diets.

The horse requires for its maintenance in weight while at rest a certain daily supply of albuminoid substance [protein], which must never fall below a certain quantity; but the extra food given when work is to be performed may consist indifferently of any digestible combustible substance, whether albuminoids or not. The horse keeper is thus at liberty to select from a wide range of foods, and is not obliged to give a preference to those which are specially nitrogenous. It should, however, be borne in mind that what has just been said applies strictly only to horses which are already in good working condition. Horses which are low in condition, and must gain in weight of muscle before they are fit for hard work, must, of course, receive a more nitrogenous diet.

A view very commonly held to-day is much the same and in accord with the above, viz, that provided an adequate quantity of protein and energy are available for maintenance, it is theoretically immaterial which class of nutrients furnish the energy for muscular work, although carbohydrates and fat are practically better suited for this purpose than protein, since any great excess of the latter is costly and may prove injurious to the health. In this case the term maintenance is not used in its strict physiological sense, but refers to a condition in which no appreciable amount of external muscular work is performed, and in which the internal muscular work is fairly uniform from day to day and the body weight practically constant. Most of the experiments reported on the effect of muscular work on the amount of nutrients required have had to do with external muscular work. A number of these investigations are referred to below. The effect of internal muscular work on food requirements has also been studied, especially in recent years. The experiments of this sort are referred to on page 68.

^a Jour. Bath and West of England Soc., 4. ser., 4 (1893-4), p. 188.

The experiments which have had to do with the rations best suited for horses employed at different kinds of work are obviously attempts to suit the food to the amount of work performed.

Lavalard^a calculated the amount of food required by army horses and mules to maintain weight on a peace and war footing as follows, the amount of work in the latter case being more than in the former.

TABLE 8.—*Calculated ration of French army horses and mules.*

	Peace footing.		War footing.	
	Oats.	Hay.	Oats.	Hay.
	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>	<i>Pounds.</i>
Cavalry horses, reserve	13	8.8	14.7	8.8
Cavalry horses, line	11.5	7.7	13.5	7.7
Light cavalry horses	10.4	6.6	11.8	6.6
Horses of artillery and train	12.3	8.5	14.2	8.5
Mules	10.8	7.5	.....	.....

Similar calculations, which have been made by others, have been summarized in Table 5, page 49.

Grandeau's experiments^b have shown the marked effect of pace on the amount of labor performed and food required. He showed that a horse walking 7.8 kilometers (5.8 miles) per day neither gained nor lost in weight on a daily ration of 8,800 grams (40 pounds) of hay, while a ration of 10,886 grams (49.5 pounds) was not sufficient, provided the horse trotted the same distance. When the horse walked the above distance and drew a load, the additional work being equivalent to 60,449 kilogrammeters (437,080 foot-pounds), a ration of 11,975 grams (26.4 pounds) of hay was sufficient for maintenance. A ration of 14,787 grams (32.6 pounds), all a horse would consume, was not sufficient for maintenance when the same work was done trotting.

According to Grandeau^b a horse of 500 kilograms (1,100 pounds) weight by the motion of forward progression through a horizontal distance of 10 kilometers (6.2 miles) at a speed of 1.5 meters (4.9 feet) per second loses 2.4 kilograms (5.3 pounds) in weight. A horse of the same weight covering a distance of 10 kilometers (6.2 miles) at a speed of 1.5 meters (4.9 feet) per second and producing 190,000 kilograms of work loses about 3.8 kilograms (8.4 pounds) in weight. Some of the reasons given for the fact that rapid work is less economical than slow work are the increased action of the heart when the horse is trotting or galloping; the lifting of his own weight at each step only to allow it to fall again, thus developing heat; and the increase of body temperature with exertion and the loss of heat by the evaporation of water through the skin and lungs. Grandeau determined the average amount of water thus evaporated under different conditions of work and rest with four different rations, the distance covered in every case being the

^a Loc. cit.

^b See note, p. 66.

same, and found that it varied from 6.4 pounds with a horse at rest to 20.6 pounds with a horse trotting and drawing a load. (See also p.38.)

The heat required for the evaporation of this amount of water is quite large and necessitates the combustion of a considerable amount of nutritive material in the body, thus diminishing the quantity of material available for the production of work.

EFFECT OF MUSCULAR WORK ON DIGESTIBILITY.

Grandeau's and Leclerc's experiments also indicate that the kind of work performed has some effect on digestibility. If the total amount of organic matter digested while at rest be represented by the number 1,000, the proportion digested during different kinds of work is shown, they consider, by the following table:

Relative proportion of total organic matter digested by horses at different conditions of rest and work.

At rest	1, 000
Walking.....	1, 032
At work walking.....	1, 007
Trotting	976
At work trotting	973
Drawing a cab	959

We see here that the moderate exercise is accompanied by a small but distinct improvement in the digestive functions, but that as soon as trotting commences digestion becomes less efficient than when at rest, while hard work while trotting still further diminishes the proportion of food digested. When we look into the details we find that the starch and sugar in the food are perfectly digested under all conditions of labor. The digestibility of the fat increases with exercise and does not diminish by labor below the point reached in repose. The digestibility of the albuminoids increases rather considerably with exercise and diminishes sharply when trotting commences. The principal matters usually grouped as soluble carbohydrates, but which in this case are merely the more digestible constituents of the fiber, undergo the greatest amount of variation, their digestibility rising considerably with exercise and falling still more considerably with hard labor. In the case of the more soluble portion of the fiber there is no rise in digestibility by exercise; the maximum rate of digestion is here obtained in repose, and diminishes considerably with increased bodily exertion. On the whole it appears that the constituents of the food which are most affected by rapid exertion are those whose digestion takes place to a large extent in the lower part of the intestines; the motion of the horse probably determines their more rapid progress through the system.

From the results of earlier experiments with German farm horses, Wolff, Kellner, and associates^a concluded that muscular work diminished digestibility little, if at all. The coefficients of digestibility of the ration when work was performed were slightly lower, but the differences were so small that they are regarded as of no importance. Grandeau's and Leclerc's values are within 3 per cent of those found by Wolff, and it seems fair to say that from a practical standpoint the diminished digestibility due to muscular work is not very important.

^a Landw. Jahrb., 8 (1879), sup. I., p. 73.

METABOLISM EXPERIMENTS AND THE DEDUCTIONS DRAWN FROM THEM.

There are many other complicated questions in horse feeding which have received much attention from investigators. As in experiments with man, the factors which serve as indices of changes going on in the body have been studied in this connection, the principal ones being (1) the balance of income and outgo of nitrogen, or nitrogen and carbon (as in metabolism experiments and respiration experiments), which is quickly modified by variations in food, work, and other conditions; (2) the amount of carbon dioxid produced per second as compared with the amount of oxygen consumed from the air, i. e., the respiratory quotient, which changes very quickly when any change takes place in the vital processes or in other forms of internal muscular work or when the amount of external muscular work varies. In determining the income and outgo of nitrogen the food, urine, and feces must be measured, and the amount of nitrogen in each determined. No very complicated apparatus is required, and such experiments are comparatively numerous. Where the income and outgo of carbon is determined, as well as that of nitrogen, the experiments necessitate the use of a respiration apparatus. In such experiments it is possible to calculate the balance of income and outgo of matter. If at the same time devices are used which permit the measurement of heat, the balance of income and outgo of energy may be studied also. The experiments of Boussingault, Wolff, Kellner, Hofmeister, Henneberg, and others, in which the balance of income and outgo of nitrogen were determined, have led to a number of interesting conclusions, some of which have already been referred to. Others follow.

Boussingault, who was one of the first to study these problems, showed that no nitrogen was assimilated from the air, but that all which was used in the body came from nitrogen compounds consumed in the food—a very important deduction, since it showed that no nitrogen could be taken from the air, and, that nitrogenous food was essential. The investigations of Grandeau, Leclerc, and their associates form one of the most extended studies ever undertaken with farm animals. The work was carried on with a very large number of horses belonging to one of the Paris cab companies, and extended over many years. There were seven series of experiments.^a In the first, a mixed ration consisting of “maize cake,” horse beans, maize, oats, hay, and straw was fed. The maize cake was made from starch factory and distillery waste, and contained a considerable portion of potato and barley as well as corn refuse. In the second series the

^a Ann. Sci. Agron., 1884, II, p. 325; 1885, I, p. 326; 1886, II, p. 351; 1888, II, p. 211; 1892, I, p. 1; 1893, I, p. 1; 1896, II, p. 113.

ration consisted of hay; in the third series, of oats and straw; in the fourth series, of hay and straw; in the fifth series, of maize and straw; in the sixth series, of horse beans and oat straw, and in the seventh series, of maize cake and oat straw. Analyses were made of the food, urine, and feces.

The effect of the rations and their digestibility was studied while the horses were at rest, walking, trotting, at work while walking, and at work while trotting. The work consisted in turning the arm of a dynamometer a definite number of times. Experiments were also made in which the horses drew a vehicle. The effects of the rations under different conditions of rest and work on temperature and weight of the animals were studied. Many of Grandeau's and Leclerc's deductions have already been referred to, one of the most interesting being a demonstration of the high value of maize as a food for horses.

MEASURING THE RESPIRATORY QUOTIENT AND THE DEDUCTIONS DRAWN FROM IT.

Experiments in which the respiratory quotient was determined are perhaps less numerous than those mentioned above. A determination of the respiratory quotient necessitates the measurement and analysis of the air taken into the lungs and excreted from them. The experiments which have been made in Germany are ordinarily carried on with the aid of a mask which covers the head, or by the insertion of a silver tube in the trachea. In both cases the air is breathed in and out through tubes provided with suitable valves, so that the air enters through one tube and leaves through the other. The air is measured and the samples analyzed. The ratio of oxygen consumed to carbon dioxid expired in a unit of time is called the respiratory quotient.

Zuntz^a and Hagemann and their associates have carried on a very extended series of investigations with horses. In most of these cases the respiratory quotient was determined. In many other cases other determinations, including the balance of income and outgo of nitrogen and carbon, were also made. Work was performed with a sort of treadmill and the amount could be measured. The deductions drawn from these experiments are of great interest, and some of the principal ones follow.

A horse weighing from 400 to 500 kilograms (880 to 1,100 pounds) excretes 26 to 40 liters (27 to 42 quarts) per minute from the lungs when no work is performed. If a horse takes exercise by walking the amount is increased to 80 to 90 liters (84 to 95 quarts) per minute. If 75 kilograms (542 foot-pounds) of work is done per second the respired air increases to 300 liters (317 quarts) per minute. If the

^aLandw. Jahrb., 27 (1898), Sup. III; see also Deut. Landw. Presse, 23 (1896), pp. 561, 571, 579.

work is still further increased the respired air amounts to 450 to 500 liters (475 to 528 quarts) per minute—in other words, 14 to 15 times what it was when no work was performed. However, in these different cases the ratio of carbon dioxid to oxygen has been found to vary very little.

PROPORTION OF ENERGY OF FOOD EXPENDED FOR INTERNAL AND EXTERNAL MUSCULAR WORK.

A horse converts 38.3 per cent of the energy of food into mechanical work. On account of the energy required for respiration, the beating of the heart, etc., only about 34 per cent of the energy of the food is actually available for external muscular work. The best record for a steam engine is said to be an efficiency per indicated horsepower of 22.7 per cent on the basis of total heat supply. Per delivered horsepower the amount is probably 10 per cent less. The animal is therefore seen to be a much more efficient machine than the engine.

Tests were made with a horse walking on a level, walking up an incline, and hauling a load on a level, and it was found that in the last case the energy of the food was not quite so economically used as in the first case. On the basis of his experiments, Zuntz computes that a horse weighing 500 kilograms (1,100 pounds) and performing no work requires 3,201 grams (7.1 pounds) of total nutrients containing 1,382 grams (3 pounds) of crude fiber. By total nutrients is meant the sum of the protein, carbohydrates, and fat multiplied by 2.4.^a Of this quantity of total nutrients not less than 2,100 grams (4.6 pounds) is required for the internal muscular work expended in digesting and assimilating the food, and 1,100 grams (2.4 pounds) for other purposes (largely some form of internal muscular work). Zuntz found that the amount of food required was affected by anything that disturbed the horse. In one experiment a horse confined in a stable was much disturbed by flies and consequently restless. The increased work in fighting the flies caused an increase of 10 per cent of the carbon dioxid excreted. This means that more food material was burned in the body than was the case when the horse was quiet, for the combustion of food in the body, it will be remembered, furnishes the carbon dioxid excreted in the breath.

In addition to other matters, Zuntz noted that the effect of body conformation had a marked effect on the economical production of work. He found that defects in external conformation and movements necessitate an increased amount of muscular exertion. This has an important bearing upon the market value of the horses. Too

^aZuntz uses this factor instead of 2.25, the factor commonly used by American investigators.

low a stall temperature also increases the amount of material required for maintenance. In many cases observed, this increase was hardly covered by 2 pounds of oats daily.

ENERGY REQUIRED TO CHEW AND DIGEST FOOD.

One of the most interesting of the lines of investigations followed by Zuntz was the determination of the energy required to chew and digest different foods. The experiments were complicated and too extended to describe here except in very general terms. As has been said, the respiratory quotient is a very delicate index of the changes which take place in the body, and it was found that the internal muscular work expended in chewing, swallowing, and digesting food could be determined by the variations in the respiratory quotient and the amount of carbon dioxid excreted when this kind of work was performed, as compared with the amount when the animal rested. Different feeding stuffs modified the respiratory quotient in different ways, and it was evident that some required more labor for digestion and assimilation than others. This is a matter of considerable importance, and it is evident that if two feeding stuffs of practically the same composition are digested with equal thoroughness but one requires for digestion and assimilation the expenditure of more internal muscular work than the other, it is really less valuable; in other words, the two may contain the same amount of digestible nutrients, but one causes the body more labor to assimilate than the other. On the basis of his average figures of composition and digestibility, 2.2 pounds of hay (1 kilogram) furnishes 0.862 pound of total nutrients, and 2.2 pounds (1 kilogram) of oats 1.353 pounds of nutrients. As regards nutritive value, hay and oats are therefore commonly said to be to each other as 400:600. As shown by Zuntz's experiments, 0.265 pound (115 grams), or 20 per cent of the total nutritive material present in 2.2 pounds (1 kilogram), of oats is expended in the labor of chewing and digesting them. In the case of 2.2 pounds (1 kilogram) of hay, 0.448 pound (205 grams), or 49 per cent of the total nutritive material, is required for the same purpose. Therefore hay and oats stand really in the proportion of 203:480. In other words, oats surpass hay in feeding value two and one-half times instead of one-half times, as they are ordinarily assumed to do.

"TRUE NUTRITIVE VALUE" OF FEEDING STUFFS.

Taking into account the internal muscular work required to chew and digest foods and deducting this from the digestible nutrients present in the foods, Zuntz calculated what we may call the "true nutritive value" of a number of feeding stuffs with special reference to horses. The results are shown in the following table:

TABLE 9.—Calculated "true nutritive value" of 1 pound of different feeding stuffs.

Feeding stuffs.	Dry matter.	Crude fiber.	Total digestible nutrients. ^a	Labor expended in chewing and digestion.		True nutritive value.	
				In terms of energy.	In terms of nutrients. ^a	In terms of energy.	In terms of nutrients. ^a
	<i>Per cent.</i>	<i>Pound.</i>	<i>Pound.</i>	<i>Calories.</i>	<i>Pound.</i>	<i>Calories.</i>	<i>Pound.</i>
Meadow hay (average quality).....	85	0.260	0.391	376	0.209	328	0.182
Alfalfa hay cut at beginning of bloom	84	.266	.453	394	.219	422	.234
Red clover hay	84	.302	.407	429	.239	303	.168
Winter wheat straw.....	86	.420	.181	535	.297	—209	— .116
Oats (medium quality).....	87	.103	.615	224	.124	883	.491
Maize	87	.017	.785	148	.082	1,265	.703
Field beans	86	.069	.720	200	.111	1,096	.609
Peas.....	86	.059	.687	183	.102	1,054	.586
Air-dry disemibittered lupines	86	.157	.645	294	.163	867	.482
Linseed cake.....	88	.094	.690	225	.125	1,018	.565
Potatoes.....	25	.010	.226	49	.027	358	.199
Carrots	15	.016	.113	37	.021	166	.092

^a Protein, plus carbohydrates, plus crude fiber, plus fat multiplied by 2.4.

As will be seen, the nutritive value of straw is negative in the above table. The authors call attention to the investigations which showed that so long as heat alone is considered, the digestible nutrients in straw should be given their full value as shown by the heat of combustion. Provided the labor of digesting a mixed ration does not exceed 2,100 grams (4.63 pounds, or 8,316 calories), the digestible nutrients in straw have a positive value. Provided the labor of digestion is greater than this an excess of straw would only increase the internal muscular work, so that approximately 116 grams (0.256 pound) of nutrients per kilogram is of no value for the body.

From the table the amount of any food or combination of foods required for maintenance may be calculated, according to the authors, as follows: When a horse weighing 500 kilograms (1,100 pounds) is fed hay alone, 8.2 kilograms (18.04 pounds) would be necessary, since, as previously stated, 3,200 grams (7.05 pounds) of nutrients are required for maintenance. As shown by the table, a kilogram of hay contains 391 grams (0.86 pound) total nutrients.

If the ration consists of 3 kilograms (6.6 pounds) of hay and 1 kilogram (2.2 pounds) of straw and it is desired to make up the balance with potatoes, the amount necessary may be calculated as follows:

	Grams.	Pounds.
Three kilograms (6.6 pounds) of hay furnish total nutrients amounting to.....	1,173	2.586
One kilogram (2.2 pounds) of straw furnishes total nutrients amounting to	181	.399
Total.....	1,354	2.984

Since the horse requires for maintenance 3,200 grams (7.053 pounds) nutrients, there remain 1,846 grams (4.07 pounds) total nutrients to be supplied by potatoes. This, divided by 226, the total nutrients in a kilogram (2.2 pounds) of potatoes, gives 8.2 kilograms (18.04 pounds) as the amount which must be added to the ration.

FIXING RATIONS ON THE BASIS OF INTERNAL AND EXTERNAL MUSCULAR WORK.

Zuntz believed that a ration suited to the performance of any kind of work can be calculated on the basis of the nutritive material and energy required for maintenance plus that needed for the work performed. The calculations are simplified by using the figures for "true nutritive value" given in the table above. On the basis of his experiments and observations he has calculated that a horse weighing 500 kilograms (1,100 pounds) requires for maintenance 3,201 grams (7.056 pounds) of true available nutrients. The amounts of true available nutrients and the energy required for the performance of work of different kinds and under different conditions by a horse weighing 500 kilograms (1,100 pounds), with a harness weighing 20 kilograms (44 pounds) are shown in Table 10. The value of total nutrients represents the protein + the carbohydrates + the fat $\times 2.4$. Fat is multiplied by 2.4, since, as stated on another page (68), it yields, according to Zuntz, that much more heat per gram than protein or carbohydrates when burned in the body.

TABLE 10.—*Available nutrients and energy needed for different kinds of work.*

	Total nutrients required.		Energy required.
	Grams.	Pounds.	Calories.
Forward progression per kilometer (3,281 feet) on level at speed of 66.7 meters (218.8 feet) per minute	37.6	0.083	149
Forward progression per kilometer (3,281 feet) on level at speed of 90 meters (295.4 feet) per minute	47.7	.105	189
Forward progression per kilometer (3,281 feet) on level at speed of 176-205 meters (577.4 feet-672.6 feet) per minute	71.5	.158	283
Climbing a gentle incline, raising body 100 meters (3,281 feet)	90.0	.198	356
Climbing a steep incline, raising body 100 meters (3,281 feet)	91.7	.202	363
Descending an incline, lowering body 100 meters (3,281 feet) on road with 5 per cent dip saves ^a	37.8	.083	150
Drawing a load on level 268 (work equivalent to plowing one hour, i.e., drawing a plow weighing 67 kilograms (147.4 pounds) a distance of 4 kilometers (13,124 feet):			
Not including forward progression	508.9	1.122	2,015
Including forward progression	659.3	1.454	2,611
Raising a load weighing 75 kilograms (165 pounds) 0.2 kilometer (656.2 feet) up incline of 10 per cent:			
A. For the 0.2 kilometer (656.2 feet) of forward motion	7.52	.017	29.8
B. For raising the body and harness 20 meters (65.6 feet)	18.33	.040	72.6
C. For 1,500 kilogrammeters (10,800 foot-pounds) mechanical work	39.15	.086	155.0
Total	65.0	.143	257.4
Trotting on level 1 kilometer (3,281 feet) with load of 75 kilograms (165 pounds):			
A. For forward motion, 1 kilometer (3,281 feet)	71.5	.158	283.0
B. For 75,000 kilogrammeters (540,000 foot-pounds) calculated mechanical work	142.4	.314	563.9
Total	213.9	.472	846.9
Progression on level 1 kilometer (3,281 feet) with 100 kilograms (220 pounds) load:			
A. At speed of 5.4 kilometers (17,717.4 feet) per hour	59.2	.131	234.5
B. At speed of 10.5-12.6 kilometers (34,451 feet-41,341 feet) trotting	91.0	.201	360.4
Climbing 1 kilometer (3,281 feet) on an incline of 10 per cent with 100 kilograms (220 pounds) load at speed of 5.4 kilometers (17,717 feet) per hour:			
A. For forward progression	59.2	.130	234.5
B. For 60,000 kilogrammeters (432,000 foot-pounds) mechanical work (climbing)	103.8	.229	411.0
Total	163.0	.359	645.5

^a As compared with forward progression.

As will be seen, the amount of total nutrients required increases with the increased speed; furthermore, a greater amount is required in climbing an incline than for forward progression on a level. In descending a gentle incline a much smaller amount of nutrients is required than in climbing the same incline, and as compared with the motion of forward progression there is also a saving in the amount of nutrients needed. In general, it was found that the energy expended was less than in traveling on a level, provided the incline was less than $5^{\circ} 45'$. At this point it was equal to the amount expended in traveling on a level. If the incline was greater, energy was required to keep the body from descending too rapidly and the expenditure was greater than on a level. The different values given in the above table for the nutrients required for the performance of different kinds of work are obtained by taking the sum of the requirements for the different components into which the work can be resolved; thus, in trotting 1 kilometer (3,281 feet) with a load of 75 kilograms (165 pounds) the total work consists in that expended for forward progression and for moving the load over the distance covered.

An example of the way in which the value of a ration was calculated by Zuntz follows:

If a farm horse weighing 500 kilograms (1,100 pounds) walks eight hours drawing a load at a speed of $\pm$ kilometers (2.5 miles) per hour, the work performed and the total available nutrients required would be as follows:

TABLE 11.—*Total nutrients required for work.*

	Total nutrients.	
	Grams.	Pounds.
32 kilometers (20 miles) forward progression	1,203	2.654
2,144,000 kilogrammeters (15,436,800 foot-pounds) mechanical work	4,071	8.975
Maintenance (exclusive of labor of digestion)	1,100	2.425
Total.....	6,374	14.054

The ration selected consisted of 3 kilograms (6.6 pounds) hay, 1.5 kilograms (3.3 pounds) straw, 2 kilograms (4.4 pounds) field beans, and a sufficient amount of oats to bring the total nutrients of the ration up to the required amount. The nutrients furnished by the hay, straw, and field beans would be as follows:

TABLE 12.—*Total nutrients furnished by tentative ration.*

	Total nutrients.	
	Grams.	Pounds.
3 kilograms (6.6 pounds) of hay, requiring per kilogram (2.2 pounds) for digestion 627 grams (1.38 pounds)	+546	+1.204
1.5 kilograms (3.3 pounds) of straw, requiring per kilogram (2.2 pounds) for digestion 445 grams (0.98 pound)	-174	- .384
2 kilograms (4.4 pounds) of beans, requiring per kilogram (2.2 pounds) for digestion 222 grams (4.9 pounds)	+1,218	+2.685
Total, 1,294 grams (2.85 pounds)	+1,590	+3.505

Subtracting 1,590 grams (3.505 pounds) from 6,374 grams (14.054 pounds) gives 4,784 grams (10.549 pounds), the total available nutrients which must be supplied by the oats. Dividing this sum by 491, the total available nutrients in a kilogram (2.2 pounds) of oats, gives 9.74 kilograms (21.43 pounds) as the amount required. This quantity of oats would require the expenditure of 1,208 grams (2.660 pounds) nutrients for the labor of digestion ($9.74 \text{ kilograms} \times 0.124 = 1.208 \text{ kilograms}$) (2.660 pounds). The total expenditure of nutrients which the ration necessitates for the labor of digestion would therefore be 2,502 grams (5.514 pounds) ($1,294 \text{ grams} + 1,208 \text{ grams} = 2,502 \text{ grams}$) (2.854 pounds + 2.660 pounds = 5.514 pounds). This exceeds by some 400 grams (0.882 pound), the value which is thought most desirable for the normal maintenance ration, i. e., 2,100 grams (4.630 pounds). The expenditure of this amount of nutrients for the work of digestion is thought desirable, because it would liberate the amount of heat which Zuntz calculates is required for maintaining the body temperature.

The ration may be adjusted on a more reasonable basis by diminishing the straw to 0.3 kilogram (0.66 pound) and the oats to 9.46 kilograms (20.812 pounds). The total quantity would be the same as before, and the amount required for the labor of digestion would be practically equal to that which is considered most desirable. The ration as adjusted would be as follows:

TABLE 13.—*Calculated ration for farm horse at work.*

Ration.	Requires for the labor of digestion.		Yields total nutrient.	
	Grams.	Pounds.	Grams.	Pounds.
3 kilograms (6.6 pounds) hay	627	1.382	546	1.204
2 kilograms (4.4 pounds) beans	222	.489	1,218	2.685
0.3 kilogram (0.66 pound) straw	89	.196	—35	.077
9.46 kilograms (20.812 pounds) oats	1,173	2.586	4,645	10.241
Total	2,111	4.653	6,374	14.207

This ration is, according to Zuntz, more satisfactory on economic grounds, since it does not contain an excess of material which must be wastefully assimilated. The fact is also pointed out that it might not prove satisfactory otherwise, since it contains a small amount of coarse fodder. The other examples given by Zuntz are more complicated.

SUMMARY.

Some of the principal deductions noted in this bulletin follow:

Horses, like other animals, require a definite amount of nutrients and energy per 1,000 pounds live weight for maintenance, and an extra amount, chiefly energy-yielding nutrients, for muscular work, the amount being proportional to the character and amount of work performed.

The amount of nutrients required increases with the amount of work done and with increased speed. More energy is required for climbing an incline than for traveling on a level. In descending an incline of less than $5^{\circ} 45'$ less energy is required than in traveling on a level. If the incline is greater than $5^{\circ} 45'$, more energy is expended (to prevent too rapid descent) than in walking on a level.

The ration should consist of concentrated and coarse feeds. The ratio by weight of coarse fodder or bulky feed to concentrated feed in the ordinary ration has been found to be about 1:1. Crude fiber may perhaps be fairly considered as the characteristic constituent of coarse fodder. The ratio of crude fiber to protein in the average of a large number of American rations has been found to be about 2:1.

Theoretically at least any sufficient and rational mixture of wholesome grains, by-products, roots, and forage crops, green and cured, may be used to make up a ration, though there is a very general prejudice in favor of oats and hay, corn and hay or corn fodder, and barley and hay (frequently that made from cereal grains), the first-named ration being perhaps that most commonly regarded as satisfactory for horses. A corn ration is very commonly fed in the middle West and Southern United States—that is, in the corn-producing belt. The barley ration is quite characteristic of the Pacific coast region. In the semiarid regions of the United States Kafir corn and alfalfa have proved to be of great value, owing to their drought-resisting qualities. Both crops have been found useful for horse feeding. Of the two alfalfa has been used much more commonly, and has given very satisfactory results.

Investigations have shown that it is often best to modify a ration, for instance, by substituting corn wholly or in part for oats, so that the horses remain in good condition, while at the same time the cost of the ration is diminished. Where large numbers of horses are fed this is often a matter of considerable importance.

Horses require a considerable amount of water daily, the quantity varying with different seasons of the year, the amount of work performed, etc. The time of watering, whether before or after feeding, is a matter of little importance, and, generally speaking, may be regulated to suit the convenience of the feeder. Horses become used to either method of watering, and irregularity should be avoided, as sudden changes are apt to prove disturbing.

Judging by the average results, representing the practice of a large number of successful American feeders, and also the results of many tests at the experiment stations in different parts of the United States, horses with light work consume on an average a ration furnishing per day 0.99 pound of digestible protein and 14,890 calories of energy per 1,000 pounds live weight. Similar values for horses at moderate work are 1.49 pounds digestible protein and 22,710 calories, and for

horses at severe work 1.12 pounds digestible protein and 19,560 calories. It is believed that these last values do not come as near representing a general average as the others, since they are based on a comparatively limited amount of data, and possibly the pace at which the work was performed may be responsible in a measure for the comparatively small amounts of nutrients and energy. Generally speaking, all these average values are less than those called for by the commonly accepted German feeding standards for horses performing the same amounts of work, yet from what is known regarding the American horses it seems fair to say that they were well fed.

Additional experiments are much needed which will result in a series of standards suited to American conditions.

Generally speaking, horses digest their feed, and especially the nitrogen-free extract and crude fiber in it, less thoroughly than ruminants.

The general deductions which have been drawn for horses apply with equal force to other animals of the same group, such as asses and mules.