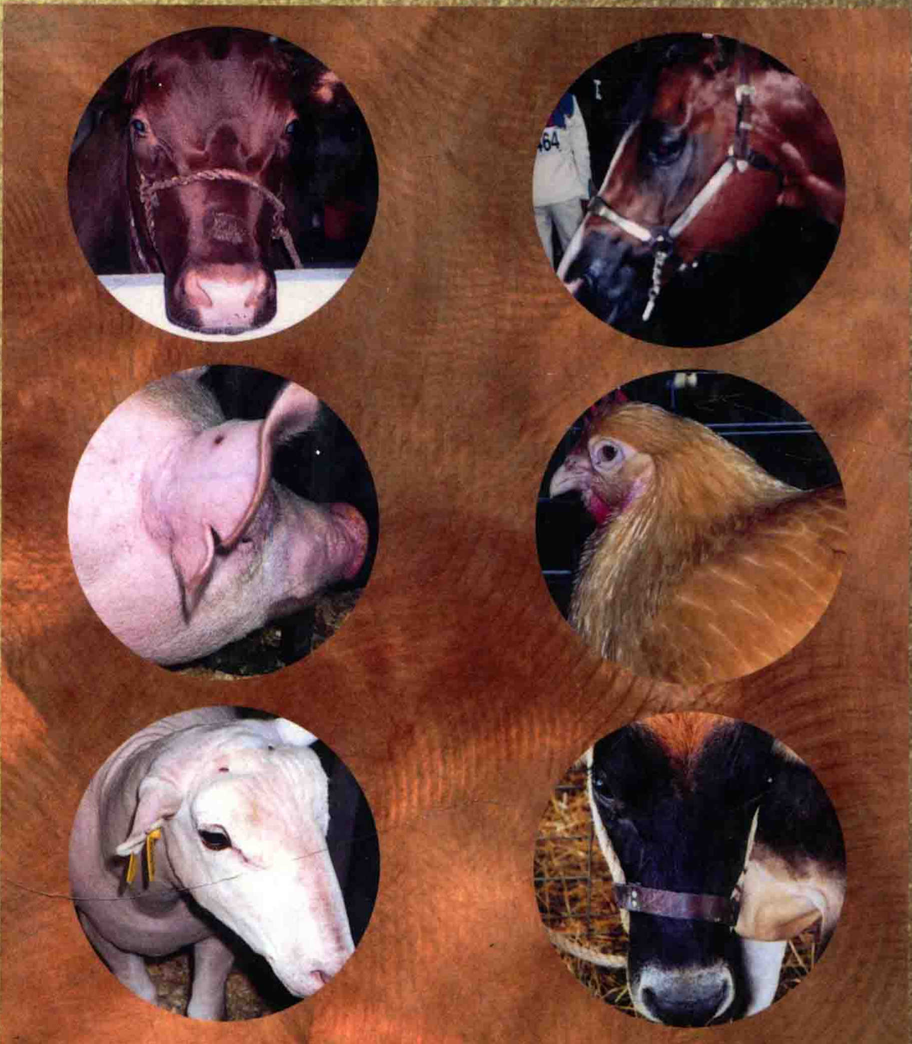
fifth edition

Feeds & Feeding



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Feeds and Feeding

Fifth Edition

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Preface

Feeds and Feeding, fifth edition, has been prepared by the senior author in order to keep current the text that was first written by Dr. Arthur E. Cullison and published in 1975. Following the traditional design and intent of Dr. Cullison—and also Dr. Robert S. Lowrey in the fourth edition—the current revision has been prepared as a text for an undergraduate course in animal nutrition and feeding. Therefore, only information pertinent to such a course has been included. While this book answers most basic questions pertaining to animal feeding and nutrition, it does not deal with more unusual feeds and is not intended as an all-purpose reference on such matters.

The overall importance of poultry meat—especially broiler chicken and turkeys—as sources of human food, has increased very rapidly, whereas meat from beef, pork, lamb, and veal has tended to either remain fairly constant or to decline. Charts have been prepared to demonstrate changes in consumption of animal and poultry meat per person, in the United States, between about 1960 and 1997, and presented in connection with the subject matter relevant to each of the species. Therefore, the fifth edition was designed to contain sections on the nutrition of laying hens, chicks for the production of broiler meat, and turkeys for the production of turkey meat. This represents a change in the format of the book.

This edition, following the tradition of the first four editions, is not meant as a review of original research literature. Most complete literature citations are found in each of National Research Council (NRC) Bulletins covering each of the species of animals for which nutrition and feeding programs have been included. Since each of the NRC Bulletins has been prepared by a committee of outstanding researchers and teachers, such bulletins have served as the ultimate authority in preparing nutrient and feed recommendations presented in this book. However, there are several other textbooks that contain excellent reviews of literature that deserve to be perused when the student wishes to go into greater depth on a subject. Although the last edition of Morrison's *Feeds and Feeding* was published nearly forty years ago, it still has a great deal of pertinent information that was useful to the senior author in preparing the fifth edition. *Feeds and Nutrition,* by Ensminger, Oldfield, and Heinemann, containing more than 1500 pages, is probably one of the most nearly complete books on the subject. In addition, more basic nutrition books such as Maynard's *Animal Nutrition* might be helpful reference books.

The fifth edition provides the latest information available on feed composition for use in ration formulation. However, because NRC Bulletins set up nutrient requirements quite differently for monogastric and ruminant animals—and even for species within a category—it is necessary to provide two sets of feed tables, one for the ruminant animals and one for the monogastric animals. Naturally, this necessitates additional pages in the text but such changes also become necessary as research findings and changes in types of animals develop. Such feed tables have been developed from those presented in the respective NRC Bulletins. The student should be made aware that different specie committees may differ in the manner in which feed table date are presented. In other words, the fact that some feed data are presented on a 100% dry matter basis, whereas other feed data are presented on an air-dry basis is a reflection of the specie committee preparing that bulletin. Either method of calculating formulations is quite effective as long as the student takes any such effects into account.

The authors wish to express appreciation to the National Academy of Sciences for permission to use the data that have been generated by the respective specie committees and presented in the respective specie bulletins. The following NRC Bulletins are cited in this fifth revision:

Nutrient Requirements of Beef Cattle, Seventh Rev. Ed., 1996.
Nutrient Requirements of Dairy Cattle, Sixth Rev. Ed., 1989.
Nutrient Requirements of Horses, Fifth Rev. Ed., 1989.
Nutrient Requirements of Poultry, Ninth Rev. Ed., 1994.
Nutrient Requirements of Sheep, Sixth Rev. Ed., 1985.
Nutrient Requirements of Swine, Tenth Rev. Ed., 1998.

The senior author, who prepared the fifth edition, would like to thank the following people for their contributions: Nancy Perry for preparation of the meat consumption per capita charts; James Herndon for the many photographic illustrations added to this revision; many people for personal communications concerning many subjects; many persons at several universities for counsel and assistance; and his wife Ena Perry for her patience while the text was being revised. However, no dedication of this edition is being made because it is a continuation of a project begun by my colleague, Dr. Arthur E. Cullison more than a quarter of a century ago.

Tilden Wayne Perry,
Senior Author, Fifth Edition

Introduction

It appears that people have been aware of how dependent they are upon all of the life of the earth, the sky, and the sea, and have attempted to aid in the propagation and nourishment of such life. Naturally, there have been exceptions wherein poor judgment in tilling the soil and management of the sources of the seas have resulted in decline in potential value of such resources. In more recent years, people are attempting to realign their vision and thinking in management of these very valuable resources.

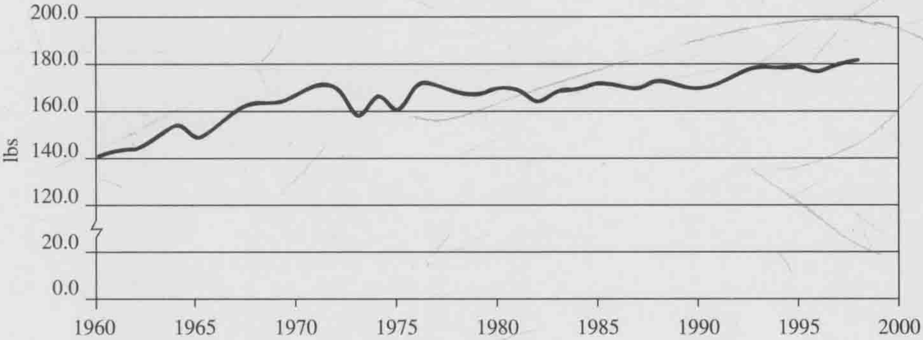
This text was meant to be of assistance in feeding several species of animals on which people are so dependent for their daily meat, milk, and eggs. A table is presented in this section that depicts how dependent people are upon the animal life for their daily food. These U.S. Department of Agriculture data demonstrate that we consume more than one-half pound (240 g) of livestock meat, poultry, and fish/shellfish per day, plus one egg every two days. Through the sciences of genetics, environmental control, nutrition, and physiology, the efficiency of meat and egg animal production has been improved. It is the hope of the authors of this text that *Feeds and Feeding* will assist the student and producer in continuing to increase the production of abundant supplies of wholesome and healthful meat animal products. The graph presented shows that people continue to utilize livestock and poultry as a source of food. In fact, the graph shows that our appetite for animal products has increased 29% (140.1 vs 180.0 lb per capita/year) from 1960 projected through 1998.

LIVESTOCK MEAT, POULTRY, AND FISH/SHELLFISH CONSUMPTION IN BONELESS EQUIVALENT WEIGHT, POUNDS PER PERSON, 1960–98[1]

	Beef	*Pork*	*Lamb and Mutton*	*Veal*	*Live-stock Meat*	*Young Chicken*	*Turkey*	*Total Poultry*	*Fish and Shellfish*	*Total Fish & Meat*	*Eggs*[2]
1960	59.8	48.9	3.1	4.2	116.0		4.9	24.1	10.3	150.4	—
1961	61.8	47.1	3.3	4.0	116.2		5.9	26.6	10.7	153.5	—
1962	62.5	47.7	3.4	3.8	117.4		5.6	26.2	10.6	154.2	—
1963	66.3	48.9	3.2	3.5	121.9	18.7	5.5	26.8	10.7	159.4	—
1964	70.5	49.2	2.7	3.7	126.1	19.1	5.8	27.4	10.5	164.0	—
1965	69.5	43.8	2.4	3.7	119.4	20.4	5.9	28.9	10.8	159.1	—
1966	73.8	43.1	2.6	3.2	122.7	22.0	6.3	30.8	10.9	164.4	—
1967	75.5	47.4	2.5	2.8	128.2	22.3	6.8	31.9	10.6	170.7	—
1968	77.5	48.7	2.4	2.6	131.2	22.5	6.4	31.7	11.0	173.9	—
1969	78.0	47.5	2.3	2.3	130.1	23.9	6.6	33.0	11.2	174.3	—
1970	79.8	48.6	2.1	2.0	132.5	25.2	6.4	34.1	11.7	178.3	311
1971	79.2	53.0	2.1	1.9	136.2	25.1	6.6	34.3	11.5	182.0	314
1972	80.8	48.1	2.2	1.6	132.7	26.2	7.1	35.8	12.5	181.0	308
1973	76.8	43.4	1.8	1.3	123.1	25.5	6.7	34.5	12.7	170.3	294
1974	80.7	47.1	1.5	1.6	130.9	25.5	7.0	34.9	12.1	172.1	288
1975	83.2	38.5	1.3	2.8	125.8	25.2	6.7	34.2	12.1	177.9	277
1976	89.1	41.0	1.2	2.7	134.0	27.4	7.2	36.6	12.9	183.5	270
1977	86.4	42.6	1.1	2.7	132.8	28.1	7.2	37.4	12.6	182.8	287
1978	82.4	42.8	1.0	2.0	128.2	29.2	7.2	39.2	13.4	180.8	272
1979	73.7	49.1	1.0	1.4	125.2	31.6	7.8	41.4	13.0	179.6	278
1980	72.2	52.6	1.0	1.3	125.5	31.5	8.3	41.9	12.5	180.6	273
1981	72.8	45.3	1.1	1.4	120.4	32.2	8.5	42.8	12.7	180.7	265
1982	72.6	45.3	1.1	1.4	120.4	32.4	8.5	43.1	12.5	175.4	264
1983	73.9	47.7	1.1	1.4	124.1	32.7	8.9	43.7	13.4	180.9	261
1984	73.8	47.5	1.1	1.5	123.9	34.1	9.0	44.9	14.2	182.6	261
1985	74.7	48.1	1.1	1.5	125.4	35.2	9.2	45.7	15.1	186.2	255
1986	74.5	45.6	1.0	1.6	122.7	36.0	10.2	47.5	15.5	185.7	252
1987	69.7	46.0	1.0	1.3	117.9	38.1	11.6	51.1	16.2	185.2	249
1988	68.7	49.2	1.0	1.2	120.1	38.3	12.4	52.1	15.2	187.4	244
1989	65.6	48.8	1.0	1.0	116.5	39.8	13.1	54.1	15.6	186.1	237
1990	64.1	46.8	1.0	0.9	112.8	41.1	13.9	56.4	15.0	184.2	235
1991	63.3	47.3	1.0	0.8	112.4	43.3	14.2	60.6	14.8	190.0	234
1992	63.0	49.9	1.0	0.8	114.7	45.4	14.1	62.6	14.9	192.9	235
1993	61.6	49.2	0.8	1.0	112.5	46.4	14.1	62.6	14.9	192.9	239
1994	63.9	49.9	0.9	0.8	115.4	47.4	14.2	62.2	15.1	192.9	236
1995	64.0	49.1	0.9	0.8	114.7	48.5	14.1	63.5	14.9	193.1	234.6
1996	64.2	45.9	0.8	1.0	111.9	49.8	14.5	64.3	14.7	190.9	237.2
1997[3]	63.8	44.9	0.8	0.8	110.3	51.1	14.2	68.3	14.7	193.9	239.7
1998[3]	62.3	48.3	0.8	0.7	112.1	54.1	14.8	68.9	NA	NA	243.4

[1] Adapted from *Feedstuffs Magazine,* Vol. 69 (No.47):14, whose source was the U.S. Department of Agriculture.
[2] Actual numbers.
[3] 1997-98 are projections.

Total Livestock and Poultry Meat Consumption per Capita per Year (Boneless Equivalent) in the United States, 1960–1998



People in America continue to show an inclination for more meat and poultry. From 1960 through projections for 1998, there has been a gradual and consistent 29% increase in consumption (140.1 lb vs 181 lb)
Source: USDA, as presented in *Feedstuffs*, 69(47):14, 1997

Contents

1 The Feed Nutrients

The proper feeding of livestock is for the most part a matter of supplying them with the right amounts of those chemical elements and compounds essential for carrying on the different life processes. These elements and compounds are as a group referred to as the feed nutrients. In view of the interchangeability of certain of these nutrients, their number is not exact; there are somewhere around 50 or more. The amount of each required varies but ranges for the different nutrients from less than a microgram per head per day for some to more than several kilograms per head per day for others. Feed materials supply livestock with these nutrients by serving as a source of the nutrients on the one hand and by serving as a carrier of the nutrients in facilitating the feeding operation on the other. It is intended that section 1 serve as a brief review of the chemical nature of the various nutrient materials.

I

Of the more than 100 known chemical elements, at least 20 enter into the makeup of the various essential feed nutrients. These 20 elements, their symbols, and their atomic weights are as follows:

Name	*Symbol*	*Atomic Wt*	*Name*	*Symbol*	*Atomic Wt*
Carbon	C	12	Magnesium	Mg	24.3
Hydrogen	H	1	Sodium	Na	23
Oxygen	O	16	Chlorine	Cl	35.5
Phosphorus	P	31	Cobalt	Co	59
Potassium	K	39	Copper	Cu	63.5
Iodine	I	127	Fluorine	F	19
Nitrogen	N	14	Manganese	Mn	55
Sulfur	S	32	Zinc	Zn	65.4
Calcium	Ca	40	Molybdenum	Mo	96
Iron	Fe	55.8	Selenium	Se	79

There is some evidence that chromium, silicon, tin, vanadium, nickel, and possibly others should be included in this group.

II

These elements, either alone or in various combinations, make up what are known as the *feed nutrients.* (The term *feed nutrient* is applied to any feed constituent that may function in the nutritive support of animal life.)

III

Many different feed nutrients are currently recognized, and new ones are still being found. Those currently recognized are as follows:

A. Carbohydrates. Carbohydrates contain carbon, hydrogen, and oxygen, with hydrogen and oxygen in the same proportion as in water. They consist largely of hexosans. These are made up of hexose or 6-carbon atom molecules. Pentosans, which are made up of pentose or 5-carbon atom molecules, are sometimes present. Tetrose, triose, and diose compounds are also sometimes present in small amounts but are generally unimportant.

1. Monosaccharides. Monosaccharides all have a chemical formula of $C_6H_{12}O_6$. They are formed in plants by the following reaction. This reaction is reversed by animals to release energy.

$$6\,CO_2 + 6\,H_2O + 673\text{ cal} \Rightarrow C_6H_{12}O_6 + 6\,H_2O$$

The more common monosaccharides are:

a. Glucose. Glucose (Figure 1-1) is found in corn syrup and also in blood. It is sometimes referred to as *dextrose* because it rotates the plane of polarized light to the right. It is about three-fourths as sweet as cane sugar.

b. Fructose. Fructose is found principally in ripe fruits and honey. It is the sweetest of all sugars.

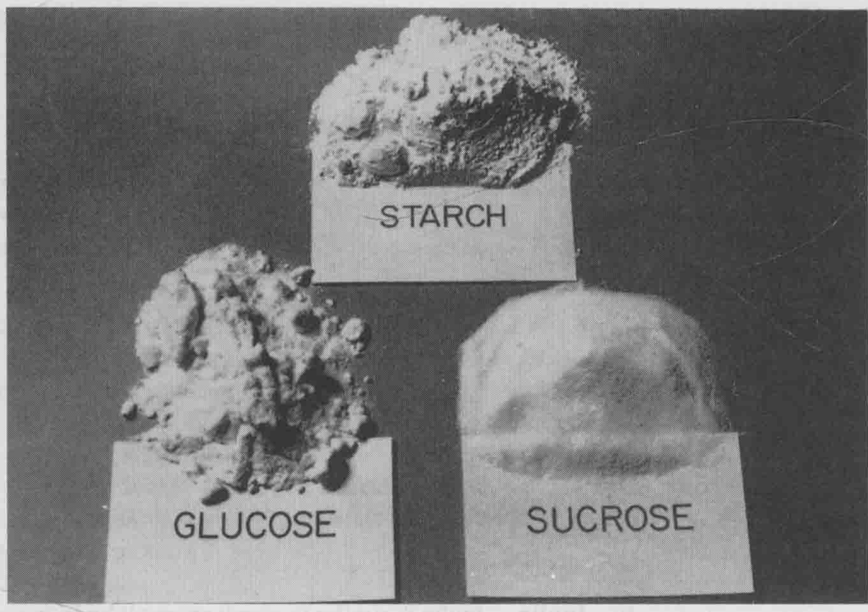


FIGURE 1-1
Essentially pure forms of a monosaccharide (glucose), a disaccharide (sucrose), and a polysaccharide (starch). (Courtesy of the University of Georgia College of Agriculture Experiment Stations)

c. **Galactose.** Galactose is obtained along with glucose upon the hydrolysis of lactose or milk sugar, a disaccharide listed below.

2. **Disaccharides.** Disaccharides all have a chemical formula of $C_{12}H_{22}O_{11}$. They are formed from two monosaccharide molecules with the loss of one molecule of water. The more common disaccharides are:

   a. **Sucrose.** Sucrose (Figure 1-1) is the same as *cane* and *beet sugar,* commonly used as food sweeteners. It is hydrolyzed by the sucrase enzyme to glucose and fructose.

   $$1 \text{ sucrose} + 1\ H_2O \rightarrow 1 \text{ glucose} + 1 \text{ fructose}$$

   b. **Maltose.** Maltose is the same as *malt sugar.* It is obtained from the hydrolysis of starch. Maltose is one-fourth as sweet as sucrose. It hydrolyzes entirely to glucose, by the enzyme maltase.

   $$1 \text{ maltose} + 1\ H_2O \rightarrow 2 \text{ glucoses}$$

   c. **Lactose.** Lactose is commonly referred to as *milk sugar.* It is found principally in milk. Lactose is one-sixth as sweet as sucrose. It is hydrolyzed by the enzyme lactase to glucose and galactose. (Lactose intolerance in humans is a lactase deficiency).

$$1 \text{ lactose} + 1\, H_2O \rightarrow 1 \text{ glucose} + 1 \text{ galactose}$$

3. **Polysaccharides.** Polysaccharides all have a chemical formula of $(C_6H_{10}O_5)_n$. They are formed by the combination of unknown numbers of hexose molecules. Those polysaccharides usually regarded as important in animal nutrition are:

   a. **Starch.** Many plants store energy in the form of starch (Figure 1-1). Starch is a major component of most livestock rations (especially fattening rations) and is highly digestible. Hence, it is a primary energy source for livestock. Starch hydrolyzes as follows:

   $$\text{Starch} + H_2O \rightarrow \text{Dextrin}$$
   $$\text{Dextrin} + H_2O \rightarrow \text{Maltose}$$
   $$\text{Maltose} + H_2O \rightarrow \text{Glucose}$$

   b. **Inulin.** Inulin is similar to starch except it hydrolyzes to fructose rather than glucose. It is not very prevalent. Inulin is found especially in Jerusalem artichokes.

   c. **Glycogen.** Glycogen is sometimes referred to as *animal starch.* Found only in the animal body, it is produced in the liver and is the primary carbohydrate reserve in the animal. It hydrolyzes entirely to glucose.

   d. **Hemicellulose.** Hemicellulose is a term used to denote a group of substances that lie chemically between sugars and starch on the one hand and cellulose on the other. Most of such substances are more digestible than cellulose but less digestible than sugars and starch. However, the extent of their presence is not reflected by the conventional proximate analysis. Consequently when they are present in a feed material in significant amounts, additional determinations are required. Hemicelluloses are distributed widely in forage crops and certain other materials frequently used for feeding purposes. They are especially abundant in the extract resulting from certain wood manufacturing processes from which the product known as wood molasses is made.

   e. **Cellulose.** Cellulose (Figure 1-2) is a principal constituent of the cell wall of plants. It is most abundant in the more fibrous feeds. It is generally low in digestibility. Also, it may reduce the digestibility of other nutrients. Cattle, sheep, and horses digest cellulose fairly effectively; it is only slightly digested by swine. Cellulose can be hydrolyzed by special processes to glucose.

   f. **Lignin.** Lignin is not a true carbohydrate. It contains too much carbon, the hydrogen and oxygen are not in the right proportion, and some nitro-

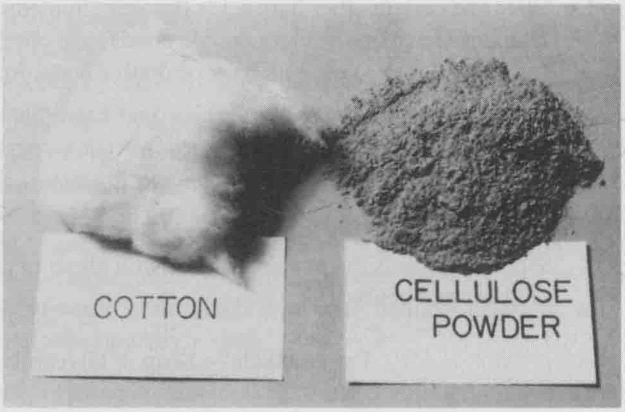


FIGURE 1-2
Two essentially pure forms of cellulose. (Courtesy of the University of Georgia College of Agriculture Experiment Stations)

gen usually is present. However, lignin is usually considered with the polysaccharides. It is found largely in overmature hays, straws, and hulls. It is essentially indigestible by all livestock. Also, it may reduce the digestibility of other nutrients, especially cellulose. Lignin is of no known nutritive value except as a bulk factor. In plants, it serves as a structural material.

B. Fats. Fats contain carbon, hydrogen, and oxygen with more carbon and hydrogen in proportion to the oxygen than do carbohydrates. Fats contain 2.25 times as much energy per lb or kg as do carbohydrates. They are formed by the combination of 3 fatty acids with glycerol.

$$\text{Fatty acid} + \text{Glycerol} \rightarrow \text{Fat} + \text{Water}$$

Examples of individual fat-forming reactions are:

$$\text{Stearic acid} + \text{Glycerol} \rightarrow \text{Stearin} + \text{Water}$$
$$3\ C_{17}H_{35}COOH + C_3H_5(OH)_3 \rightarrow C_{57}H_{110}O_6 + 3\ H_2O$$

$$\text{Palmitic acid} + \text{Glycerol} \rightarrow \text{Palmitin} + \text{Water}$$
$$3\ C_{15}H_{31}COOH + C_3H_5(OH)_3 \rightarrow C_{51}H_{98}O_6 + 3\ H_2O$$

$$\text{Oleic acid} + \text{Glycerol} \rightarrow \text{Olein} + \text{Water}$$
$$3\ C_{17}H_{33}COOH + C_3H_5(OH)_3 \rightarrow C_{57}H_{104}O_6 + 3\ H_2O$$

1. Stearic acid and palmitic acid are two of many different saturated fatty acids (no double bonds) that combine with glycerol to form two of the more common saturated fats (stearin and palmitin).