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Farm Manure

Robt. M. Salter and C. J. Schollenberger

OHIO
AGRICULTURAL EXPERIMENT STATION
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FARM MANURE[1]

ROBT. M. SALTER AND C. J. SCHOLLENBERGER

INTRODUCTION

One billion tons of manure, the annual product of livestock on American farms, should produce, if completely recovered, carefully preserved, and efficiently used, 3 billion dollars' worth of increase in crops. The potential value of this agricultural resource is three times that of the Nation's wheat crop and equivalent to $440 for each of America's 6,800,000 farm operators. The crop nutrients in this amount of animal excrement, if purchased in the form of commercial fertilizers, would cost more than six times as much as American farmers paid for fertilizers in 1936. The organic matter content is twice the soil organic matter destroyed in the growing of the Nation's grain and cotton crops.

Unfortunately, only a small fraction of the potential crop-producing and soil-conserving value of the excrement from farm stock is actually realized. Probably one-half of the excrement is dropped on pastures, and its full value remains unrealized because of improper distribution. A smaller and indeterminate amount is dropped on roads and lanes. Enormous losses occur in handling through failure to save the valuable liquid portion, through loss of nitrogen in fermentation and drying, and through the leaching out of soluble nutrients by rain. Practices in the field application of manure are frequently inefficient. It is, therefore, probably safe to assume that not more than one-fourth to one-third of the potential value of the manure resource of the Country is now realized on harvested crops. Manure dropped on pastures produces some return and thus is not dead loss. A regrettably large part of the shrink in the value of the manure resource arises in wasteful methods of handling that portion which is theoretically recoverable. That it is economically feasible to prevent much of this loss has been conclusively demonstrated both experimentally and practically.

The wasteful and inefficient methods of handling manure obvious in all sections of the Country may be taken as evidence that farmers generally do not understand the true nature of manure and especially the perishable character of its valuable constituents or the losses incurred in its improper handling. The purpose of this bulletin is to present facts regarding the production, losses, care, and field management of manure pertinent to an intelligent understanding of the manure problem and to its successful solution on the practical farm. The background for this discussion is found in the published reports of literally hundreds of scientific studies that have been conducted in the field and laboratory both in America and in Europe. The mass of accumulated information is so great that specific reference must be limited to results chosen as typical of those bearing upon each phase of the problem.

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[1]A part of the material appearing in this bulletin has been published under the title "Farm Manure" by Robt. M. Salter and C J. Schollenberger in the 1938 Yearbook of Agriculture of the U. S. Department of Agriculture, pages 445-461.

TABLE 1.—Annual production of animal excrements in the United States

Based on livestock on farms reported in 1935 census

	Annual production	Produced for each acre in crops and pasture
	Tons	*Tons*
United States	897,865,000	1.02
New England States	13,754,000	1.31
Middle Atlantic States	43,713,000	1.58
East North Central States	146,857,000	1.48
West North Central States	260,111,000	1.08
South Atlantic States	65,324,000	1.28
East South Central States	69,030,000	1.33
West South Central States	155,050,000	.86
Mountain States	96,200,000	.59
Pacific States	47,826,000	.90

Based on Ames and Gaither's values for daily production, Ohio Agricultural Experiment Station Bulletin 246, page 726. (All totals have been reduced 20 per cent to allow for immature animals in census totals.)

Class of animal	Solid excrement	Liquid excrement	Total
	Tons	*Tons*	*Tons*
Horses and mules	85,787,000	19,504,000	105,291,000
Cattle	519,258,000	193,698,000	712,956,000
Sheep	15,890,000	9,856,000	25,746,000
Hogs	31,163,000	17,893,000	49,056,000
Chickens	4,768,000	....	4,768,000
Total	656,866,000	240,951,000	897,817,000

THE MANURE PRODUCTION PROCESS

The greater ease of maintaining soil productivity under livestock farming than under cash cropping arises directly from the fact that a relatively large part of the nitrogen and mineral elements in the feed is not retained by the animal. Together with a somewhat smaller fraction of the original organic matter, they are voided in the excrement and are available for return to the soil. A consideration of the processes of digestion and excretion is helpful in evaluating the fertility economy of livestock farming and in understanding the true nature of manure.

The nature of these processes is aptly pictured by Russell and Richards of the Rothamsted Experiment Station (84):[2]

> "....we have to look upon the animal as a huge tube with thick walls and open ends, one end being the mouth and the other the anus, while the walls form the animal's body. Food is taken into the tube through the mouth, but although inside the tube it is still virtually outside the body, and cannot enter until it has been broken down by various digestive fluids and changed to something simple and soluble. Material that for any reason cannot be broken down in this way is not taken up, and simply passes on to be excreted as the solid faeces.
>
> "On the other hand, the material that is dissolved or digested can pass through the wall into the animal's body, where it undergoes further changes, some being built up into body substance, meat, etc., some made into milk, some oxidized and breathed out as carbonic acid and water, and some passes out into the urine.

[2]Numbers in parentheses refer to general bibliography.

"We have, therefore, to distinguish two kinds of excretions, the solid faeces, representing the undigested material that the animal cannot deal with, and the liquid urine, representing the digested material dissolved, assimilated and then passed out by the animal."

The chemical changes undergone by various constituents of the animal's food in the digestive tract are highly complex. They are effected by enzymes of the digestive fluids and by the numerous bacteria which inhabit the intestinal tract. The importance of the latter is indicated by the fact that their living and dead cell masses make up 20 to 30 per cent of the solid excrement. Various constituents of the feed undergo digestion in different degree. Sugars and starches are almost wholly digested. Fats, hemicelluloses, and celluloses are somewhat less attacked but still highly digestible, the latter almost solely by the aid of bacteria. In contrast, lignins are very resistant and hence tend to accumulate in the feces. Proteins, which carry most of the nitrogen of the feed, vary considerably in digestibility. For example, the protein of cottonseed meal, a "concentrate", is about 80 per cent digestible, whereas only about one-half of that in timothy hay, a typical "roughage", is digested. One-fifth of the nitrogen of the cottonseed meal is excreted in the feces as undigested protein, and four-fifths is absorbed and is excreted in the urine, except for the part built into flesh or milk. Of the timothy hay, half of the nitrogen passes into the feces and only half is absorbed. Thus, feeds containing highly digestible protein produce a nitrogen-rich urine. With increasing amounts of digestible protein in the ration, the tendency is toward reduction in the proportion digested and absorbed and increased amounts in the feces, which are thereby enriched in nitrogen. Most of the potassium of the feed is absorbed during digestion and is excreted in the urine. In contrast, relatively little of the phosphorus is absorbed by the animal; the larger fraction passes directly into the feces together with a part of the absorbed phosphorus which has been thrown off in intestinal secretions. Of the phosphorus absorbed only a trace is excreted in the urine except in the case of swine, whose urine contains appreciable amounts.

The solid excrement.—In general, the feces contain roughly one-half of the nitrogen, nearly all of the phosphorus, and one-third of the potassium excreted. The nature of the nitrogenous compounds is of special interest. They exist chiefly in two forms: (a) protein materials that have resisted the attack of digestive juices and intestinal bacteria and hence presumably are resistant to the further biological decomposition necessary in the manure heap or soil for rendering their nitrogen available to plants, and (b) microbial protein in the cells of living and dead bacteria. According to Egorov (18), one-half to two-thirds of the nitrogen is present in the latter form. The protein of microbial cells has been shown to be readily attacked by soil microorganisms, and has a nitrogen availability similar to that of such organic fertilizers as dried blood and cottonseed meal (30, 46). However, feces contain a rather large amount of lignin, largely freed from the associated cellulose and hemicellulose of the feed by the digestion process. Waksman and Iyer (114) have found that lignin tends to combine with proteins to form compounds that are highly resistant to biological decomposition and hence possess low nitrogen availability for plants. In fact, the chief constituent of soil humus, the dark-colored, colloidal portion, appears to be essentially a lignoprotein compound of this kind. Crops can seldom recover more than 2 per cent of the soil nitrogen from it in a single season. It appears probable that the low availability of nitrogen observed in many studies with solid manures is partly the result of the lignin's combining with the microbial protein to form resistant humus-like compounds. This idea is supported by the work of Siegel (99), who found that of the organic matter in fresh urine-free cattle manure, 28 per cent, equivalent to over 50 per cent of that in the straw-free dung, was already in a "humified" condition as indicated by its resistance to solution in acetyl bromide. Likewise Jones (48), using solution in hydrogen peroxide as the criterion of humification, found that fresh dung contains up to 50 per cent of its organic matter in a "humified" state.

The liquid excrement.—The urine differs notably from the solid excreta in its low content of phosphorus, richness in potassium, and variable but often high content of nitrogen. All these constituents are soluble and hence readily available to plants. The composition varies with the ration and the amount of water drunk. When voided, the nitrogen exists chiefly as urea, hippuric and uric acids.[3] These compounds themselves are not volatile at ordinary temperatures, even when the urine is dried. Under moist and warm conditions they are, however, quickly acted upon by urea-decomposing bacteria, especially numerous in the solid dung, and changed to ammonium carbonate. Even in solution this compound tends to decompose with loss of ammonia gas, especially at higher temperatures, and with drying all its ammonia is lost to the atmosphere. This tendency of the urine nitrogen to change to ammonia and be lost creates a major problem in the handling of animal manures.

Quantity and composition of excrement.—Wide variations occur in both the quantity and composition of the excrement of animals of a given class. Factors responsible for these variations include the amount, composition, and digestibility of the feed, the age of the animal, milk production (with cattle), and individuality of the animal. From the numerous data available, those presented in table 2 probably represent a fair average from mature animals. In the case of horses, the liquid forms a smaller proportion of the total excrement than with other classes of animals. Moreover, the solid excrement of both horses and sheep is considerably drier (higher in percentage of dry matter) and the urine is more concentrated than that of cattle and hogs. Owing to their dryness and richness, horse and sheep manures tend to heat quickly in storage and are commonly designated as hot manures in contrast with cow and hog manures, which heat less and are known as cold manures. The percentage nitrogen content of the liquid is from two to three times that of the solid excrement except with hogs, whose solid is higher. Phosphoric acid occurs largely in the solid excrement, but even so its percentage content is appreciably below that of nitrogen. The solid excrement is consistently low and the liquid excrement high in percentage of potash.

Recovery of fertilizing constituents of feed.—No measurable loss of any of the fertilizing elements of the animals' feed occurs through any body processes other than excretion in feces and urine. Accordingly, these excreta will contain all the original fertilizer ingredients that are not retained by the animal in body tissue or secreted as milk. With an animal that is neither gaining nor decreasing in weight nor producing milk, such as a mature work horse, the recovery of nitrogen, phosphoric acid, and potash in the excrement is practically complete. Young growing animals and milking cows take the greatest toll of fertilizing elements from the feed. For each 1,000 pounds of milk produced,

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[3]The chemical formulas of these compounds are, respectively: $CO(NH_2)_2$; $C_6H_5CO \cdot NHCH_2 \cdot COOH$;

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     NH·CO·C·NH
CO<        ..   >CO
     NH——C·NH
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TABLE 2.—Average daily amount and composition of solid and liquid excrement of mature animals

	Daily production per animal		Composition of the fresh excrement									
			Dry matter		Nitrogen		Phosphoric acid (P_2O_5)		Potash (K_2O)		Lime (CaO)	
	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid	Solid	Liquid
	Lb.	*Lb.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Horses	35.5	8.0	24.3	9.9	0.50	1.20	0.30	Trace	0.24	1.50	0.15	0.45
Cattle	52.0	20.0	16.2	6.2	.32	.95	.21	0.03	.16	.95	.34	.01
Sheep	2.5	1.5	34.5	12.8	.65	1.68	.46	.03	.23	2.10	.46	.16
Hogs	6.0	3.5	18.0	3.3	.60	.30	.46	.12	.44	1.00	.09	.00
Hens	.1	....	35.0	....	1.00	....	.80	....	.40	....	....	....

Note: Data for daily production and for nitrogen, phosphoric acid, and potash content (except hen manure) are taken from the compilation of Ames and Gaither (3). Data for lime content are from Ruschmann (82). Composition of hen manure is that given by VanSlyke (110).

approximately 5 pounds of nitrogen, 2 pounds of phosphoric acid, and 1.8 pounds of potash will be removed. Similarly, for each 100-pound increase in weight a growing calf will remove about 3 pounds of nitrogen, 1.8 pounds of phosphoric acid, and 0.2 pound of potash. On the other hand, an animal that is losing weight, and is not producing milk, will excrete more nitrogen than is contained in the feed; the excess comes from broken-down body tissues and is excreted in the urine.

The data in table 3 compiled by Thorne (108) from experiments of Forbes at the Ohio Experiment Station show the proportion of fertilizing elements of the feed that was recovered in the urine and feces of (a) rapidly growing young pigs and (b) Holstein cows in the first part of their lactation period.

TABLE 3.—Recovery and distribution of fertilizing elements contained in the feed

Distribution	Percentage recovery		
	Nitrogen	Phosphoric acid	Potash
From pigs			
In feces	21	60	35
In urine	51	23	55
Total excrement	72	83	90
Balance in growth	28	17	10
From cows			
In feces	40	63	17
In urine	28	1	61
Total excrement	68	64	78
In milk	29	40	20
Balance in growth	3	−4	2

Variation in the recovery among different classes of livestock and within the same class with different conditions—rations, age, breed, milk production, etc.—is illustrated by the data compiled in table 4. Some uncertainty attends the figures for nitrogen recovery in some of the earlier experiments reported, since it is by no means certain that some loss of nitrogen from the fresh manure did not occur before the analyses were made.

Generalized values for the recovery of fertilizing constituents applicable to mixed classes of livestock are suggested as follows: nitrogen, 75 per cent; phosphoric acid, 80 per cent; and potash, 85 per cent. A similar value for the recovery of the organic matter of the feed is 40 per cent.

LITTER

The term "stable manure" as commonly used refers to the mixture of litter with animal excrements. Litter serves the double purpose of keeping the animals clean and comfortable and preventing losses of fertilizing constituents in the stable and manure pile. The chief value of litter as a preserving agent lies in its absorption of the urine, which in general carries over one-half of the fertilizing value of the total excrement. The efficiency of different litters as

TABLE 4.—Recovery of fertilizing constituents of feed in fresh manure

Class of animal and location	Percentage recovery		
	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
Dairy cows, Ohio*	68	64	78
Dairy cows, Illinois†	80	73	76
Dairy cows, Pennsylvania‡	85	71	91
Dairy cows, South Dakota, Test 1§	66	48	73
Dairy cows, South Dakota, Test 2§	71	33	85
Dairy cows, England‖	72	75	90
Dairy cows, average	74	61	82
Steers, Ohio**	61	87	82
Steers, Pennsylvania***	69	75	81
Steers, England‖	96	93	99
Steers, average	75	85	87
Heifers, England****	78	78	86
Sheep, Ohio*****	68	87	92
Pigs, Ohio*	72	83	90
General average	73	79	87

*Thorne, C. E. 1930. The maintenance of soil fertility, p. 243. Orange Judd Pub. Co., New York.
†Hopkins, C. G. 1910. Soil fertility and permanent agriculture, p. 201. Ginn and Co., Boston.
‡Sweetser, W. S. Penn. State Coll. Ann. Rep. 1899-1900, pp. 321-351.
§Wells, C. F., and B. A. Dunbar. 1925. Jour. Agr. Res. 30: 985-988.
‖Hall, A. D. 1928. Fertilizers and manures, p. 195. E. P. Dutton and Co., New York.
**Thorne, C. E. 1907. Ohio Agr. Exp. Sta. Bull. 183, p. 200.
***Frear, W. 1903. Penn. Agr. Exp. Sta. Bull. 63.
****Wood, T. B. 1907. Jour. Agr. Sci. 2: 207-215.
*****Thorne, C. E. 1907. Ohio Agr. Exp. Sta. Bull. 183, p. 202.

urine absorbers can be stated in terms of the amount of liquid which a given weight of material will absorb. A secondary value of litters lies in their ability to fix both ammonia and potash in a relatively insoluble form that protects them against loss by leaching. Ammonia thus fixed is also less volatile. This effect of litters, shown in only slight degree by cereal straws, corn stover, and wood shavings but important with peats, loam, and certain tree leaves, is a manifestation of the property of "base exchange" possessed by the lignin and to a greater extent by "humified" organic materials, probably lignin-protein complexes, present in the litter. Litter contributes some fertilizing constituents to the manure, but these are relatively small in amount and the nitrogen is usually of low availability, particularly so in the case of peats. The potash furnished by straw or cornstalks is largely available. Litter also affects notably the process of biological decomposition of manures, both in the manure heap and in the soil. The tendency for manure to heat, favoring loss of ammonia and the change of ammonia nitrogen into less available organic forms is much influenced by the amount of readily oxidizable, energy-supplying carbohydrates, chiefly hemicellulose and cellulose, contained in the litter. These effects will be more fully discussed in a later section. The hygienic properties of different litters are of some importance. Dusty or germ-laden materials are undesirable, especially in the dairy stable. Ruschmann (82) reports that peat contains 1 to 9 million organisms per gram, against 31 million in sawdust and 116 million in straw, also that up to 40 per cent of the bacteria in milk have been traced to the straw litter. Hall (24) reports that with the use of peat moss litter in a horse stable the ammonia content of the air was practically zero for 6 days, whereas with straw litter ammonia was present in objectionable and rapidly increasing amounts. Kennard and Nettleton (49) found both domestic peat and German peat moss unsatisfactory as a poultry litter for laying pullets with all-mash feeding. Both materials became dusty; the domestic peat so much so that pullets were seriously affected with bronchitis and other respiratory troubles and it was necessary to remove the peat after 4 weeks. The same investigators found granulated (water-cooled) blast furnace slag a very promising litter under the same conditions. This material did not become dusty, and its slightly alkaline reaction together with the release of hydrogen sulfide from the sulfides contained was believed to give it disinfecting properties. The same material has found some use as a litter in dairy barns, where it has the merit of reducing slipperiness of floors. Its alkalinity, however, is not favorable to the conservation of nitrogen and available phosphoric acid (P_2O_5) in the manure. The contribution of litter to the comfort of the animal may have economic value. Lemmermann (56) cites experiments in which animals gained considerably more weight when bedded with peat litter than when bedded with straw. The explanation was that the peat was drier and warmer and that the animals spent more time lying down on it, in which position they require 8 per cent less energy than when standing.

Quantity of litter.—Common practice in America is to combine the liquid and solid excrement. With this method, the minimum desirable amount of litter is that quantity required to absorb the liquid completely. For this purpose the daily requirement of long wheat straw per head, assuming 24-hour stabling, will be about: for cattle, 9 pounds; horses, 4 pounds; sheep, ¾ pound; and hogs, 1½ pounds. With other litters these quantities will vary in accordance with the liquid-absorbing capacity. More than these minimum quantities may be desirable where cleanliness and comfort of the animal are important. For example, although cut straw will absorb more liquid than long straw and produce a shorter, easier handled manure, Doane at the Maryland Station (15) found that it required one-third more cut wheat straw than long wheat straw to keep dairy cows clean. The cut straw did not adhere to the floor as well and was kicked about more. In the same work, sawdust and shavings rated higher than cut corn stover, and the latter higher than either cut or uncut straw in cleanliness of the animals. With horses, as much as 10 to 15 pounds of straw are sometimes recommended. However, too generous amounts of "high-energy" litters, such as straw and cornstalks, are to be avoided, since an excess prevents ready compaction of the manure and may tend to set up undesirable microbial action resulting in a decreased availability of nitrogen.

In Denmark, and to a less extent in Germany and France, a common practice is to collect the solid and liquid excrements separately. The urine is permitted to drain from the stable and is collected in cisterns or tanks. This method is followed, partly because of the scarcity of suitable litter, and partly because losses of the valuable fertilizing constituents of the liquid can be more readily controlled. In some Alpine districts, the scarcity of litter is so great that all the excrements are collected together in a cistern beneath the stable, with washings from the stalls and such straw as must be used, and the straw is dried for re-use. The fermented liquid manure with suspended solids is known as "Gülle", and is carried to the fields in tank carts.

TABLE 5.—Characteristics of litter materials

Compiled from various sources

Material	Litter required to absorb 100 lb. of liquid	Fixing capacity for ammonia nitrogen, nitrogen held per ton of litter	Content of fertilizing ingredients per ton of air-dry material			Content of cellulose and hemicellulose
			Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Pct.*
Wheat straw	45	4.5	11	4	20	65
Oat straw	35	7.1	12	4	26	High
Rye straw	45	3.4	12	6	17	62
Chopped straw	20–30	.....	.....	.....	.....	.....
Cornstalks (shredded)	25–35	5.3	15	8	18	51
Sawdust	25	.0	4	2	4	.....
Wood shavings	25 (softwood) 45 (hardwood)	.0	4	2	4	.....
Spent tanbark	25	.....	10–20	.....	.....	.....
Leaf litter	25–60	26.6 (oak)	16	6	6	28 (oak)
Peat moss (sphagnum)	10	40.0	16	2	3	22–37
Peat (sedge and woody)	15–25	30.0–60.0	20–60	2	3	2–10

THE ROTTING OF MANURE

As ordinarily handled, profound changes occur in the nature and value of the excrement-litter mixture upon standing. The numerous and diverse organic and inorganic compounds in the mixture, the multitude of microbial species present (bacteria, actinomycetes, fungi, etc.), and the wide variety of environmental conditions (air supply, moisture, temperature) obtaining in the stable, manure heap, and yard, make the rotting process extremely complex. Although studied extensively, some phases are still not well understood. The following important changes are known to occur.

Decomposition of urea.—Although sterile when voided, the urine is quickly contaminated with many species of urea-decomposing bacteria from dust or bedding or from the solid excrement, which carries large numbers. The fresh urine is relatively rich in nitrogen (cattle urine, 0.8-1.5 per cent), chiefly in the form of urea, $(NH_2)_2 CO$. In decomposing, the urea combines with water, H_2O, to form ammonium carbonate, $(NH_4)_2CO_3$, and this combines with carbonic acid in the urine or mixed manure to form ammonium bicarbonate, NH_4HCO_3. Both the carbonate and bicarbonate are unstable and tend to lose gaseous ammonia and carbon dioxide into the atmosphere. This tendency increases with temperature, alkalinity, and drying. Fresh urine of herbivora is normally neutral or alkaline except when animals are underfed and losing weight. With the change of urea to ammonium carbonate the reaction becomes more alkaline, and in absence of much carbon dioxide may reach pH 9.5. Mixed manure also becomes alkaline with urea decomposition but not to the same degree. The decomposition of urea is inhibited if the reaction is kept below pH 7.0 and practically ceases at acidities greater than pH 6.6 (54). The change of urea to ammonium carbonate takes place very rapidly and may be practically complete within 2 to 5 days.

Decomposition of carbohydrates.—Solid dung contains considerable amounts of cellulose and hemicellulose together with some proteins. These constituents have escaped digestion and probably represent, therefore, the more resistant fractions of the feed. The dung is relatively rich in lignin and in proteins, both residual from feeds and in microbial cells. It is probable that these are combined to a considerable extent as humus-like lignin-protein complexes not easily decomposed biologically. Litters like straw and corn stover add considerable cellulose and hemicellulose and small amounts of sugars, fats, and proteins to the manure, much of these in easily decomposable form.

The rate and course of decomposition of the carbohydrates (chiefly cellulose and hemicellulose) of mixed manure depend greatly upon the degree of aeration. This varies with temperature, moisture content, degree of compaction, surface exposed, and exposure to wind. Decomposition is most rapid with a fairly high temperature, 35° C. (95° F.), and plentiful air supply, as in loose heaps in the open in warm weather. Under such aerobic conditions carbohydrate decomposition starts quickly, although it may be delayed somewhat in the presence of much urine nitrogen by the alkaline reaction resulting from the still more rapid decomposition of urea. The principal change is an oxidation of the cellulose and hemicellulose brought about by many different types of microorganisms, with carbon dioxide and water as the chief end products. Much energy is released in the form of heat, which may raise the temperature of the heap to as high as 70° C. (158° F.) during the early stages when the more readily decomposable carbohydrate fractions are being attacked. The microbes concerned in the process use a part of the energy, together with some carbohydrate carbon and ammonia nitrogen, in building their cell protoplasm, thus increasing the organic nitrogen of the manure at the expense of the ammonia nitrogen. Under the conditions outlined, after the course of bacterial decomposition has passed its climax, fungi may appear and consume more of the remaining manure substance. Since water and volatile carbon dioxide are the chief end products of this type of decomposition, it is accompanied by a decrease in total dry matter which is rapid at first and slows up as the supply of readily attacked carbohydrates is exhausted.

Carbohydrate decomposition in the absence of air (anaerobic decomposition), a condition never completely attained in practice but possible in laboratory studies, is much slower and follows a different course. It is characteristically an acid type of fermentation similar to that of silage, with end products including the gases carbon dioxide, methane (CH_4), and hydrogen, and certain volatile organic acids—acetic, butyric, and possibly lactic. These acids tend to combine with any ammonia present, lowering the pH of the manure and reducing the volatility of the ammonia. In cow dung stored anaerobically for 30 days at 20° C. (68° F.), Heck (31) found nearly three times as much volatile acid as necessary to combine with the 0.084 per cent of ammonia nitrogen present. The reaction was distinctly acid, pH 5.27. Stored under similar conditions, a mixture of cow dung and urine contained volatile acids just equivalent to the 0.278 per cent of ammonia nitrogen and had a reaction of pH 7.37. Adding straw to the same proportion of dung and urine increased considerably the production of volatile acids; the amounts found after storage were one-half more than enough to combine with the 0.271 per cent of ammonia present. The pH was correspondingly reduced to 6.79. The amounts of heat liberated when manure is fermented anaerobically are so small that the temperature rises only slightly. The loss of dry matter is also at a minimum. In a laboratory experiment, Russell and Richards (85) observed a loss of only 2 per cent of the dry matter of steer manure stored anaerobically for 3 months at about 15° C. (60° F.). In a farm-scale experiment with cow manure built into a very compact heap, the loss of dry matter in 3 months (January 23 to April 30) was only 4.4 per cent. In this case the highest temperature reached was 9° C. (48° F.).

Decomposition of nitrogenous organic compounds.—The organic nitrogen compounds other than urea occur chiefly in the undigested food protein and previously elaborated microbial protein of the dung, both more or less resistant to biological decomposition. However, lower organisms decompose these compounds to some extent under both aerobic and anaerobic conditions. In the process some carbon is lost as carbon dioxide and some is built into organic acids. Part of the nitrogen compounds are ammonified and part are built into microbial protein, with, however, a net loss in the total amount of organic nitrogen present. The foul-smelling compounds, indole, skatole, mercaptans, hydrogen sulfide, and amines, are by-products of protein decomposition. The nitrogen of amines, which are characteristic products of protein decomposition under putrefactive conditions, is not readily converted by further biological action in the manure heap or soil into forms available for use by plants. The formation of amines (as well as putrefactive processes in general) is inhibited at low pH values, another reason for the importance of conserving the acids produced by the primary carbohydrate fermentation under anaerobic conditions. These acids are consumed by molds, but the latter cannot grow if air is excluded. It is difficult to measure the amount of decomposition of the original organic nitrogen compounds of manure, since in the rotting process the microorganisms attacking the carbohydrates are continually synthesizing new protein from the ammonia nitrogen of the manure. The rate of protein synthesis must ordinarily be too slow to compensate for the protein being decomposed, since in only a few instances have there been reported absolute increases in the amount of total organic nitrogen after storing manure. Generally, the trend in total organic nitrogen is downward. For example, Russell and Richards (85) report losses of 11, 20, and 25 per cent of the original organic nitrogen of cow manure after storage in loose heaps in the open for 3, 6, and 9 months, respectively, with corresponding losses of 24, 34, and 38 per cent in total nitrogen.

Nitrification and denitrification.—Nitrification (the biological oxidation of ammonia to nitrite and nitrate nitrogen) is not normally an easily demonstrated important process in manure, although in exceptional cases as much as 20 to 30 per cent of the total nitrogen has been found in nitrate form (71, 72). A good supply of oxygen is essential for the process, but well-aerated manure heaps often develop high temperatures (50-60° C.) (122-140° F.) which are above the thermal death point of the nitrifying organisms. Hence, nitrates are most likely to be produced in the loose, fairly dry, and cooler outer parts of the heap. Chief interest in nitrification lies in the opportunity it affords for denitrification, a process carried on by numerous organisms leading to the formation of free nitrogen gas from nitrate and nitrite nitrogen. The fact that considerable amounts of the total nitrogen lost from manure heaps often cannot be recovered as ammonia has been known for a long time. In a critical study of the problem, Russell and Richards (85) demonstrated that this unaccounted-for nitrogen was lost as gaseous nitrogen. Such loss did not occur under either strictly aerobic or strictly anaerobic conditions, but only under the "partial aerobic and anaerobic conditions that obtain when the mixed trampled materials of farmyard manure are exposed to air." Apparently it occurs when nitrate is formed in the drier outer layers and the deliquescent nitrates formed are then transferred by leaching or capillary action to the interior of the heap where they are reduced to nitrogen gas, although Niklewski (72) believes that the explanation is in symbiotic relations among bacteria, and that the entire process can take place on one tiny particle of manure even with abundant oxygen supply. The possibility that free nitrogen may also be formed by the reaction of nitrites with the amino nitrogen of proteins has been suggested (75).

"Humification."—The most important constituents of soil organic matter are brown to black colloidal substances characterized by their solubility in alkali, precipitation by acids, high base-exchange capacity, and slow rate of biological decomposition. Although variable in composition, they usually contain around 5 per cent of nitrogen and 50 to 55 per cent of carbon. They are frequently referred to as α-humus. According to the views of Waksman (112) and others, they are probably compounds of lignin and protein, the latter chiefly of microbial origin. It has already been pointed out that as much as half of the organic matter of feces appears to exist in a form similar to α-humus. Since both bedding and feces contain much lignin and since considerable microbial protein may be synthesized in the rotting process, an increase in the amount of "humified" compounds might be expected to occur in the manure heap through the combination of lignin and microbial protein. In studies of the decomposition of cells of microorganisms, Jensen (46) found that a part of the nitrogen contained was already present in a resistant form similar to α-humus. This finding suggested that some α-humus might be left in rotted manure as a residue from decomposing microbial cells. In fact, there is a common impression that rotted manure contains much more "humified" organic matter than fresh manure. Work of Siegel (99), however, indicates that this idea may be incorrect. He determined the amount of "humified" organic matter (insoluble in acetyl bromide) present in fresh cow manure and in cow manure rotted by different methods. Rotting by all methods increased the percentage of "humified" material in the dry matter. Compared with an average of 28 per cent for fresh manure, yard manure averaged 37.3 per cent; cold fermented manure, 32.9 per cent; and hot fermented manure, 37.2 per cent. There were, however, losses of total dry matter in all cases, and a calculation of the absolute amounts of "humified" organic matter showed actual losses of 5.6 per cent for hot fermentation and 9.1 per cent for yard manure, with a slight increase of 4.5 per cent for cold fermented manure. These results indicate that any production of "humified" organic matter in the rotting process is approximately balanced by the decomposition or loss of "humified" material already present in the fresh manure.

Changes in mineral constituents.—The larger part of the potassium of manure is voided in the urine, and of the total amount present in the mixed manure (dung, urine, and litter), from 75 to 100 per cent is soluble in water. Although this point has not been investigated, it seems probable that the insoluble portion of the potassium may largely be held in "exchange" form by the lignin and "humified" organic matter. The high (almost complete) availability of the potassium of both fresh and rotted manure to plants (9, 79, 22) supports this view.

The phosphorus excreted by herbivorous animals occurs almost entirely in the feces. The nature of the phosphorus compounds present has been little studied. They probably include a number of inorganic salts of phosphoric acid together with such organic compounds as lecithin, phytin, nucleoprotein, phosphoprotein, etc. (20). The power to decompose organic phosphorus compounds and form inorganic phosphates is possessed by a large number of microorganisms (111), and it is probable that such changes occur in the rotting of manure. This idea is supported by work of Romashkevich (79), who found that storage of mixed horse and cow manure for 4 months increased the phosphorus soluble in hydrochloric acid threefold. Since some organic phosphorus compounds are not readily used by plants, this effect may be of considerable practical importance.

LOSSES FROM MANURE

Several processes are responsible for losses of fertilizing constituents and organic matter. Depending upon the kind of manure and the particular procedures followed in collecting, storing, and spreading, these processes contribute in different degree to the total shrink in value of the final product.

Loss of liquid portion.—Failure to recover or retain all of the liquid portion is a serious source of loss and occurs chiefly through failure to use sufficient bedding, leakage through holes or cracks in stable floors, or seepage into the earth floors of feeding pens. Loss also occurs with the drainage of liquid from manure heaps which ordinarily accompanies rotting and consolidation. The extent to which the value of manure may be reduced by loss of liquid is indicated by the data in table 6 showing the percentages of the fertilizing elements and value of the total fresh excrements which are normally furnished by the liquid portion.

TABLE 6.—Proportion of total fertilizing elements and value of the fresh excrement occurring in the liquid portion

	Nitrogen	Phosphoric acid (P_2O_5)	(Potash K_2O)	Value*
	Pct.	*Pct.*	*Pct.*	*Pct.*
Horses	35	0	58	50
Cattle	53	5	71	65
Sheep	63	4	86	75
Hogs	22	13	55	40

*Calculated from data of Ames and Gaither (3), assuming prevailing fertilizer prices for phosphoric acid, potash, and liquid nitrogen. Nitrogen of dung is valued at one-fourth that of liquid per pound.

That the saving of the liquid manure may warrant considerable investment for litter, concrete stable floors, and the like is evident, as the fertilizing elements voided as liquid annually by a single dairy cow would cost about $9.00 in the form of fertilizers and could be expected to produce increased crops worth two to four times this amount. That one-half or more of the liquid is lost on many farms is a safe assumption.

Where animals are fed in stalls or pens with earth floors, considerable seepage into the soil takes place even though the earth is well compacted and an abundance of litter is used. This seepage is explainable in part by the stronger capillary pull of the soil than of the solid manure for the liquid. In a 6-month feeding period at the Ohio Station with two lots of fattening steers, one on concrete and the other on a well-packed earth floor, data were obtained indicating that about one-fourth of the liquid seeped into the earth floor, reducing the fertilizing value of the manure produced by one-sixth (3). The loss was deemed large enough to have paid the cost of the concrete floor in two 6-month feeding periods.

Loss by leaching.—When manure is exposed to the leaching action of rain water the losses may be even more serious than those from mere seepage of the liquid, since water-soluble constituents of the solid portion are also removed.

In table 7 are given the percentages of individual fertilizing elements and of organic matter that are water soluble in different farm manures including litter, according to data of Ames and Gaither (3).

TABLE 7.—**Proportion of fertilizing elements and of organic matter of farm manures (including litter) that is soluble in water**

	Organic matter	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
	Pct.	*Pct.*	*Pct.*	*Pct.*
Horses	5	53	53	76
Dairy cows	7	50	50	97
Steers	7	56	36	92
Sheep	7	42	58	97

In manures containing considerable ammonia, the reaction is alkaline, and under these conditions "humified" organic material is leached out as water-soluble ammonium and potassium humates. These materials give the dark color to leachings from the manure pile.

The losses from leaching naturally vary with the amount of water passing through the manure, and are highest where roof or surface water supplements the normal rainfall falling on the manure. Losses also vary with the surface exposed by a given volume of manure, being greater from low heaps with a large surface than from high heaps with a small surface. The influence of the surface exposed is better appreciated by considering the fact that 9 inches of rain (the average amount falling in 3 months in Ohio) are equivalent to nearly 6 gallons of water for each square foot of horizontal surface. For leaching to occur, the water must pass through the manure. Where drainage is impeded by the manure's resting on impervious soil or the freezing of the lower layers, the losses will be less than under conditions of good drainage.

Loss of ammonia nitrogen by volatilization.—Considerable amounts of ammonia are produced in manure from the decomposition of the urea and other nitrogenous compounds of the urine and from the much slower decomposition of the nitrogenous organic compounds of the feces and bedding. Where the urine is collected and stored separately (a common practice in Europe) the ammonia is found to occur almost entirely in combination with carbonic acid as ammonium carbonate and bicarbonate. These compounds also account for much of the ammonia in mixed manures, especially in the earlier stages of rotting. As rotting proceeds, an increasing proportion of the ammonia is found combined with the less volatile organic acids—acetic, butyric, and lactic—formed by the anaerobic fermentation of carbohydrates of litter and feces in the more compact and wetter portions of the heap, and with the colloidal humic acids of the "humified" organic material.

In common with solutions of ammonium salts of weak acids in general, the salts formed tend to set up a certain vapor pressure of gaseous ammonia in the atmosphere over the solution, leading to the more or less rapid loss of ammonia. The chemical reactions involved are typified by those occurring with ammonium carbonate:

1.	$(NH_4)_2CO_3$ ammonium carbonate	$+H_2O$ water	$\rightleftharpoons$	$2NH_4OH$ ammonium hydroxide	+	H_2CO_3 carbonic acid
2.	NH_4OH ammonium hydroxide		$\rightleftharpoons$	NH_3 gaseous ammonia	+	H_2O water
3.	H_2CO_3 carbonic acid		$\rightleftharpoons$	CO_2 carbon dioxide gas		H_2O water

These reactions are all reversible and tend to reach an equilibrium with cessation of decomposition of the ammonium carbonate except as the end products, gaseous ammonia and carbon dioxide, are lost to the atmosphere, in which case the reaction proceeds until the ammonium carbonate is completely decomposed and all ammonia has been lost.

The equilibrium concentration of gaseous ammonia, and hence the ammonia vapor pressure and tendency for loss, increase with concentration, alkalinity, and temperature, a fact of vital importance in relation to loss-prevention measures.

When solutions of ammonium carbonate (or fermented urine) are exposed to the air, carbon dioxide tends to be lost more rapidly at first than ammonia. Accordingly, there result some accumulation of ammonium hydroxide and an increase in alkalinity, which may reach pH 9.5, with a corresponding increase in the vapor pressure of ammonia and its tendency to volatilize. In contrast, where the ammonia exists in combination with acetic acid (or other organic acids formed under anaerobic conditions), the acid formed by the first reaction, reaction No. 1, does not undergo decomposition, and is less volatile. Hence, as the reaction proceeds with loss of ammonia, the acid tends to be left behind, rendering the solution more acid and slowing up the whole process. From the excellent work of Jensen in Denmark dealing with factors affecting the loss of ammonia from urine (47), it appears that very little loss of ammonia takes place at about pH 7 at ordinary air temperatures, and practically none at pH 6.5 or below. When ammonia exists in combination with a strong acid, such as sulfuric (in ammonium sulfate), only a very small amount of ammonia is lost before the solution becomes so acid that all decomposition stops. As will be noted later, this fact is important in the action of chemical preservatives on manure.

Temperature exerts an important influence on the ammonia vapor pressure, hence also on loss of ammonia from manure. Jensen (47, II) found that the loss of ammonia from urine more than doubled with each increase in temperature of 10° C. (18° F.). Thus the loss during a given time at 30° C. (86° F.) was more than four times as great as at 10° C. (50° F.). These facts suggest the importance of controlling the temperature of rotting manure as an aid in preventing loss of ammonia nitrogen. The high temperature produced by aerobic fermentation in a loose manure heap, 50 to 70° C. (122 to 158° F.), is conducive to very rapid loss of ammonia, although the effect is mitigated somewhat by the tendency of the ammonia to be trapped in the cooler outer layers of the heap.

Paradoxically, freezing has a similar, although less marked, effect on the tendency toward loss of ammonia. This is due to increase in concentration of the solution from the crystallization of the water. Freezing is not likely to cause an appreciable loss of ammonia from manure in large heaps, but it may be an important cause of losses from fermented manure spread on frozen ground, especially if there is no snow. Losses of ammonia from frozen manure were determined by Midgley and Weiser (65), who exposed 50-gram samples of cow manure fermented 1 month to outdoor conditions at about —5° C. (23° F.). Under these conditions, the small masses of manure, approximately 2 ounces each, or about the largest size likely to be delivered by a good spreader, lost 48 per cent of their ammonia content within 48 hours. From a 10-ton application containing 48 pounds of ammonia nitrogen 23 pounds were lost to the air in 2 days of exposure.

Air movement is also an important factor affecting loss of ammonia. Jensen (47, II) exposed filter paper soaked with fermented urine to moving air and observed a loss of 61 to 63 per cent of the ammonia present in 30 minutes. The corresponding loss in quiet air was 18 per cent. The effect of moving air (wind) on manure is to hasten the evaporation of water, and with the loss of water the capacity to hold ammonia in solution is reduced until at the air-dry condition only a small fraction of the original ammonia of the manure is left. Heck (31) exposed fermented cow manure to both still and moving air at 20° C. (68° F.) and measured the rate at which the ammonia nitrogen was lost. His results are given in table 8.

TABLE 8.—Loss of nitrogen from fermented cow manure exposed to drying

Time and temperature	Fraction of original nitrogen lost			
	Ammonia nitrogen		Total nitrogen	
	Still air	Moving air (8½-mile wind)	Still air	Moving air (8½-mile wind)
	Pct.	*Pct.*	*Pct.*	*Pct.*
12 hours at 20° C. (68° F.)	15.2	49.4	7.7	25.1
36 hours at 20° C.	46.0	61.0	23.4	30.9
3½ days at 20° C.	63.9	70.0	32.4	35.6
7 days at 20° C.	71.3	73.5	36.2	37.3
7 days at 20° C.+24 hours at 80° C.	95.0	95.2	48.2	48.3

The fact that almost one-half of the ammonia nitrogen (one-fourth of the total nitrogen) was lost in the short time of 12 hours at ordinary temperatures under exposure to moving air indicates how important may be such factors as air circulation in loosely piled heaps, forking over fermented manure thus exposing the moist portions to drying, storing in heaps exposed to wind, and permitting spread manure to dry or freeze before plowing under.

Loss of organic matter.—The quantities of organic matter present in 1 ton of fresh manure from different animals are shown in table 9. These data apply to the mixed solid and liquid excrements to which have been added the minimum amounts of straw necessary to absorb the liquid.

TABLE 9.—Organic matter in 1 ton of fresh manure*

	Total organic matter	Organic matter from straw	Nitrogenous organic matter (protein)†
	Lb.	*Lb.*	*Lb.*
Horses	482	144	52
Cows	388	188	34
Sheep	650	268	54
Swine	376	228	50

*Includes minimum quantities of straw required to absorb liquid.
†Nitrogen of solid excrement and straw × 6.25.

It is observed that roughly one-third to one-half of the organic matter of fresh manure is derived from the litter, also that of the total organic matter present, around 10 per cent exists as proteins. In rotting, manure suffers important losses in organic content. These losses fall mainly on the carbohydrate constituents, since the nitrogenous compounds are on the whole highly resistant to decomposition. Organic matter is lost chiefly through biological oxidation, and the loss is most rapid under aerobic conditions. The energy released in the process is responsible for the heating of manure heaps. Under a given set of conditions (air temperature, wind, etc.) the temperature attained is a fair measure of the rate of oxidation and loss of organic matter taking place.

The relationship of temperatures reached in the manure heap to the loss of organic constituents taking place is shown by the data of Russell and Richards (85), who stored both cow and steer manures in compact and loose heaps, under cover and in the open yard. These data are given in table 10 and are interpreted graphically in figures 1 and 2.

TABLE 10.—Maximum temperatures and losses of dry matter and nitrogen from heaps of cow and steer manures stored for 3 months (January to April)

Data of Russell and Richards (85)

	Cow manure				Steer manure			
	Under cover		Exposed		Under cover		Exposed	
	Compact	Loose	Compact	Loose	Compact	Loose	Compact	Loose
Maximum temperature	9°C.	16°C.	....	21°C.	51°C.	71°C.	40°C.	55°C.
Loss of dry matter, per cent	4	7	....	21	30	35	39	41
Loss of total nitrogen, per cent	0	7	....	25	26	26	28	27
Loss of organic nitrogen, per cent*	−5 (gain)	−1 (gain)	....	10	15	10	12	11
Loss of ammonium nitrogen, per cent*	4	9	....	15	11	16	16	16

*Percentages are of total nitrogen present at the start.

In figure 1 a direct relationship is observed between the loss of dry matter and the maximum temperature reached in the heap. This is to be expected, since during the period covered, January to April, the temperature of the heaps must have depended largely upon the release of energy by oxidation. The larger loss of dry matter from exposed heaps than from covered heaps at comparable temperatures may result both from the leaching out of the soluble organic constituents by rain water and from the greater loss of heat to the air and leaching rain water, requiring the oxidation of more organic matter to maintain the optimum temperature in the heap.

From figure 2, in which the data for both exposed and covered heaps are combined for plotting, it appears that the loss of organic nitrogenous constituents, as measured by the loss of organic nitrogen, bears a different relation to the temperature reached than does the loss of organic matter. In the cooler heaps, up to a temperature of 21° C. (70° F.), the losses of total dry matter and nitrogenous constituents increase together. As the maximum temperature of the heap increases above 21° C. (70° F.), a further progressive loss of organic matter occurs, but the loss of nitrogenous organic constituents remains nearly constant; there is, in fact, an apparent dropping off at the higher temperatures.

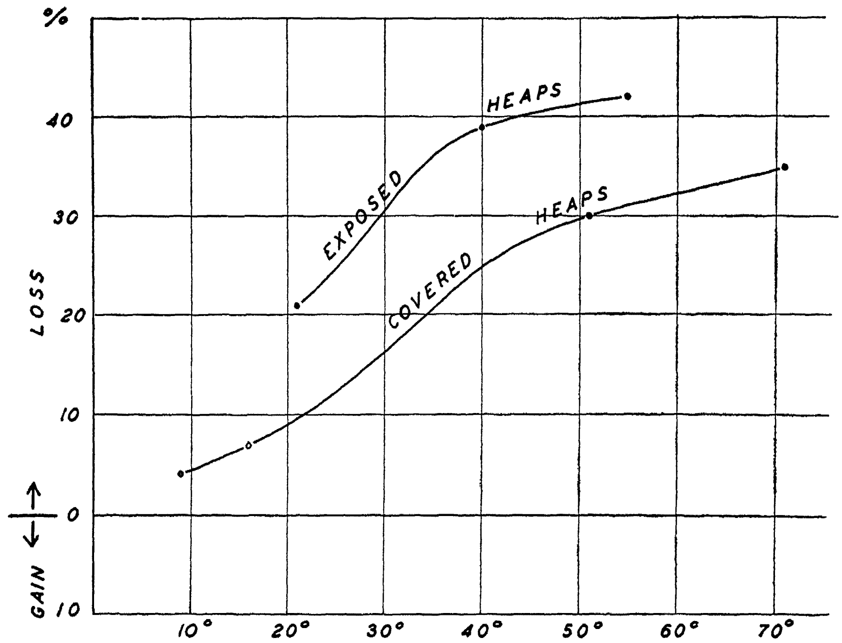

Fig. 1.—Relation of loss of dry matter to temperature of manure heaps
From data of Russell and Richards given in table 10

In the coldest heap, a very compact heap of cow manure under cover, there was an actual increase in organic nitrogen during storage. The explanation probably lies in the comparative rates at which organic nitrogen compounds were being synthesized (as microbial protoplasm) and the original nitrogen compounds of the manure were being decomposed. At the lower temperatures the loss of organic nitrogen is apparently more than compensated by the gains taking place. The opposite is true in heaps attaining temperatures higher than 16° C. (61° F.). Figure 2 also shows the loss in total nitrogen, which increases rapidly with temperature, reaching 25 per cent at 21° C. (70° F.) but increasing very little further at higher temperatures. All the nitrogen lost was presumably lost through the volatilization or leaching of ammonia, although denitrification may have been responsible for a part. A portion of the ammonia lost came from the organic nitrogen decomposed and a part, nearly constant above 21° C. (70° F.) and measured by the spread between the two curves, represents loss of ammonia that was present in the manure at an early stage of its fermentation, chiefly derived from the urine.

From the data presented, it may be concluded that losses of both organic matter and nitrogen are at a minimum under storage conditions where temperatures of the heap do not exceed about 16° C. (61° F.). With increased heating the amount of organic matter lost increases rapidly, but the loss of either total or organic nitrogen does not increase appreciably as the temperature rises

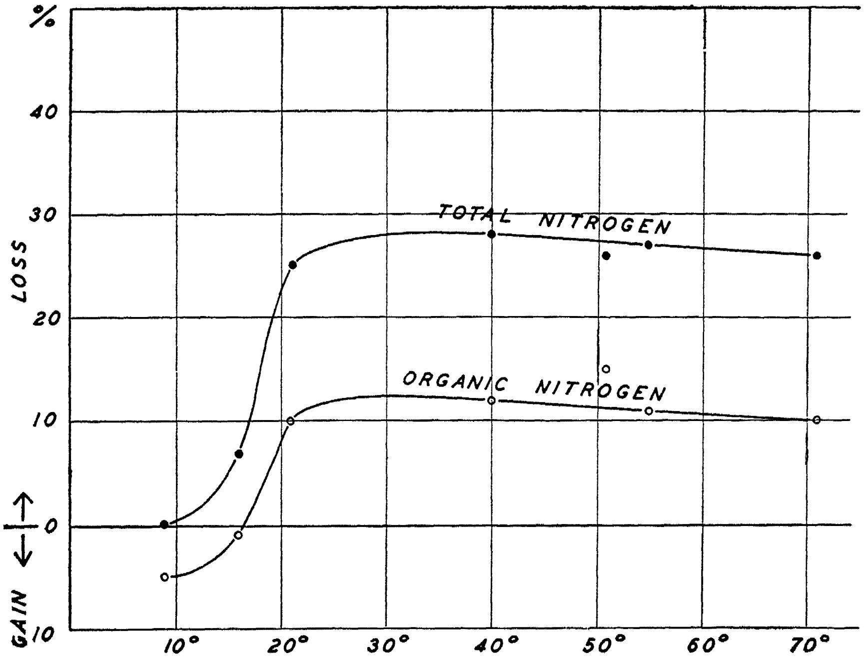

Fig. 2.—Relation of loss of total and organic nitrogen to temperature of manure heaps
From data of Russell and Richards given in table 10

above about 21° C. (70° F.). The loss of organic matter is increased by exposure to weather, probably largely through the leaching of soluble materials. Exposure does not affect greatly the loss of either total or organic nitrogen.

Manure stored during the summer heats more and loses more organic matter and nitrogen than manure stored in winter. This fact is illustrated by the data of Siegel (99) shown in table 11.

TABLE 11.—Maximum temperatures and losses of dry matter and nitrogen in winter versus summer storage of cow manure, practically urine free, with straw litter

Data of Siegel (99)

	Maximum temperature (Centigrade)	Loss of dry matter Pct.	Loss of total nitrogen Pct.
Covered and compact heap			
3 months in winter	16°	3	6
3 months in late summer	33°	16	15
Exposed and loose heap			
3 months in winter	About 50°	22	16
3 months in late summer	*	32	19

*Not reported, probably 65 to 70° C.

Change of nitrogen into organic form.—The final product of rotting of manure and vegetable materials generally is similar to soil humus, in which the residual carbon and nitrogen are in an approximately constant ratio of 10. Since the carbon to nitrogen ratio (C/N) for straw is about 50, and for fresh manures including litter usually 15 to 25, carbon tends to be lost (chiefly as carbon dioxide), whereas nitrogen tends to be retained in the bodies of the organisms causing the rotting. When nitrogen is present as ammonia or other nonprotein forms, as in fresh manures, it tends to be fixed as microbial protein together with a part of the carbon. This fixation is in one sense advantageous in that it protects against loss of ammonia by volatilization and leaching, but the possible advantage may be more than offset by the accompanying decrease in availability of the nitrogen. Aerobic conditions favor the process. Under controlled laboratory conditions, by passing air through mixtures of straw with feces and urine of both horses and steers for 4 weeks, Russell and Richards (85) were able to transform the ammonia nitrogen present almost quantitatively into organic nitrogen compounds. Under conditions of practical manure storage, however, the high temperatures and contact with moving air ordinarily associated with the required aerobic conditions favor loss of ammonia. Moreover, decomposition of the nitrogenous organic compounds already present may be appreciable. The net result is that the content of organic nitrogen as well as of ammonia is apt to be reduced rather than increased. Thus, Russell and Richards found in some 20 different experiments with different kinds of manure and methods of storage that only one showed any gain in complex nitrogen compounds, and in that the increase was only 8 per cent. It may be concluded, therefore, that rotting as a method of fixing nitrogen and preventing its loss is a wasteful process under practical conditions; the tendency is to accelerate losses and to lower the availability of the nitrogen present.

USE OF CHEMICAL PRESERVATIVES

Much study has been given to the use of chemicals in arresting the losses of ammonia that occur in the heap and from drying in the field. The possibility of retaining most of the ammonia has been demonstrated repeatedly. On the other hand, views differ widely as to the practicability of chemical preservation. In America the use of superphosphate as a preservative has been long and widely recommended, although the economics of its use still require investigation. In Germany, the use of chemical preservatives is generally considered inferior to methods depending upon biological control of the rotting process. The opinion is held that rotting is essential to realizing the maximum value of manures, and that chemicals interfere with the process.

The aim of the use of preservatives may be (a) to prevent the biological decomposition of the urea, hippuric and uric acids carried in the urine to ammonium carbonate and thereby prevent loss, since these compounds are not volatile at the temperatures obtaining and are stable on drying, or (b) to convert the ammonium carbonate formed into the nonvolatile salt of a strong acid.

To be completely effective, chemical preservatives must be so used that the liquid excrement is brought into thorough contact with the chemicals soon after being voided, since decomposition and loss start almost immediately. Lemmermann (56) cites results showing losses in the stable of 10 per cent of the total nitrogen of manure in winter and 13 per cent in summer even with daily removal. The necessary contact of urine and chemicals is more readily obtained in dairy stables, where the urine drains into a gutter than where all the manure collects under the feet of the animals.

Use of antiseptics.—Several materials having bactericidal properties have been found effective. These include formalin, chloropicrin, and the sulfates of copper, zinc, and iron. These materials act to some extent by preventing the decomposition of urea and in part by depressing natural fermentation and heating. They are relatively costly, and up to the present time their use has not found much application in practice.

Use of strong acids.—Strong acids, including sulfuric, phosphoric, and hydrochloric, have been proved highly effective. They act in two ways. By rendering the manure acid they prevent urea decomposition—practically nil below pH 6.5—and check fermentation generally, including denitrification. A second important action is to decompose ammonium carbonate with the formation of a nonvolatile ammonium salt and the loss of carbon dioxide as gas. The reaction with sulfuric acid is:

$$\underset{\text{ammonium carbonate}}{(NH_4)_2\,CO_3} + \underset{\text{sulfuric acid}}{H_2SO_4} \rightarrow \underset{\text{ammonium sulfate}}{(NH_4)_2\,SO_4} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2}$$

Since sulfuric acid is relatively cheap, its use would seem to have practical possibilities. Although difficulties attend the use of so corrosive a material, these should not be insuperable. Recently Henglein and Salm (34) have suggested the use of diluted sulfuric acid (5 per cent), added in amounts to bring the manure to pH 5.0. This method was found effective.

With the development of methods for the direct production of phosphoric anhydride (P_2O_5) at low cost, the use of this material or of liquid orthophosphoric acid (H_3PO_4), formed by the interaction of the anhydride and water, may become practical for acidifying and preserving manure. Midgley and Weiser (65) found the acid, used in an amount equivalent to 50 pounds of 20 per cent superphosphate per ton of manure, much more effective in preventing losses of ammonia. In their experiment, fermented manure dried without any addition lost 92.7 per cent of its ammonia. With superphosphate the loss was 66.2 per cent; and with the equivalent amount of phosphoric acid, 49.0 per cent. In addition to conserving nitrogen, added phosphoric acid directly increases the fertilizing value of manure by addition of the element in which it is naturally most deficient, and the fixation of ammonia in this case is not attended by the reduction in value of the added phosphoric acid which is the principal disadvantage of using superphosphate.

Part of the difficulty in handling strong acids can be obviated by substituting for them the strongly acid salt, sodium acid sulfate or "nitre cake", produced as a by-product in the manufacture of nitric acid from Chilean nitrate.

Use of salts of strong acids.—The salts offering most promise of practical value are calcium chloride, calcium nitrate, and calcium sulfate (gypsum). The effectiveness of these materials in preserving liquid manure has been demonstrated and the reactions explained by Jensen (47). The value of gypsum in preserving mixed manures has been known and the method has been used for many years. The reaction of gypsum with ammonium carbonate is:

$$\underset{\substack{\text{calcium sulfate}\\\text{(gypsum)}}}{CaSO_4} + \underset{\text{ammonium carbonate}}{(NH_4)_2\,CO_3} \rightleftharpoons \underset{\text{calcium carbonate}}{CaCO_3} + \underset{\text{ammonium sulfate}}{(NH_4)_2\,SO_4}$$

Gypsum differs from the other salts mentioned in being only slightly soluble. Calcium carbonate, formed in the reaction, is insoluble and tends to precipitate upon the surface of the gypsum particles rendering them inactive and ineffective. This probably explains the inferior results often reported with gypsum as a manure preservative. Jensen (47, II) reports that it is necessary to stir gypsum-treated liquid manure thoroughly for the gypsum to be effective.

Another difficulty with all these salts is that although they prevent volatilization of ammonia from moist manure, they are less effective in preventing loss from drying, for the reason that as the ammonium sulfate in solution becomes more concentrated it reacts with the precipitated calcium carbonate again to form ammonium carbonate, which decomposes with loss of ammonia. In other words, the reaction is reversible. With liquid manure it is advised to draw off the liquid manure from the calcium carbonate, which settles to the bottom of the tank, before spreading in the field.

Use of superphosphate.—Superphosphate has been extensively used as a manure preservative. Its action is similar to that of gypsum, which it contains in amounts varying from 4 to 5 per cent in treble superphosphate, 40 to 46 per cent available phosphoric acid, up to 50 to 60 per cent in the ordinary 16 and 20 per cent grades. Its action is more complex than that of gypsum owing to its content of monocalcium phosphate. In recent studies of superphosphate as a preservative, Midgley (64) found that superphosphate was more effective in preventing loss of ammonia on drying than either monocalcium phosphate or gypsum used separately. The reaction with ammonium carbonate is:

$$\underset{\text{gypsum}}{2\,CaSO_4} + \underset{\text{monocalcium phosphate}}{CaH_4(PO_4)_2} + \underset{\text{ammonium carbonate}}{2(NH_4)_2CO_3} \rightarrow \underset{\text{tricalcium phosphate}}{Ca_3(PO_4)_2} + \underset{\text{ammonium sulfate}}{2(NH_4)_2SO_4} + \underset{\text{water}}{4H_2O} + \underset{\text{carbon dioxide}}{2CO_2}$$

Instead of the calcium carbonate formed when gypsum alone is used, insoluble tricalcium phosphate is formed in this reaction. This compound does not react with the ammonium sulfate on drying as does calcium carbonate, so that loss of ammonia is prevented. Of the three grades of superphosphate tested by Midgley (16 per cent, 20 per cent, and 40 per cent P_2O_5), the 20 per cent grade contained the most gypsum—58 to 60 per cent—and should give the least loss of ammonia. Granular 20 per cent superphosphate was found to absorb less urine than the 20 per cent pulverized goods, but was less slippery on stable walks and less dusty to apply.

Since superphosphate has been the most widely recommended preservative for manure, the economics of its use for this purpose will be discussed briefly. On the basis of Midgley's data, 1 ton of 20 per cent superphosphate, costing about $23.50 in 1937, could be expected to fix about 140 pounds of ammonia nitrogen,[4] worth in terms of sulfate of ammonia about $12.18. In the process of fixing this nitrogen all the monocalcium phosphate would be transformed into tricalcium phosphate. Precipitated tricalcium phosphate, presumably its most active form, was found by Salter and Barnes (89) to have an availability equal to 66 per cent of that of monocalcium phosphate for wheat on a soil with a reaction of pH 5.5. Its availability at pH 6.0 was reduced to 47 per cent and at pH 7.0 was only 19 per cent. Thus, particularly on slightly acid to alkaline soils, the reduction in availability of the phosphoric acid may completely offset the value of the nitrogen saved.

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[4]The theoretical value is 158 pounds.

Midgley and Weiser (65) report later work with superphosphate as a manure preservative in which its efficiency has proved less than indicated by the earlier experiments. Although 67 pounds of 20 per cent superphosphate are theoretically sufficient to fix the 5.2 pounds of ammonia nitrogen in a ton of the manure used in their experiments, even 300 pounds did not effect this result in practice. With the best mixing possible in small-scale laboratory experiments and a 50 per cent excess of superphosphate, 100 pounds per ton of fermented manure, their data indicate that $1.18 worth of superphosphate saved only 21 cents' worth of ammonia nitrogen, or 2.4 pounds. In pot tests with corn, they report the following in their table 10:

TABLE 12.—Effect of adding 20 per cent superphosphate to manure before and after fermentation on recovery of ammonia and maize yields from an application of 10 tons of treated manure per acre

Data of Midgley and Weiser (65)

Treatment	Ammonia recovered	Corn yields, two harvests
	Lb.	*Gm. per pot*
Check, no manure	....	15
Manure fermented, not dried	45.3	192
Manure fermented, dried	3.5	35
Manure, superphosphate added before fermentation, dried	32	152
Manure, superphosphate added after fermentation, dried	10.2	46
Nitrogen, phosphate, potash (no manure)	....	248

They attribute the low efficiency of superphosphate in preventing loss of ammonia when added to fermented manure to the large quantity of ammonium carbonate present; reaction is slow and does not follow the expected course, and the practical difficulties in mixing are great. They recommend that the superphosphate always be added to the fresh manure in the stable, although Tottingham and Hoffman (109) have shown that the efficiency of superphosphate as a phosphorus carrier is seriously impaired by fermentation with manure.

Another practical deterrent to the method is that the amount of superphosphate required is so high that when such treated manure is applied to the field, even a moderate dressing of 8 tons per acre may carry over 500 pounds of 20 per cent superphosphate, which is considerably more than most farmers care to apply to corn or other crops in general farming. Moreover, the phosphate, along with the manure, is distributed in a broadcast fashion which makes it necessary to sacrifice the economy which attends the use of relatively light applications in the hill or row with row crops. Thus, the practicability of the method may be justly questioned under many conditions. It would appear to offer greatest promise where the manure is to be applied to acid soils for certain vegetable crops requiring considerable amounts of both nitrogen and phosphoric acid, or for top-dressing grass pastures and meadows or winter small grains.

The theoretical daily requirement of 20 per cent superphosphate per horse, cow, or steer (stabled 24 hours) is from 2 to 2½ pounds, for other animals, in proportion to weight (higher than the usual recommendations). With horses it is best scattered just before cleaning the stable. Dusting in the gutter of cow stables after cleaning is most satisfactory. For manure that accumulates under the feet of animals, applying just previous to each bedding of the pen or lot is preferable.

Use of peat.—In addition to its value as a liquid absorbent, peat litter has considerable preservative action. Peat acts in three ways: (a) It absorbs ammonia nitrogen, in amount equal to 1.5 to 3 per cent of its dry weight. The use of 6 pounds of peat per cow and day in the dairy stable might be expected to fix from one-half to all of the ammonia nitrogen in the excrement. (b) Low-lime peats act through rendering the manure acid. Kuznetzov (54) observed that with peat bedding the reaction of manure was pH 4.8. He attributed the conservation of nitrogen to the inability of urea-decomposing bacteria to function at this acidity, as well as to the absorption of the ammonia by the peat. (c) Compared with straw, peat contains relatively small amounts of easily decomposable carbohydrates. Hence, peat litter manures heat less and lose less ammonia than manures with straw litter.

Lemmermann (56) cites data showing that 6.6 pounds of peat per animal and day reduced nitrogen loss in the stall from 11 down to 1 per cent with daily removal of manure. The total losses of nitrogen in stall and heap were 31 per cent without peat and 7 per cent with peat. That the availability of the nitrogen of the manure is apt to remain higher with peat litter has been shown in a number of field experiments.

Where litter must be purchased, the preservative power of peat, together with its high liquid absorption (2 to 4 times that of straw), makes it worthy of wider consideration in this country. Considerable amounts of baled sphagnum (peat moss) are now imported and used as packing material by nurserymen and for other agricultural purposes. It could be produced in the United States, as large deposits occur in some northern states.

FRESH VERSUS ROTTED MANURE

Before practical methods of handling manure are considered, attention must be given to the effect of rotting on the final value of the product. The belief that rotting adds value to manure, at least for use on some crops and on some soils, has been held for many years and is still voiced by modern writers. This view, perhaps to a considerable extent traditional, is probably based on field comparisons of equal weights of the fresh and rotted product, and reflects the higher nutrient content of the latter. That manure increases in concentration of crop nutrients with rotting is well known and is illustrated by the data of Shutt (98) in table 13.

TABLE 13.—Composition of fresh versus rotted manure. Mixed horse and cow manure rotted 3 months (April-July) under cover

Data of Shutt (98)

	Present in 1 ton of manure			
	Organic matter	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)
	Lb.	*Lb.*	*Lb.*	*Lb.*
Fresh manure	485	12.0	6.2	15.2
Rotted manure	590	26.6	16.6	43.8

That this increase in concentration, even under the best practical conditions, is obtained at the expense of large loss of organic matter and considerable loss of nitrogen (chiefly the readily available ammonia nitrogen), has not been fully

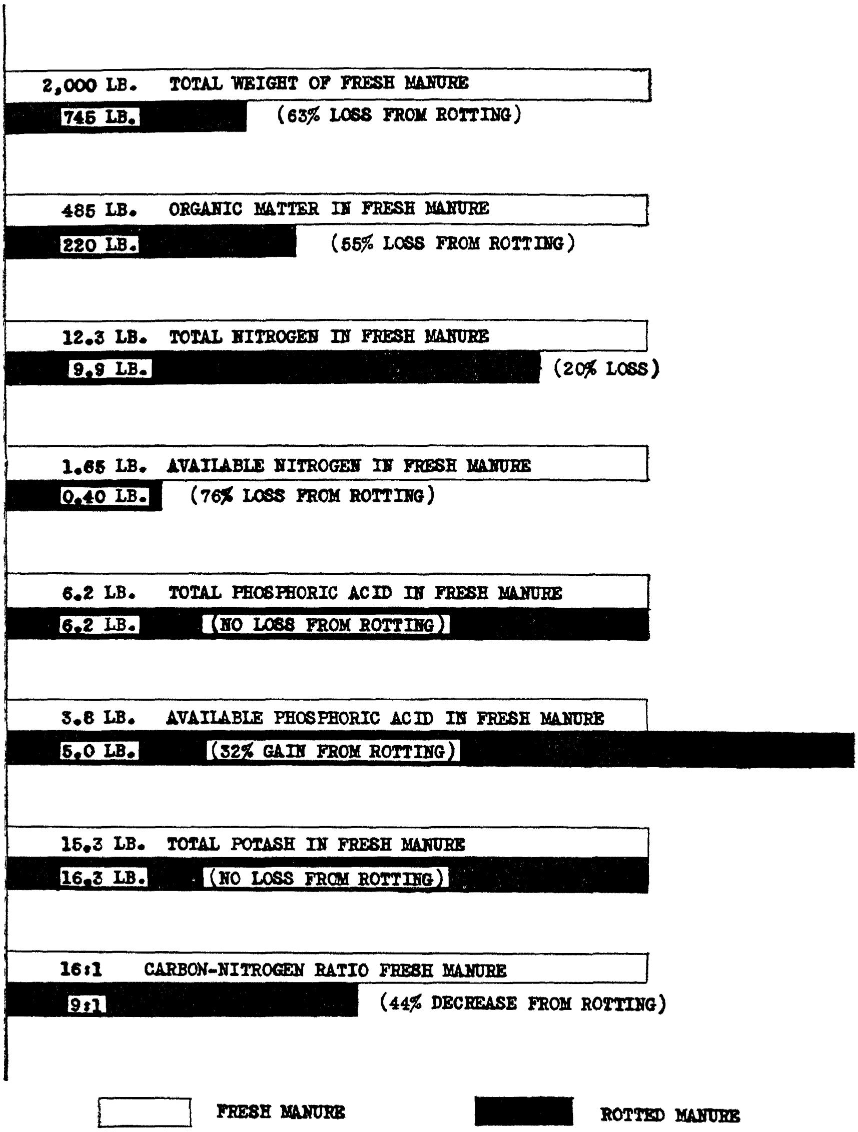

Fig. 3.—Effects of rotting of mixed horse and cow manure under shelter from April 29 to July 29
Data of Shutt (98)

appreciated. Also, that these losses, notably increased when manure is rotted under exposed conditions, may more than offset any benefits accruing from the rotting process is strongly indicated by many experimental data.

The absolute changes in amount of the various constituents originally present in a given quantity of fresh mixed horse and cow manure during 3 months of storage in a tight-floored shed are shown in figure 3, data of Shutt (98). After storage the manure was described as "thoroughly rotted." It showed only minor changes in composition after further storage for 9 months. The advantages claimed for rotted manure will be briefly considered in relation to these data.

The advantage of the decreased weight to be handled with rotted manure is appreciable, but the maximum area that can be covered is reduced. The superior physical condition of the rotted manure makes for easy and better distribution, but the total amount of organic matter returned to the land is decreased by more than 50 per cent. The advantage of rotted manure in that it does not tend to "burn" the crop or to force rapid vegetative growth which may result in the lodging of small grains, in tobacco leaves' being coarse and of low quality, etc., merely reflects the fact that the highly available ammonia nitrogen, the most valuable ingredient in the fresh manure, has been largely sacrificed in the rotting process. Such effects of fresh manure might be avoided more economically by reducing the acre rate of application and making such additions of mineral fertilizers as are needed to supply the wanted amounts of phosphoric acid and potash. The superior physical effects of the coarser fresh manure upon heavy clayey soils are recognized, but such manure is said to render sandy soils too dry and open, whereas rotted manure makes such soils more cohesive and retentive of water. Against this may be urged the fact that with a given amount of fresh excrement available, the maximum amount of stable soil humus formed, and hence the maximum long-time benefit to the soil, will result from the incorporation of the manure before its humus-building ingredients, the organic matter and ammonia nitrogen, have been dissipated in the rotting process. Finally, it is frequently stated that fresh manures incorporated immediately before planting the crop may exert a temporary depressing effect upon early growth. The easily decomposable carbohydrates in unrotted manure (chiefly from the litter) are thought to supply food for microorganisms which compete with the crop for available nutrients, especially nitrates and ammonia. This effect cannot be questioned in very strawy manures, but it is doubtful with manures containing only normal amounts of litter. Much work with crop residues, artificial manures, and composts indicates little unfavorable effect from the incorporation of organic materials with a ratio of carbon to nitrogen of 20 or less (87). Fresh manures containing enough straw to absorb all the liquid but not much in excess possess carbon-nitrogen ratios ranging from 16 to 23. The mixed horse and cow manure used by Shutt (98) (see fig. 3) had an initial ratio of about 20, which was reduced to 11 by 3 months of rotting. In a greenhouse experiment at the Wisconsin Station, Heck (31) compared the nitrogen recovery in four crops grown after initial applications of fresh and fermented cow manure (dung, urine, and straw). The latter was fermented for 4 weeks at 20° C. (70° F.) and lost 11 per cent of the original nitrogen. The crops grown recovered 12 per cent less nitrogen from the fermented than from the fresh manure. Even granting that some temporary depressing effect may result from incorporating fresh manures immediately before planting, it should be less costly to forestall this effect by plowing the manure down some time in advance of planting or by increasing somewhat the amount and nitrogen content of the chemical fertilizer applied than by rotting the manure, with its attendant losses of organic matter and nitrogen.

PRACTICAL METHODS OF HANDLING MANURE

The total prevention of losses from manure is impossible by any practical methods of handling. Theoretically, all loss might be prevented and the maximum potential fertility effect realized if the strictly fresh excrement could be spread at once on the field and immediately incorporated with the soil. Actually, loss of 10 per cent or more of the nitrogen as ammonia may be expected in the stable even with daily removal unless chemical preservatives or acid peat litter is used. Additional losses occur in storage, so that under the best conditions—manure well compacted and protected, low temperatures, and tight floors—the total loss of nitrogen is seldom less than 15 per cent and is usually higher. Moreover, with either fresh or stored manure, unless plowed down immediately after being applied to the field, further loss of ammonia nitrogen, sometimes seriously high, is apt to occur from drying. Fortunately, neither phosphoric acid nor potash is volatile, so that their complete recovery is possible with proper handling. Although some loss of nitrogen and organic matter is inevitable under practical conditions, the total shrink in the value of manure may with good management be kept at a low point in comparison with that occurring when manure is exposed for long periods in the open yard.

Daily hauling and spreading.—The daily use of the manure spreader is generally regarded as the ideal method of preventing losses from manure. Although this method is doubtless greatly superior to the methods of handling practiced on most farms, considerable evidence indicates that it may lose much of its advantage where the spread manure remains unincorporated for more than a short time, particularly in dry weather, or where the land is sloping and surface washing occurs. The question of whether greater losses occur from daily spreading or from holding the manure in storage will be considered in a later section dealing with the field management of manure. In any event, since it is impractical to haul and spread manure during certain seasons of the year, and since the competition for labor at busy seasons militates against the practice, resort to some storage of manure is necessary on most farms.

What is good storage?—From extensive studies at the Rothamsted Experiment Station, Russell and Richards (85) concluded that manure keeps best when it is (a) thoroughly compact, (b) sufficiently moist but not too wet, (c) under shelter, and (d) not moved. Some of their data comparing losses in compact and loose heaps, under cover and exposed to the weather, have already been presented in table 10. Data from some early work of Maercker and Schneidewind in Germany (62) illustrate the need for keeping manure moist in storage. After a feeding period of about 3 months, manure that had accumulated under the feet of steers in a deep stall with a concrete floor was found to contain all but 13 per cent of the nitrogen of the feed after allowing for that stored as meat. In a similar experiment, differing only in that the manure was left undisturbed for a month after the steers were removed and hence dried out considerably, the loss of nitrogen amounted to 35.5 per cent. On the other hand, Russell and Richards (85) found that adding water periodically to a loose heap of cow manure under cover actually increased nitrogen losses compared with those from unwatered heaps, and concluded that adding water was a poor substitute for keeping the manure as compact as possible. Another of their experiments illustrates the unfavorable effect of moving stored manure after it has become more or less consolidated. A heap of cow manure stored under cover for 3 months was found to have lost 7 per cent and 5 per cent of the original dry matter and nitrogen, respectively. The heap was moved and remade, and at the end of a second 3-month period was found to have suffered additional losses of 26 per cent in dry matter and 30 per cent in nitrogen. During the second period the temperature rose to 32° C. (90° F.) compared with a maximum of 16° C. (61° F.) during the first period.

Accumulation in covered lot or deep stall.—Accumulating manure under the feet of animals bedded with sufficient litter to absorb the liquid but not much excess is one of the most efficient and practical methods of preservation. The tramping of the animals works the manure into a dense mass and the liquid voided keeps the manure properly moist so that air is excluded and fermentation losses are kept at a minimum. Maercker and Schneidewind (62) were able to recover in manure and meat all but 13 per cent of the nitrogen of the feed when steers were fed for 4½ months in a deep stall with cement floor. A comparable group of steers was fed for the same period in ordinary stalls and the manure removed daily and stored in a covered heap. At the end of the feeding period the loss of nitrogen was 37 per cent, nearly three times as great as in the deep stall method. Where earth floors are employed with this method, considerable loss may result from seepage of liquid. This fact has already been mentioned in the discussion of seepage losses, and reference has been made to the Ohio Station experiments showing that the saving effected by a concrete floor was sufficient to have paid for the floor during two 6-month feeding periods with steers. Accumulation in the covered lot or pen is an excellent method of preserving manure where either cattle, sheep, or hogs are being fed. Equally good results are possible with dairy cattle, by providing an accumulation pen where the cows run loose at all times except when being milked or fed grain. In some places the sanitary regulations applying to the production of market milk do not permit the use of this method, however.

In connection with the use of the covered lot, a good practice is to arrange for conveying manure produced in horse and cow stalls to the covered lot where it can be added to and mixed with that of the animals confined there. One advantage of the covered lot method is that it permits more flexibility in the time of hauling.

Shed storage.—Some provision for the temporary storage of manure from horse and cow stalls is necessary on most farms. The practice of merely throwing such manure out in loose piles in the open yard, frequently under the eaves of the barn, is one of the most common and at the same time one of the most wasteful methods possible. The data in table 14 show the nature of the losses to be expected.

The chief menace of open storage is leaching, which causes loss of all three fertilizing elements together with some organic matter. Some additional loss of ammonia nitrogen occurs from the drying action of wind. Storing manure under cover, preferably in a closed shed, is the most practical method of preventing these losses. The use of the covered feed lot or accumulation pen for storage is excellent practice, since the tramping of the animals keeps the manure compact. Where this cannot be done, a special roofed storage structure with a watertight floor and four continuous walls is desirable. An ideal arrangement is a shed or pit with concrete floor connected to the barn by a

TABLE 14.—Losses from exposure of manure in the open yard

	New Jersey* 2½ months, early summer, cow manure	Canada† 3 months, Apr.-July, one-half horse, one-half cow	Ohio‡ 3 months, Jan.-Apr., steer	New York§ 6 months, Apr.-Sept.	
				Horse	Cow
	Pct.	*Pct.*	*Pct.*	*Pct.*	*Pct.*
Organic matter	....	60	39	....	....
Nitrogen	31	29	30	60	41
Phosphoric acid	19	8	24	47	19
Potash	43	22	59	76	8

*Thorne, C. E. 1914. Farm manures, p. 146. Orange Judd Pub. Co, New York.
†Shutt, M. A. 1898. Barnyard manure. Canadian Dept. Agr. Cent. Exp. Farm Bull. 31.
‡Thorne, C. E., et al. 1907. The maintenance of soil fertility. Ohio Agr. Exp. Sta. Bull. 183.
§Roberts, I. P., and H. H. Wing. 1889. On the deterioration of farmyard manure by leaching and fermentation. Cornell Univ. Agr. Exp. Sta. Bull. 13.

shelter under which the manure spreader can stand, and so located with respect to the stables that the manure can be moved in a trolley carrier and dumped either into the spreader or shed. The stored manure should be kept as compact as possible. With the relatively dry manure from horses and sheep, this is best achieved by mixing with the wetter manure from cattle or hogs. Manure thus stored loses no phosphoric acid or potash and only minimum amounts of nitrogen and organic matter, more of the latter in summer than in winter. Russell and Richards (85) report one experiment in which cow manure stored in a very compact heap under cover from January to April lost only 4 per cent of its organic matter and no nitrogen whatever. However, drier and richer steer manure similarly stored lost 30 per cent of its organic matter and 26 per cent of its nitrogen. In general, losses with this method may be expected to be nearer the latter than the former figures.

Open storage.—Where it becomes necessary to resort to outdoor storage, placing the manure in compact piles of considerable height, so located that they receive neither roof nor surface water, aids somewhat to reduce losses. Covering such piles with boards or a few inches of soil offers additional protection against loss.

EUROPEAN STORAGE PRACTICE

In Europe farmers hold manure in higher esteem than in this country, a fact attested by the care given to its preservation and proper use.

Separate storage of liquid manure.—A fairly common practice prevalent in Denmark and to a less extent in Germany and other European countries is to collect, store, and apply the liquid and solid manures separately. This method recognizes the relatively high value of the liquid portion, its peculiarly perishable character, and the greater ease of preventing losses when it is stored separately. Provision is made for draining the liquid into tanks or cisterns. Here decomposition of the urea to ammonium carbonate occurs very rapidly. Gerlach (21) found 59 per cent of the nitrogen in ammonia form after 8 days and 90 per cent after 32 days at 15 to 16° C. (59-61° F.). Loss from evaporation of ammonia from open tanks may be very rapid but is readily controlled; protection from the air is most important. Covering the tank with a tight hardwood cover and floating a thin layer of cheap tar or oil on the liquid manure are effective. Heinrich (33) observed a loss of 42.2 per cent of the nitrogen from an open tank in 3 months, 22.6 per cent from a tank with a tight wood cover, and only 6.8 per cent where in addition to a tight cover, the liquid was covered with about one-eighth inch of oil. Preservatives may be added to the liquid manure. Jensen (47, II) found gypsum effective if thoroughly stirred, otherwise not. He also suggests adding calcium chloride, 8 parts for each part of ammonia nitrogen present, or calcium nitrate. Adding 12.5 per cent by weight of peat was found effective by Ortmann (74). Special precautions must be taken to prevent loss of ammonia when spreading liquid manure in the field. In a series of field experiments at the Danish State Experiment Station, Iverson (43) found that plowing immediately after application gave maximum increases with oats, swedes, and mangels. Harrowing at once was 8 to 28 per cent less efficient than plowing, whereas delaying the harrowing 24 hours was from 17 to 43 per cent less efficient than harrowing in immediately. Machines are now in use that place the liquid manure beneath the surface of the soil when it is spread.

If handled to prevent loss, the fertilizing constituents in liquid manure (1.0 to 1.5 per cent of nitrogen and 1.0 to 2.0 per cent of potash) have been found equal in value to those in chemical fertilizers. At present prices the nutrients in 1 ton of fresh liquid manure from cattle would cost about $2.60 and those from horses, about $3.40. On this basis the annual value per head of the liquid manure from cattle would be about $9.60; that for horses, about $6.20.

The expense of storing liquid manure is considerable, as about 100 cubic feet of tank space are required per head of stock when emptied once or twice annually. Moreover, special equipment is required for spreading in the field. Probably the costs involved, as well as the abundance of litter materials, account for the slight extent to which the method has found practical use in America. However, the high efficiency possible in the preservation of crop nutrients, and the possibility of timing the application better to meet the current needs of the crop, may warrant its more serious consideration, particularly in intensive dairy sections.

In 1929, Teutsch (105) reported that dairy farmers in Tillamook County, Oregon, were using the liquid manure system. Introduced about 18 years before by a Swiss immigrant, the method had largely come into use to supplement the usual plan of manure storage. The advantages claimed by dairymen were higher value of the manure, greater cleanliness, decreased labor, and the possibility of application to pastures. A special advantage was that it enabled rotational grazing of pastures without fencing; wherever the liquid was spread, cows would not graze for a time and the grass was able to make fresh growth.

The Krantz method of hot fermentation.—A unique method of storing solid manures which has been extensively advocated in Germany is the so-called hot fermentation method devised by H. Krantz (53). In this procedure the manure is not allowed to heat at will but undergoes regulated treatment. The fresh manure is piled loosely in single blocks in a layer about 3 feet high and allowed to ferment until the temperature averages 60° C. (140° F.). This requires 2 to 4 days. It is then trodden solid and another layer added, which is allowed to ferment in the same way. In this manner the manure is built to a final height of 9 to 18 feet, and it is then covered with a layer of soil. The manure is left undisturbed 4 to 5 months; it is then said to be uniformly dark in color, crumbly, and odorless. Essentially, the process consists of a short period of intense aerobic fermentation with rapid oxidation of carbohydrates which causes the manure to heat to the desired temperature of 60° C. (140° F.), followed by a prolonged ripening period under anaerobic conditions with slowly falling temperature. The high temperature reached in the initial stage kills off all but the more heat-resistant sporeforming microorganisms, so that later changes are largely chemical or enzymatic in nature. One advantage claimed is the killing of weed seeds, pathogenic organisms, and parasites. Another is that only small losses occur in handling and spreading the rotted products (72). It is further claimed that the organic matter of the manure is almost completely "humified", and the product is in so many respects superior that it is called "Edelmist", literally, "noble manure."

The merits of hot fermentation for improving and conserving values in farm manures have been much disputed by German investigators. The highly favorable indications of the earlier laboratory and small-scale experiments of Löhnis and others, cited with approval by Ruschmann (82), are not confirmed by recently reported extensive experiments on a practical scale. Siegel (99) conducted an experiment simulating conditions on the average south German peasant holding with four cows; the dung with 7 to 9 pounds of straw daily per head and the minimum possible inclusion of urine was stored by the Krantz procedure, with immediate compaction in a Württemberg dungstead for cold fermentation and also compact storage in piles in an open yard for comparison. It was found that hot fermentation did not yield a product with markedly superior properties throughout the mass, but only in a border zone where there had been limited access of air, precisely the conditions which probably prevailed throughout in the earlier small-scale experiments. Losses of total and "humified" organic matter were greater with hot than with cold fermentation, and the hot fermentation made a good showing only in comparison with yard storage with no effort to prevent loss by leaching; whence it was concluded that cold fermentation in the Württemberg dungstead is the best procedure. Maiwald and Siegel (63) draw similar conclusions from later work on a large estate scale.

The Württemberg dungstead.—The Württemberg dungstead mentioned is a rectangular structure preferably tightly walled with boards, although poles may be used to reduce the cost; a watertight cemented base for collection of leachings is an essential feature. The leachings flow away through a trapped pipe (to prevent access of air beneath the manure) and are stored with the stable drainage as liquid manure. The fresh mixed farm manure as produced is packed as tightly as possible in this structure to a height of 6 feet or more. No roof is provided, but a covering of earth may be added to aid by its weight in keeping the mass compact and to exclude air. This result is so completely attained (aided by retention of the carbon dioxide produced by fermentation) that the temperature does not rise above 35° C. (95° F.) even in summer. The conditions are thus similar to those in a silo, and the same type of acid fermentation is desired, to prevent loss of ammonia and organic matter from excessive heating.

Numerous other reports (22, 50, 55) on the comparative value of manure produced by hot and cold fermentation and yard storage in heaps are in agreement that the practical value of hot over cold fermentation is negligible. Weigert and Fürst (115) conducted large-scale experiments with mixed manures, and conclude that yard storage in compact heaps at least 7 feet high, with vertical sides and flat tops, is practically as good as special fermentation procedures. Scheffer and Zöberlein's (91) comparisons with manure from 70 cows were inconclusive. It should be noted that in their work, the amount of straw included with the manure was so great that in every case the temperature exceeded that specified for the cold fermentation method. They conclude that although special hot and cold fermentation methods may have theoretical advantages, the extra labor required is likely to make them unprofitable. Schmidt (93) states that on a large and well-managed estate a minimum of 53 man-hours is required for handling the manure annually produced by one horse or cow, and one-third more time is required for hot fermentation.

Practically all German writers agree in condemning the practice of fermenting dung and urine together, holding that the prevention of excessive losses of nitrogen is impossible with this procedure; the only exception mentioned by Ruschmann (82) is when acid peat has been used as litter or fermentation is prevented by addition of antiseptics. The pumping of leachings back over the solid manure, apparently frequently done to keep the temperature down, is also generally condemned as increasing losses and without practical value, although Niklewski (72) considers this a valuable means for preventing losses from nitrification. Regulation of the temperature of fermenting manure is considered very important, but control by thorough compaction and exclusion of air is the proper method. If the mass of stored manure is built to the proper height and the sides are protected, the natural rainfall can be depended upon to keep the material properly moist, or water may be added if necessary. The leachings contain soluble and easily volatile nitrogen compounds, hence should be handled separately from the solid manure to minimize losses in storage and application. The attention and labor required by these elaborate fermentation procedures appear excessive in comparison with any practical advantages to be gained. They are of interest chiefly in showing how important the careful German farmer considers the proper preservation of manure.

FIELD MANAGEMENT OF MANURE

In this country, prompt spreading of manure on the field has been generally considered the best method of preventing the losses so prevalent in the usual methods of storage. It must be recognized, however, that appreciable loss may take place from spread manure not plowed under promptly, and even with prompt incorporation some loss in effectiveness attends the application of manure too far in advance of the planting of the crop. Moreover, under practical conditions of manure handling, the higher its content of nutrients in quickly available form, the more subject it becomes to losses in the field.

Some idea of the losses taking place from manure after spreading is gained from a 40-year field experiment at the Ohio Station started by Thorne in 1897. In this test, manure, usually produced by fattening cattle, has been taken from the stable in January and divided into two parts. One-half has been spread upon the clover sod in a rotation of corn, wheat, clover. The other half has been left piled in the barnyard until April, when it has been spread alongside the first half and both have been plowed under for corn; the application has been at the rate of 8 tons of the original manure per acre. The soil, a Wooster silt loam, is moderately sloping, 2 to 4 per cent, and has been regularly limed on corn since 1905. For the entire 40-year period, the manure exposed in the yard from January to April has produced 13.4 per cent less total weight of crops than the manure spread on the field in January. Repeated analyses of the two manures showed that the yard manure, when applied, carried 30 to 40 per cent less nitrogen, 15 to 25 per cent less phosphoric acid, and 40 to 60 per cent less potash than the fresh manure spread in January (108). The fact that the field response for the two manures differs much less than their nutrient content points strongly to a considerable loss of nutrients from the January-spread manure before it was plowed under in April. Such losses may have occurred in three ways: (a) through loss of ammonia nitrogen by drying or freezing, (b) through surface wash removing soluble portions of all three nutrients, or (c) through leaching of nutrients carried into soil by rain and then out in the drainage water (probably the least serious).

The losses of ammonia nitrogen resulting from the drying of manure, as shown by the work of Heck at the Wisconsin Station, have already been discussed (see section on "Losses from Manure"). The practical effects of such losses have been studied extensively in Denmark. Iverson (40) found the following losses of nitrogen from manure lying on the surface of the soil at different times of the year:

	December	March	April
	Pct.	*Pct.*	*Pct.*
After 24 hours	2	3	21
After 4 days	15	10	29

The importance of such losses in reducing the effectiveness of the manure has been demonstrated in an extensive series of field experiments on the Danish State Experimental Farms. Iverson (42) summarizes these results as follows:

TABLE 15.—Experiments on plowing stable manure under at different times after application

	Relative value in increasing crop yields			
	Oats (15 experiments)	Swedes (12 experiments)	Mangels (6 experiments)	Potatoes (1 experiment)
Manure plowed under immediately	100	100	100	100
Manure plowed under 6 hours after spreading	79	84	90	86
Manure plowed under 24 hours after spreading	73	79	71	70
Manure plowed under 4 days after spreading	57	64	58	44

The data in table 15 point strongly to the advisability of plowing manure under immediately after spreading. However, Lemmermann (56) suggests that on heavy, intractable soils, spreading the manure on the plowed ground in fall or winter and following with shallow incorporation in the spring may so improve the granulation and general tilth of such soils as more than to compensate for the losses that attend the use of the method. The favorable effect of the manure presumably arises from the protection afforded against the beating, crust-forming action of rain and against drying by sun and wind, favoring better biological action and granulation in the surface layers. An analagous effect of light surface coatings of manure in improving the stands obtained with legume and mixed meadow seedings has been observed at the Ohio Station. Seedings made in winter wheat are notably improved by top-dressing the small grain with manure during the preceding winter. Seedings made without a companion crop in the spring and particularly in summer are benefited by following the seeding with a light topcoating of manure. These effects probably arise both from the improved moisture and tilth in the top soil layer and from the nutrients supplied by the manure.

In 16 Danish experiments the loss in effectiveness of manure spread some time before plowing under was compared with the loss taking place when the manure was left in piles. The average results of four experiments with root crops were as follows:

TABLE 16.—Manure spread on field compared with manure left in piles

	Relative value in increasing crop yields
Manure spread and plowed under immediately	100
Manure spread 2 days before plowing	71
Manure in piles 2 days before spreading and plowing	80
Manure spread 14 days before plowing	49
Manure in piles 14 days before spreading and plowing	55

Iverson states, "In all experiments an actual gain is made by allowing the manure to lie in piles and be spread just before plowing, instead of leaving it spread over the field for 2-14 days."

The Danish work indicates that manure in good storage is likely to lose less value than if spread on the field without being plowed under. However, the old practice of placing manure in small piles distributed over the field and permitting it to remain for several months before spreading is to be condemned most strongly. Not only are losses from heating and drying large with this method, but the soluble nitrogen, phosphoric acid, and potash sure to be leached out by the rain are not uniformly distributed in the soil as in the case of spread manure, but are concentrated in spots, reflected in the following crop by over-rank growth in these spots and correspondingly less growth elsewhere.

Time of application in relation to time of planting.—Much work with chemical fertilizers indicates that their effectiveness is decreased if they are applied much in advance of planting the crop. The explanation lies in the opportunity afforded for the loss of nitrates (applied as such or formed biologically from ammonia) and the tendency for both phosphoric acid and potash to be fixed by the soil in less available forms. Since well-kept manure contains large amounts of soluble nutrients, strictly comparable with those in fertilizers, the same principles should apply.

Iverson (41) reports 18 field experiments in Denmark, ranging in duration from 1 to 15 years and including six different crops, in which fall and spring applications of manure were compared. Without exception, manure applied in the fall produced smaller average yields than that applied in the spring. The loss in efficiency from fall application averaged 32 per cent and ranged from 8 to 61 per cent. It varied considerably with the weather in different seasons and tended to be higher on sandy than on loamy soils. In a 16-year experiment with mangels, applications made at six times from October to April were compared; they showed the following relative efficiencies:

October 15	58	February 1	83
November 15	68	March 1	75
December 15	84	April 15	100

The differences noted in the foregoing experiments applied only to the crop of the first year. No significant difference in the residual effect on later crops was observed; the losses from fall application must have been chiefly of the quickly available nutrients in the manure. It would appear, therefore, that with manure that has already lost most of its readily available constituents through heating and exposure, the time of application would be less important.

Depth of incorporation of manure.—Whether to apply manure on the surface and disk it in or to plow it under deep or shallow depends upon the climate, the type of soil, and the kind of manure. In general, manure should be so incorporated that sufficient air will be admitted for normal decomposition. Shallower incorporation is probably desirable on heavy or wet soils than on light porous soils. With manure polluted with weed seeds, plowing under gives less trouble from weeds than incorporation by disking. Iverson (42) reports heavy losses from merely harrowing manure into the surface compared with plowing under, indicating that whatever method is followed, manure must be placed below the surface of the soil if losses from drying are to be prevented. Additional evidence of this fact is provided by the data from a 5-year field experiment at the Iowa Station (101) given in table 17.

TABLE 17.—Different methods of incorporating manure for corn (corn, oats, clover rotation on Carrington silt loam)

Data of Stevenson and Brown (101)

Method of incorporating manure	Increase in yield for manure (6 tons)		
	Corn 5-yr. av.	Oats 5-yr. av.	Clover 4-yr. av.
	Bu.	*Bu.*	*Lb.*
Plowed under	6.4	5.1	820
Disked in after plowing	7.1	5.4	940
Cultivated in after corn was up	3.1	1.0	660

Heck (32) found more rapid nitrate development after disking manure in compared with plowing down, and in a single test with barley the nitrogen recovery was slightly higher for disking, although the yield was a little lower than from plowing the manure under. In general it appears that method and depth of incorporation are less important than provision for completely covering the manure.

Intermixing of manure and soil.—It is commonly recommended that manure be thoroughly mixed with the surface soil; disking the manure in before plowing is one method of attaining the result. Reliable evidence appears to be lacking on this point, however. In view of the higher efficiency usually obtained from localized placement of chemical fertilizers, and the fact that placing manure in the row for cotton produced 82 pounds more seed cotton than broadcasting and harrowing in as a 2-year average at the South Carolina Station (4), the question obviously requires further investigation.

Manure is sometimes buried in furrows between irrigation ditches in California orchards, to prevent losses from exposure and to bring the nutrients within reach of the tree roots. Prompt covering and thorough wetting to avoid heating are noted to be essential with this method (5). For widely spaced hill crops, such as melons, it is a rather common practice in northern Ohio to work about one-half bushel of well-rotted cow manure into the hill before planting the seed.

Method of applying manure to small grains.—Top-dressing winter wheat has been found an effective method of ensuring better stands of meadow crops seeded in wheat. On the other hand, experiments in Michigan (97), Ohio (88), Utah (26), and Canada (61) indicate that for wheat, oats, and barley, larger increases in yield of the small grain are obtained from applying the manure before plowing than from top-dressing the growing crop.

COMPOSITION OF MANURE

Manure varies widely in its content of fertilizing constituents, ranging from as high as 60 pounds of crop nutrients per ton for high-grade fresh sheep manure to as low as 15 pounds or less for much leached yard manure. Composition varies with the class, age, individuality, and production of the animal, with the composition and digestibility of the ration, and with the method and time of storage. Many hundred analyses are available. Those in table 18 are fairly typical.

TABLE 18.—Composition of manures

Kind of manure	Contained in 1 ton of moist manure, usually 75-80 per cent water content			Authority
	Nitrogen	Phosphoric acid (P_2O_5)	Potash (K_2O)	
	Lb.	*Lb.*	*Lb.*	
Fresh manures				
Horse, with straw	11 (9.8-14.6)	5.5 (4.1-10.4)	13.2 (10.8-18.0)	Thorne*
Steer, with straw	11 (9.6-15.8)	7.0 (6.2-7.4)	9.6 (8.2-10.0)	Thorne
Dairy cow, with straw	9 (8.6-9.4)	6.0 (5.7-6.4)	8.4 (7.2-9.6)	Thorne
Sheep, with straw	20 (12.6-34.0)	9.0 (7.8-12.0)	16.8 (10.8-28.0)	Thorne
Hog	13 (10.8-16.8)	12.7 (7.8-16.8)	9.6 (6.4-14.5)	Thorne
Poultry	18 (9.2-24.8)	17.5 (14.0-20.2)	9.6 (4.9-22.3)	Thorne
Stall manure, fattening cattle	12.0	6.2	11.2	Ames and Gaither†
Yard manure, fattening cattle	7.5	5.3	3.1	Ames and Gaither
Mixed horse and cow, fresh	12.0	6.2	15.2	Shutt‡
Same rotted 6 months, protected	34.0	22.4	50.6	Shutt
Same rotted 6 months, exposed	16.1	10.8	21.4	Shutt
Commercial manures:				
Pulverized sheep manure airdry	45	19	26	Shutt and Wright§
Shredded cattle manure airdry	42	31	29	Shutt and Wright
Pulverized cattle manure airdry	40	30	36	Shutt and Wright
Stockyard manure, moist	9.6	2.8	9.4	Shutt and Wright

*Thorne, C. E. 1913. Farm manures, p. 93. Orange Judd Pub. Co., New York.
†Ames, J. W., and E. W. Gaither. 1912. Barnyard manure. Ohio Agr. Exp. Sta. Bull. 246.
‡Shutt, F. T. 1898. Barnyard manure. Can. Dept. Agr. Cent. Exp. Farm Bull. 31.
§Shutt, F. T., and L. E. Wright. 1931. Manures and fertilizers, their nature, functions and application. Dom. of Canada, Dept. of Agr. Bull. 145, New Series.

The contents of only the important fertilizing constituents are shown in table 18. Data on the occurrence of the so-called "minor" or "trace" elements in manure are extremely meager. An analysis of manure showing 0.008 per cent manganese, 0.005 per cent boron, with a trace of fluorine but no copper, has been published (118). Zinc has been reported present in stable and chicken manure (6). Selenium is known to occur in manure from animals fed seleniferous crops and to persist for considerable periods after the poisonous feed has been discontinued, from its gradual elimination by the animal (10). Since soil deficiencies in such elements as manganese, copper, zinc, boron, etc., are reflected in the composition of the crops grown, manure produced by feeding these crops might be expected to show similar abnormalities in composition and be ineffective in correcting deficiencies in the same elements. However, purchased feeds, presumably of normal composition, are so widely used, and traces of elements such as zinc and copper are so likely to find their way into manure from the common use of these metals about stables that their occasional presence in effective amounts in manure would not be surprising. The Florida Station has reported experiments on manganese-, copper-, and zinc-deficient soils which indicate that manure apparently supplied these elements in significant amounts (6, 7, 100).

Němec (69) has published analyses showing that manure from feeding crops grown on soils at low fertility levels is of considerably less value than that produced on soils naturally richer or adequately fertilized. The available potash and phosphoric acid, as indicated by solubility in a 1 per cent citric acid solution, in nine good and five poor soils of one district in Czechoslovakia, with the averaged composition of manures produced on the same soils, are shown in table 19.

TABLE 19.—Fertility elements in manure from feeding crops grown on soils varying in fertility

Data from Němec (69)

Available K_2O in soil	K_2O in manure		N in manure	
	Solid	Liquid	Solid	Liquid
Lb. per acre	*Pct.*	*Pct.*	*Pct.*	*Pct.*
482–1,054	0.44	0.60	0.34	0.21
162– 256	.32	.35	.39	.27

Available P_2O_5 in soil	P_2O_5 in manures from—					
	All soils		Low K_2O soils		High K_2O soils	
	Solid	Liquid	Solid	Liquid	Solid	Liquid
Lb. per acre	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*	*Pct.*
534–896	0.25	0.035	0.18	0.023	0.32	0.048
188–486	.16	.019	.18	.018	.16	.020

QUANTITY OF MANURE PRODUCED

The quantity of manure produced by farm animals varies with the same factors that affect composition. In table 20 are presented average figures for the daily and annual production of fresh manure by different animals, compiled from various sources. The annual figures assume that the animals are continuously housed and that the total excrement plus normal amounts of litter goes into the manure.

TABLE 20.—Manure produced per 1,000 pounds of liveweight by different classes of farm animals (of mixed ages and on common rations)

Class	Daily production	Annual production
	Lb.	*Tons*
Horses	48	9
Steers	46	8½
Cows	85	15
Sheep	41	7½
Hogs	98	18
Poultry	23	4¼

*Does not include litter.

In practice, the actual amounts of manure recovered are likely to be considerably less than the amounts indicated, owing to the dropping of manure on pastures, lanes, roads, etc. Hence, in estimating the manure production of a farm, appropriate allowance must be made for the time that the animals are not confined in the stable or lot. Further allowance must be made for losses of weight in storage, which may run as high as 60 per cent when manure is exposed for a considerable time in the open lot.

From a study of the amounts of manure actually hauled out on 224 dairy farms in Illinois, Ross (80) reports the amounts of manure recovered annually to be as shown in table 21. The amounts are stated in terms of loads (approximately 1 ton) per animal unit. One animal unit is equivalent to 1 mature cow, horse, or steer; to 2 head of young stock; to 5 hogs, 7 sheep, or 100 chickens.

TABLE 21.—Average amounts of manure recovered per animal unit on 224 dairy farms in Illinois

Data of Ross (80)

	Manure recovered per animal unit
	Loads
Dairy cattle (cows, bulls, young stock)	6.6
Work animals (horses, mules, colts)	5.5
Steers	1.2
Hogs (sows, shoats, pigs)	1.7
Poultry (mostly hens)	1.9
Sheep (ewes, lambs)	.8

It will be noted that the amounts of manure recovered under these practical farm conditions are much lower than the quantities produced shown in table 20. The discrepancy in the case of work animals and dairy cattle can be attributed to the dropping of manure at times when the animals were not stabled and to the shrink in storage. The much wider discrepancies with steers, hogs, and sheep are attributed to the same factors plus the fact that these animals are rarely kept on the farm throughout the entire year.

Relation of amounts of manure and feed.—The amount of manure produced can be estimated from the weight of crops fed. In a comparison of livestock and grain farming at the Ohio Station, all the crops except the wheat grain, including the straw and stover, produced on one section of land in a 4-year rotation of corn, soybeans for seed, wheat, clover, are either fed or worked into the bedding with steers in a covered shed with a concrete floor. As a 14-year average, the manure produced has been equivalent to 1.5 pounds for each pound of crops. If an average dry matter content of 90 per cent in the crops is assumed, the manure production per pound of dry matter has been 1.7 pounds. From another experiment at the Ohio Station, in which two lots of steers were fed for 6 months in a covered shed, one lot on concrete and the other lot on earth floors, Thorne (106) obtained a production of manure equivalent to 1.81 pounds for each pound of dry matter in feed and bedding for the steers on concrete, compared with 1.66 pounds for those on the earth floor. The foregoing figures apply to manure that has been accumulated under excellent storage conditions. They might easily be reduced as much as 50 per cent where the manure undergoes extensive loss through heating and leaching.

THE FERTILIZING PROPERTIES OF MANURE

The growth-promoting effects of manure are largely produced by the nitrogen, phosphoric acid, and potash contained. To a minor degree, they may be influenced by the organic matter present, by the microorganisms carried, or by certain growth-promoting compounds called "auxins" (11). Compared with commercial fertilizers, manure is low in nutrient content. Stated in fertilizer terms, fresh cow manure approximates a 0.5-0.3-0.4 analysis, with a total of 1.2 units of plant nutrients compared with 16 to 20 units in ordinary mixed fertilizers. In spite of its low nutrient content, the relatively heavy rates at which manure is applied, usually 50 to 100 times those of chemical fertilizers, make the actual acre application of nutrients considerably higher than is customary with fertilizers. To some extent this is offset by a lower availability of the nitrogen of manure.

Availability of fertilizing constituents.—Numerous investigations have shown that the nitrogen of the urine is equal in availability to that of such mineral fertilizers as sulfate of ammonia and nitrate of soda. On the other hand the nitrogen of the dung is of a very low grade. The results of Heck (31) at the Wisconsin Station reported in table 22 are fairly typical of many investigations of the availability of the nitrogen in solid manures.

TABLE 22.—Recovery of nitrogen from manure. Greenhouse experiment at the Wisconsin Station

Calculated from data of Heck (31)

Kind of manure	Nitrogen applied	Nitrogen recovered					
		First crop	Next three crops	Total	First crop	Next three crops	Total
	*Lb. per acre**	*Lb.*	*Lb.*	*Lb.*	*Pct.*	*Pct.*	*Pct.*
Fresh cow manure							
Solid only	62.3	2.3	8.4	10.7	3.7	13.4	17.2
Solid plus liquid	131.4	55.2	14.9	70.1	42.0	11.3	53.3
Fermented cow manure							
Solid only	57.9	4.6	20.5	25.1	8.0	35.3	43.3
Solid plus liquid	117.7	40.6	14.2	54.8	34.5	12.0	46.5
Fresh horse manure							
Solid only	67.1	— .7	16.5	16.5	0	24.6	24.6
Solid plus liquid	127.0	38.9	17.9	56.8	30.6	14.1	44.7

*One acre is assumed to be equal to 2,000,000 pounds of soil.

It is observed that the recovery of nitrogen from the solid in the first crop varies from none for horse dung to 8 per cent for fermented cow dung. In contrast, the recovery from the urine, applied with the solid, is high. With fresh cow manure, the addition of 69.1 pounds of urine nitrogen increased the nitrogen recovered in the first crop by 52.9 pounds, indicating that 76.6 per cent was recovered. The residual effect shown by the recovery in the three subsequent crops tended to be higher than the immediate effect with the solid, whereas the liquid appears to have had little effect beyond the first crop.

The availability of the nitrogen in ordinary farm manures varies from about 25 to 50 per cent of that of mineral nitrogen fertilizers, depending upon the kind of manure and the changes taking place in storage. Data for fresh horse and cow manure obtained in a 20-year field experiment at the New Jersey Station (58) are shown in table 23.

TABLE 23.—Availability of manure nitrogen in the field (Rotation: corn, oats, oats, wheat, timothy)

Data of Lipman, Blair, and Prince (58)

	Availability of nitrogen* (Nitrate of soda=100)	
	First 5 years	Entire period
Cow manure, 16 tons annually	32.3	42.1 (20 years)
Horse manure, 16 tons annually	29.7	46.1 (15 years)

*Average for limed and unlimed soils. The availability was somewhat lower on limed than on unlimed plots.

From a study of German investigations of the problem, Honcamp (36) states that under practical farm conditions the availability of manure nitrogen may be expected to be from 25 to 30 per cent of that of mineral nitrogen fertilizers.

The availability of the phosphoric acid and potash of manure differs from that of the nitrogen in that it is practically equal to that of mineral fertilizers. A typical experiment is that of Schneidewind (94), who determined the nutrients recovered from stable manure in comparison with chemical fertilizers in a field experiment with the results shown in table 24.

TABLE 24.—Recovery of nutrients from stable manure and chemical fertilizers

Data of Schneidewind (94)

	Recovery of nutrients applied		
	Nitrogen	Phosphoric acid	Potash
	Pct.	Pct.	Pct.
Sugar beets followed by barley			
Stable manure	40.9	41.9	47.5
Chemical fertilizers	93.5	23.2	48.7
Potatoes followed by wheat			
Stable manure	36.2	32.7	78.2
Chemical fertilizers	76.9	14.6	52.7

The higher recovery of phosphoric acid with stable manure than with chemical fertilizers indicated in table 24 has been observed by other workers and has been variously attributed to the action of carbon dioxide produced in the decomposition of manure in increasing the assimilation of mineral soil phosphates by plant roots, the effect of the soluble organic matter supplied by the manure in keeping phosphoric acid in solution and favoring its mobility, or the general superiority of phosphorus in organic combinations occurring in manure.

Effect of litter upon availability of fertilizing constituents.—A temporary repression of the availability of the fertilizing constituents of fresh manures often occurs when straw or cornstalks are used as litter. The readily decomposable carbohydrates in these materials provide energy for soil microorganisms which assimilate the available nutrients in competition with the crop. This effect is absent or slight with peat litter, which carries very little decomposable carbohydrate. Heck (31) found that adding 6 per cent of straw to fresh cow dung and urine reduced the recovery of nitrogen by the first crop 17 per cent. The corresponding reduction with fresh horse manure was 18 per cent. In neither case was the recovery of nitrogen by three subsequent crops affected appreciably. Superior results from peat litter manure compared with straw litter manure in the first year have been frequently reported. Akhromeiko (1) found that fresh manure with straw increased the first-year yield of legumes but depressed that of cereals. This was explained by a repression of nitrification lasting for about 3 months. It was not observed with fermented manure. According to Niklewski (72) the cause is immobilization of available nitrogen in bacterial protoplasm. Unless manure contains excessive amounts of straw so that the carbon-nitrogen ratio is raised much above 20, these depressive effects are not serious (87, 99).

Lasting quality of manure.—Owing to the slower availability of its nitrogen and to its contribution to the soil humus, the effects of manure tend to be distributed over a longer time than those of chemical fertilizers, and with repeated applications the cumulative effects tend to be larger. These facts are illustrated by data from the 5-Year Rotation Fertility Experiment presented in tables 25 and 26.

TABLE 25.—Comparative direct and residual effects of manure and chemical fertilizers (Rotation: corn, oats, wheat, clover, timothy)

Ohio Agricultural Experiment Station, Wooster, Ohio
5-Year Rotation Fertility Experiment

Plot No.	Nutrients applied per rotation*				Average increase in total produce per rotation (1894–1936)†			
					Direct effect of treatment		Residual effect of treatment	
	Nitrogen	Phosphoric acid	Potash	Total	Grain crops (corn, wheat, oats)		Hay crops (clover and timothy)	
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Relative*	*Lb.*	*Relative*
18, manure	145	80	130	355	6,909	89	4,211	153
12, chemicals ..	112	51	130	293	7,781	100	2,747	100
20, manure	72	40	65	177	3,983	69	2,248	150
14, chemicals ..	50	35	90	175	5,766	100	1,497	100

*Chemicals divided among all three grain crops; plot 18 receives 16 tons of manure, divided between corn and wheat, and plot 20 is manured in the same way but at one-half the rate.

†Averages for limed and unlimed ends.

TABLE 26.—Comparative cumulative effects of manure and chemical fertilizers

Ohio Agricultural Experiment Station, Wooster, Ohio
5-Year Rotation Fertility Experiment

Plot	Treatment*	Average increase in total produce per rotation†		Increase stated as per cent of that for chemicals	
		First 10 years	Entire 43 years	First 10 years	Entire 43 years
		Lb.	*Lb.*	*Pct.*	*Pct.*
18	Manure........	6,142	11,120	79	106
12	Chemicals.....	7,731	10,528	100	100
20	Manure........	4,024	6,231	68	86
14	Chemicals....	5,891	7,263	100	100

*See table 25.
†Averages for limed and unlimed ends.

The long-time cumulative effects of manure probably result from its contribution to the stable humus supply of the soil, in part from the resistant organic materials of the manure itself and in part from the root and stubble residues of the larger crops grown. These effects are not great with the rates of application commonly employed in general farming. They tend to be smaller on well-aerated coarse-textured soils and larger on heavy or wet soils. With heavy rates of application they may effect great changes in soil properties and productivity, a fact well known to those engaged in greenhouse or intensive vegetable cropping. The lasting effects of heavy applications of manure are shown by an experiment at the Rothamsted Station (25). A continuous barley plot, manured annually for 20 years at the rate of 14 tons per acre, was divided into two parts. One continued to get the same yearly dressing of manure; the other received no further treatment. Both were cropped to barley for an additional 40 years. The relative yields are shown graphically in figure 4. For comparison, the yields of a plot continuously untreated from the beginning are shown. It is interesting to note that the yield of the plot which received manure for 20 years but none thereafter was still double that of the continuously unmanured plot after 40 years of cropping. The lasting effect of manure is illustrated by recently reported yields of sugar beets grown under irrigation in western Nebraska (29). Over a 5-year period, the total effect of one 30-ton application of manure at the start was only 2 per cent inferior to that of five annual 6-ton applications. The residual effects shown during the next 5 years without further manuring were also in practically the same ratio.

Manure compared with chemical fertilizers.—That the crop increases produced per pound of nutrients applied are apt to be somewhat higher with chemical fertilizers than with manure was shown by Thorne (107) in an analysis of long-time field experiments in this country and at Rothamsted. He states that "in order to get as large a relative return from manure as from chemicals it has been necessary not only to reinforce the manure with phosphorus—but also to compute the nitrogen in manure at a lower rate than that indicated by chemical analysis—." He attributes the common idea that farm manure possesses fertilizing properties additional to those due to its nitrogen and mineral elements to the fact that manure has usually been applied in such amounts as to carry much larger quantities of these elements than are given in chemical fertilizers.

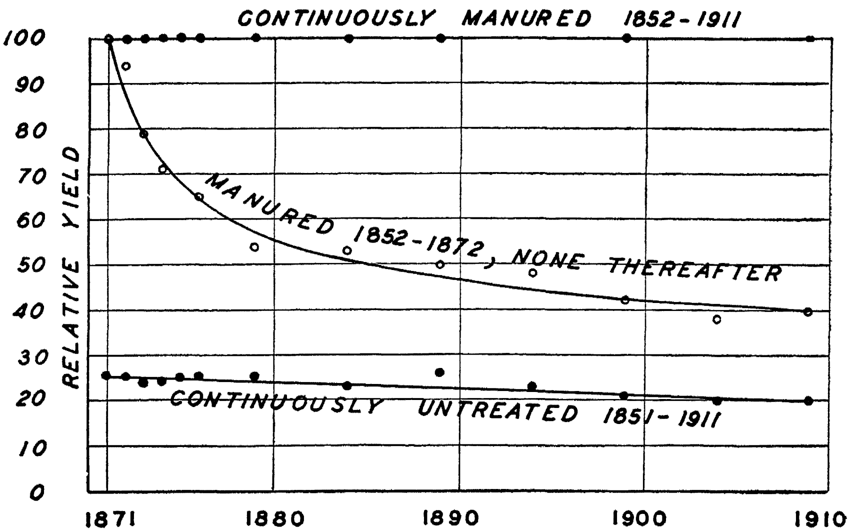

Fig. 4.—Residual effects of heavy applications of manure
Rothamsted Experiment Station. Reported by Hall (25)
Continuous barley; manure applied at rate of 14 tons annually

In comparisons with the plant nutrients applied in practically equal amounts as fertilizers and as manure, the supposed superiority of the latter has seldom been evident. Thus Nielsen (70) reported after 9 years of work with grains, root crops, and clover that the percentages of utilization from standard applications of manure and equivalent chemicals were as follows: for nitrogen, 32 and 54; for phosphoric acid, 32 and 38; for potash, 54 and 73, respectively. With manure, yields were less and the contents of plant foods in the crops lower than with fertilizers.

Typical data showing the response of crops to equal amounts of nutrients supplied in the form of manure and chemicals are shown in table 27.

TABLE 27.—**Comparison of manure and chemicals carrying equal amounts of nutrients (Rotation: corn, oats, wheat, clover. Basic treatment: 2 tons of ground limestone on corn)**

Ohio Agricultural Experiment Station. Data of Salter et al. (88)

Plot No.	Treatment (all on corn)	20-year average increase				Value of increase
		Corn	Oats	Wheat	Clover	20-year average
		Bu.	*Bu.*	*Bu.*	*Lb.*	*Dol.*
29	4 tons of manure	10.1	4.3	2.1	304	11.19
26	Chemicals equivalent to 4 tons of manure	10.0	5.6	3.5	202	12.40
30	4 tons of manure and 380 pounds of 20 per cent superphosphate	13.9	7.6	8.8	553	22.07
27	Chemicals equivalent to treatment on plot 30................................	13.4	9.4	9.0	701	23.41

Pryanishnikov (76) has summarized the English, Danish, and Russian work on this problem and finds that with equal amounts of nutrients, manure is always less effective, in spite of what advantage it may possess in improving the physical condition and buffer capacity of the soil and in increasing carbon dioxide production. However, the nature of the crop appeared to affect the comparison. Substituting half nutrients from chemicals and half from manure for full nutrients from manure alone increased the yield of beets 20 per cent but reduced that of potatoes 10 to 20 per cent. Grains were intermediate. At the Rhode Island Experiment Station (14), however, in a 10-year comparison of 32 tons of manure with 16 tons of manure plus chemicals for vegetable crops (cabbage, tomatoes, celery, beets, spinach, and lettuce) the yields were in all cases larger for the lighter dressing of manure plus chemicals, even though the total amounts of nutrients supplied were less than for the full application of manure.

The idea that manure treatment tends to outyield chemicals in bad seasons, thus tending to stabilize crop yields, cannot be substantiated, according to Thorne (107), who concludes that "It does not seem that either chemicals or manures possess any regular superiority in unfavorable seasons." The authors have calculated the coefficients of variability for yields of corn and wheat on comparable manured and chemically fertilized plots in long-time experiments at the Ohio Station and have found no significant differences.

Supplemental values of manure.—Although the crop increases produced by manure are no larger and are generally less than those from the equivalent amount of nutrients supplied in chemical fertilizers, it cannot be concluded that manure possesses no value aside from its direct fertilizing effect. Instead, it seems that the relatively low availability of the nitrogen of manure should decrease the value of manure compared with chemicals below that usually found. It may well be that this lack of availability is partially offset by certain supplementary effects of the manure. The benefits from large dressings of manure upon the physical properties of the soil have often been demonstrated and are well recognized by farmers. On the other hand, it appears that the physical effects produced by the usual amounts of manure applied in general farming have been overestimated, particularly on normally well-aerated soils. The insignificant effects upon physical properties produced by long-continued manuring at the Ohio Station will be discussed later in this work.

The large number of microorganisms introduced by manure have been thought to hasten desirable biological changes in the soil. However, Barthel (8) found no effect on the soil microflora from applications of manure, and considers the biological action of manure to be indirect—the supplying of organic food materials—rather than direct. An increased carbon dioxide production in manured soils has been shown frequently. That this extra carbon dioxide may be of value is indicated by work of Samoilov (90), who buried manure at different rates in a wooden channel between rows of potatoes in such a way as to exclude the action of the nitrogen and observed increases in yield in proportion to the amount of manure used.

But in experiments with potatoes, Bushnell (12) has repeatedly observed marked increases in yields on heavy soils into which chopped corn stover had been incorporated. Since similar benefits were also obtained from incorporated sand or granular slag, and even from lines of perforated drain tile buried under the potato rows, a considerable part of the effect was attributed to increased aeration.

Flieg (19) demonstrated that soluble humates increase the solubility and mobility of mineral phosphates and suggests that part of the value of manure may be due to the soluble humates contained. Also, Niklewski (73) concluded, from a review of the literature, that the water-soluble and colloidal constituents of manure have a definite value aside from the accompanying nutrient salts.

Creatinine occurs in manure, has been isolated from soil, and is known to be beneficial to plant growth (113).

The probability that manure carries small quantities of certain growth-promoting substances which act in a manner similar to hormones and vitamins in animals has been suggested by Breazeale (11). Compounds of indole with acetic, propionic, and butyric acids are known to stimulate root development and plant growth when present in very low concentrations (35). They belong to a group of compounds known as "auxins." Skatole has also been found to have growth-promoting properties (23). Both indole and skatole are formed in the putrefactive processes occurring in the animal intestine and in the manure pile. They are chiefly responsible for the characteristic fecal odor of manure.

The sex hormones of animals, found in greatest amounts in the urine of pregnant females, are known to stimulate plant growth in culture solutions. Schoeller and Goebel (95) suggested that their presence in manure may explain the opinion of farmers that animal manure is superior to chemical fertilizers. However, Nehring and Möbius (67) tested concentrated preparations of these hormones obtained from the urine of stallions and pregnant mares and concluded that they are not important factors in the action of manure because they occur in too small concentration to be active on plants grown in soil.

Whether these growth-promoting substances contribute anything to the practical value of manure cannot be said at present. The same is true for the effects attributed to the soluble organic matter and colloids of manure. However, possible evidence of their significance is found in work of Hartley and Greenwood (28) in Nigeria. They obtained increases in cereals from as little as 1 ton of manure per acre that were much greater than those produced by equivalent amounts of nutrients supplied as chemical fertilizers.

MANURING FOR CROP PRODUCTION

Maximum returns from manure can be obtained only by applying it with due recognition of the following facts:

1. Manure carries relatively high proportions of nitrogen and potash to phosphoric acid; well-preserved mixed manure contains approximately 10 pounds of nitrogen, 5 pounds of phosphoric acid, and 10 pounds of potash per ton, equivalent in total nutrients to 100 pounds of a 10-5-10 fertilizer. More properly, allowing for the relatively low availability of the nitrogen in manure, a ton of such manure may be considered equivalent to 100 pounds of a 3-5-10 or 4-5-10 fertilizer. Even so, its content of phosphoric acid is relatively low if compared with the fertilizer analyses found most efficient for most crops and soils. Used without phosphate supplements, it might be expected to produce larger effects on crops requiring relatively large amounts of potash and nitrogen, such as corn, sugar beets, potatoes, and tobacco, than on crops with high phosphate requirements, such as wheat or tomatoes. Legumes, such as alfalfa and clover, although requiring considerable potash, benefit from more phosphate than carried in manure, and have little need for the nitrogen sup-

plied. Over a 30-year period, 5 tons of yard manure annually, applied to crops grown in continuous culture at the Ohio Station, have produced average increases of: corn, 21.7 bushels; oats, 15.1 bushels; and wheat, 11.1 bushels. The same amount of manure applied annually to crops grown continuously at the Utah Station has produced 10-year average increases of: sugar beets, 14 tons; corn, 16.1 bushels; alfalfa, 3.6 tons; and wheat, 8 bushels. In the same test, 10 tons of manure increased the yield of potatoes 123 bushels.

Reinforcing manure with phosphate fertilizers, applied either with the manure or at other times in the rotation, has been found highly effective in general cropping. Few fertility practices have been proved more universally profitable. Typical of the results obtained in many widely scattered field experiments are those from an experiment at the Ohio Station, where the addition of 320 pounds of 16 per cent superphosphate as a supplement to 8 tons of stall manure applied to corn in a corn, wheat, clover rotation has produced 36-year average increases of corn, 10.3 bushels, wheat, 6 bushels, and clover, 840 pounds, a return at present prices of about $16.38 for an investment of about $3.20 in the phosphate. In this test, both manure and phosphate were applied to the corn. A better practice, in rotations including both corn and wheat, is to apply the manure to the corn and the phosphate to the wheat.

2. At the rates at which manure is commonly applied, the total acre application of nutrients is usually much higher than with the usual applications of chemical fertilizers. Thus, 8 tons of manure per acre, a common application on corn, will carry roughly 200 pounds of total nutrients, as much as in 1,000 pounds of a 20-unit mixed fertilizer. Many experiments comparing increasing rates of application of manure show a marked falling off in the crop increases produced per ton of manure as the application is increased.

In tests with sugar beets under irrigation in western Nebraska, manure was applied at various rates, 6 to 30 tons to the acre, at various intervals and annually. From data of 5 years, it is concluded that on the plot receiving 12 tons of manure annually, the return per ton from the second 6 tons of this application was 140 pounds of beets; with increasing rates of application, 18, 24, and 30 tons annually, the immediate returns showed steady decreases, being, respectively, 113, 87, and 80 pounds of beets for each ton of manure in excess of the base rate, 6 tons annually. It is concluded that farm manure is most efficiently utilized from the lighter applications and that one between 6 and 12 tons is most practical (29). Other data illustrating this tendency are shown in table 28.

The falling off in value of increase per ton of manure with increasing application is seen to be greater with the crops directly manured than with subsequent crops in the rotation in experiment B; also, the value of increase per ton falls off faster in the first 15 years of experiment A than for the full 36-year period. These facts indicate that the residual, or long-time, effects of manure are less subject to the "law of diminishing returns" than are its more immediate effects and that full returns from heavy applications are more likely to be realized when the results are measured over a considerable period of time. The Nebraska results referred to show the same tendency.

In experiment C, the second 10-ton increment of manure has produced increases of: tobacco, 124 pounds, wheat, 4.5 bushels, and clover, 572 pounds, with a total value of $19.26 for the rotation. Another plot in this experiment received 400 pounds of 16 per cent superphosphate as a supplement to 10 tons of manure. The phosphate produced increases of: tobacco, 160 pounds, wheat,

TABLE 28.—Diminishing returns per ton from increasing applications of manure

Ohio Agricultural Experiment Station

Rate of application	Value of increase per ton of manure		
Experiment A Manure applied to wheat in potato, wheat, clover rotation, at Wooster, 36 years			
	First 15 years	Entire 36 years	
4 tons	$5.77	$7.13	
8 tons	4.41 (second 4 tons, $3.06)	6.13 (second 4 tons, $5.02)	
16 tons	2.99 (last 8 tons, $1.69)	5.69 (last 8 tons, $5.26)	
Experiment B Manure divided between corn and wheat in corn, oats, wheat, clover, timothy rotation, at Wooster, 33 years			
	Grain crops	Hay crops	Total
Unlimed land			
8 tons......	$3.39	$1.36	$4.75
16 tons.	2.86 (second 8 tons, $2.34)	1.41 (second 8 tons, $1.46)	4.27 (second 8 tons, $3.80)
Limed land			
8 tons.......	3.23	1.66	4.89
16 tons.......	2.60 (second 8 tons, $1.98)	1.52 (second 8 tons, $1.40)	4.12 (second 8 tons, $3.38)
Experiment C Manure applied to tobacco in tobacco, wheat, clover rotation, at Germantown, 33 years			
10 tons.........	$7.13		
20 tons.........	4.58 (second 10 tons, $1.93)		

5 bushels, and clover, 698 pounds, with a total value of $24.30 for the rotation. The second 10-ton increment of manure is estimated to have carried about 80 per cent as much phosphoric acid as the 400-pound application of superphosphate. Since the increase produced was also about 80 per cent as large as for the phosphate, it may be concluded that the effect of the second 10 tons of manure was solely due to its phosphoric acid content, that the first 10 tons supplied all the nitrogen and potash needed under the conditions. Other experiments corroborate this one in indicating that lighter applications of manure are justified if sufficient phosphate is applied to balance properly the other nutrients carried.

In general, it appears that greater returns from a given quantity of manure are likely to be realized when the manure is applied at light rates over a large area than at heavy rates over a small area.

3. Previously it has been noted that storage losses from manure are much higher in summer than in winter. Obviously, manure produced during the winter and early spring months is more efficiently used if applied to spring-planted crops than if held over and applied to wheat or some other fall-planted crop. Thorne (106) has cited data supporting this statement. When spring crops follow sod, there is the further advantage of greater ease of spreading and less likelihood of loss from drying in the field before incorporation.

4. Mention has also been made of the fact that whereas the fertilizing properties of manure are most fully realized when it is promptly incorporated after spreading, the mulch effects from surface coatings may be of considerable value in improving the structure of heavy soils and in helping to ensure satisfactory stands of legume and grass seedings. The data in table 29 illustrate

the comparative effects of applying manure to wheat at seeding time and as a winter top-dressing, upon the yields of wheat and hay following. Table 30 shows the benefit derived by the hay crop from a very light coating (2 tons) applied to wheat during the winter prior to seeding the hay crop.

TABLE 29.—Applying manure to wheat at seeding time versus winter top-dressing

Ohio Agricultural Experiment Station

Method of applying manure*	Average increase in yield		Value of increase
	Wheat (20 crops)	Clover (18 crops)	
	Bu.	*Lb.*	*Dol.*
Plowed under for wheat	4.4	842	8.59
As top-dressing to wheat in December	.9	1,604	8.89

*Manure used equivalent to one-half that produced by feeding crops in corn, soybean, wheat, clover rotation.

TABLE 30.—Hay seeding benefited by light winter top-dressing of manure on wheat

Calculated from data of Wiancko, Walker, and Mulvey (117)
Indiana Experiment Station

Method and rate of application	Average increase in yield (1919–1934)			Value of increase
	Corn	Wheat	Hay	
	Bu.	*Bu.*	*Lb.*	*Dol.*
6 tons plowed under for corn	13.2	4.5	283	12.46
4 tons plowed under for corn 2 tons on wheat in winter	12.7	6.3	752	15.64

5. The distribution of nutrients following an application of manure is comparable to that from a broadcast application of chemical fertilizers. Many experiments have demonstrated the general superiority of hill or row placement of fertilizers for crops planted in hills or rows. One important advantage of the localized placement is the large amount of nutrients at the immediate disposal of the plant in its early stages of growth. This appears to be most important with crops planted in the early spring and on soils of low fertility. An application of 200 pounds of fertilizer (20-unit goods) placed in the hill for corn gives a concentration of nutrients within a 4-inch radius around the hill about seven times as great as a broadcast application of 8 tons of manure carrying five times as much total nutrient. Supplementing manure applications with moderate hill or row applications of fertilizers is usually beneficial on corn, potatoes, tobacco, and most vegetable crops and more economical than attempting to meet the early demands of the crop by heavier applications of manure. In a 5-year test at the Ohio Station, 8 tons of manure applied to corn in a corn, oats rotation gave average increases of 11.9 bushels of corn and 6.3 bushels of oats. When the manure was supplemented with 200 pounds of 4-12-4 fertilizer in the hill for corn, additional increases of 8.1 bushels of corn and 2.1 bushels of oats were obtained. The yields of untreated corn and oats were 30 and 25 bushels, respectively.

6. A general principle in applying both manure and fertilizers is that largest returns are usually realized from applications made to the crop of highest acre value. This applies particularly to crop rotations including such crops as tobacco, potatoes, or vegetables. In a 36-year experiment at the Ohio Station, 8 tons of manure applied to potatoes in a potato, wheat, clover rotation produced increased crops per rotation having a value of $58.30. Where the same amount of manure was applied to wheat instead of potatoes, the value of the increase was $48.95.

7. Applications of manure as surface dressings to meadow and pasture crops, although often beneficial, suffer in efficiency from drying losses and from the lack of incorporation of insoluble nitrogen compounds and mineral nutrients below the soil surface. In general, manure is preferably applied to crops permitting its incorporation, and chemical fertilizers are used in supplying the nutrients needed on meadows or pastures. In an experiment of the Pennsylvania Station (116) phosphated manure and chemical fertilizers supplying nearly equivalent nutrients were applied to DeKalb silt loam, in one case to crops in a 4-year rotation of corn, oats, wheat, clover and in the other case to a bluegrass sod containing some sweet clover. The yields of total produce on the two areas for the period 1916-1920 are shown in table 31.

TABLE 31.—Comparison of returns from manure versus fertilizers on cropped land versus pasture

Pennsylvania Station (116)

Treatment	Total increase, 1916–1920			
	Cropped land		Pasture	
	Lb.	*Relative*	*Lb.*	*Relative*
Complete fertilizer and lime	13,308	100	15,983	100
Phosphated manure and lime	12,677	95	9,707	61
Lime alone	2,082	16	3,787	24

However, no rule can be laid down with regard to manuring grassland. With plentiful supplies of manure available, as on livestock farms where most of the crops are fed, applying part of the manure to permanent meadows or pastures may return more than applying all of it to the cultivated land. Moreover, grassland makes a convenient place to spread manure at seasons when it cannot be applied to plowland, and the decrease in efficiency may be no greater than losses to be expected from storage.

For grass meadows and pastures, fresh or well-preserved manure containing plenty of ammonia nitrogen is best, but an effort should be made to spread it in cool, damp weather to reduce loss of ammonia by drying. A moderate rainfall immediately following spreading is favorable, as the available nitrogen will thereby be washed out of the manure and into the soil, where it will be safe from loss. For leguminous meadows, strawy manure or manure that may have lost much of its nitrogen in rotting is satisfactory providing it has not lost its mineral nutrients through leaching.

The odor of manure spread on pastures is objectionable to grazing livestock, and it is desirable to manure only a part of the available grazing land in a single season. The same factor causes animals to avoid the lush growing grass surrounding animal droppings on pastures. Spreading droppings on pastures once or twice each season with a special chain pasture harrow or a spike-tooth harrow (improved by tying brush beneath it) adds considerably to their fertilizing effect.

8. The returns per ton of manure are commonly higher on poor than on good land. Hence, on farms or fields including soils of different productivity, if the supply of manure is limited, the poorer soils should receive first consideration in its application. By liberal manuring of the poorer spots in a field, a notable improvement in uniformity of the crops can be effected.

MANURING THE CROP ROTATION

The proper distribution of manure among the crops of the rotation depends upon the amount of manure available, the fertility of the soil, the particular crops grown, and the use made of chemical fertilizers. The problem is simple when a high-acre-value crop, such as tobacco or potatoes, is included which may logically receive all the manure. In general farm rotations, the successful growth of sod legumes, alfalfa, clovers, etc., is of so great importance to economic crop production and soil conservation that wherever difficulty is experienced in getting stands of these crops, special attention to them is warranted. Under these conditions probably the first use of manure should be for light top-dressings of 2 to 4 tons an acre, applied in winter to winter small grain companion crops or directly after seeding the legume when it is sown with spring grain or alone. On land where good stands of these legumes are regularly obtained without such use of manure, it offers no particular advantage. Additional manure up to 6 or 8 loads per acre probably can best be applied to the corn crop. Applications of this size properly supplemented with moderate amounts of chemical fertilizers in the hill or row ordinarily produce more profitable returns than larger applications, providing effective use can be made of the additional manure elsewhere. Where wheat follows 1 or 2 years after a manured corn crop and is adequately fertilized with a high-phosphate fertilizer, the use of manure at seeding time is not to be recommended, except possibly on light sandy soils. A better place for additional manure is on grass meadows or pastures or on alfalfa in the second or later hay year.

EFFECT OF MANURE ON FEEDING VALUE AND QUALITY OF CROPS

Fresh or well-preserved manure, owing to its relatively high nitrogen content, acts similarly to mineral nitrogen fertilizers in increasing the protein content of nonleguminous forage and grain crops. Certain studies indicate that it contributes beneficial nutritive properties to crops in a way not shared by chemical fertilizers. In Italy (103, 104) turkeys fed on grain from manured land were found to be healthier, more vigorous, and more resistant to disease than those fed grain from chemically fertilized land. In India (77) rabbits grew 20 per cent faster when fed plants grown on manured soil than when fed plants from unfertilized or chemically fertilized soil; the difference was traced to differences in the digestibility of the respective plants. Rowlands and Wilkinson (81), also McCarrison (60) found grass seeds grown on manured soils richer in vitamin B than seeds grown with artificial fertilizers. Dye and Crist (17) found that sheep manure increased the vitamin A content of lettuce, but not as much as chemical fertilizers.

Harris (27) found that unfertilized wheat and that grown with manure alone at Rothamsted had the same vitamin B_1 content, as indicated by tests with rats. The grain grown with mineral fertilization only, no nitrogen supplied, contained less, but with the addition of sulfate of ammonia or with the latter alone, more vitamin B_1; the comparative figures are 100, 80, and 120, respectively. Isgur and Fellers (39) review the influence of fertilization upon the vitamin contents of crops and describe their own experiments, with the conclusion that stimulation of growth by fertilization causes no decrease in vitamins; on the contrary, improvement in the quality of crops from any cause is likely to be attended by increases in vitamins as well as yields. A well-balanced fertilization with both manure and chemicals would seem most likely to be of maximum benefit in this respect; this opinion is supported by German investigations (44, 92).

Salt fed to animals appears in the manure and, according to Němec (68), in sufficient quantity, 1.7 per cent of chlorine in solid and 2.5 per cent in liquid, noticeably to injure the quality of potatoes grown on land to which large amounts have been applied. The effect is to increase the water content of the tubers. Nothing of this kind has been noticed in the United States. It is well known that chlorine in fertilizers may be injurious to the burning quality of cigar tobacco, and hence there has been some prejudice among growers against the use of manure for this crop. Ames and Boltz (2) found that with 20 tons to the acre of horse manure containing 0.2 per cent of chlorine, the chlorine content of leaf tobacco was raised to 1.33 per cent, as compared with 0.16, 0.29, and 3.36 per cent in tobacco grown without fertilizer, with 480 pounds of superphosphate, and with the same plus 180 pounds of muriate of potash, respectively. The fire-holding capacities of cigars made from these lots of leaf were, respectively: 7 minutes, 7 seconds; 6 minutes, 41 seconds; 7 minutes, 11 seconds; and 3 minutes. The ash of all was firm, and except with the last, was light colored. Flavor and aroma of the tobacco grown with manure were good, superior to those of the tobacco grown without fertilizer, but not quite equal to those of the tobacco that received superphosphate only. These investigators detected a tendency toward decrease of chlorine absorption by tobacco with increase in available nitrogen supply, which may explain why the 80 pounds of chlorine in the manure had so little effect compared with about the same amount in the muriate fertilizer carrying no nitrogen.

A slight but significant depression of 0.8 per cent of the sucrose content and 2.3 per cent of the apparent purity coefficient (both taken as 100 for sugar beets receiving no manure) was noted by Hastings et al. (29) when manure was applied at the rate of 12 tons to the acre. This decline in quality was very slight compared with the increases in yield of beets and recoverable sugar production, which ranged from 108 to 134 and from 95 to 112 per cent, respectively, for different rotations.

The connection between composition of soil, crop, and manure is also shown by recent investigations on the selenium problem in certain western states, where it has been found that manure from feeding seleniferous crops contains selenium in a highly available form, and if returned to the soil will further increase this poisonous element in the next crop (10).

EFFECTS OF MANURE UPON THE SOIL

Many properties of the soil—chemical, physical, and biological—are influenced by applications of manure. The most important immediate effects are chemical, in that the contents of available nutrients are increased. Immediate physical effects are less marked, although the coarse organic matter carried tends somewhat to increase aeration and the infiltration of water. Indirectly, the increased growth of crop roots produced may have important granulating effects, and the larger top growth with close-growing crops aids in retaining a good physical condition by protecting the soil from beating rains. Manure also produces a rapid increase in the biological activity of the soil, but the crop effect of this increase is probably slight. More important are the long-time effects that accompany repeated application of manure. Chief of these is the contribution made to the stable humus supply of the soil, which serves both as a reservoir of nitrogen and as an agent promoting desirable physical and biological properties. The high regard in which manure is held as an aid to soil conservation is largely attributable to this action. Additions to the active mineral supplies of the soil, especially of potash, are also involved.

Effect on soil organic matter and nitrogen.—The superior qualities of dark-colored soils well supplied with organic matter are generally recognized by farmers. This fact, together with the often demonstrated fact that under cropping the trend in organic content is almost invariably downward, has led to much emphasis upon the humus-supplying power of manure. Analysis of the available data, however, indicates that this effect of manure generally has been overrated, that the amounts of manure available in practice are too small ordinarily to do more than retard the decline. Light-colored, low-humus soils cannot be transformed into dark-colored, high-humus soils by any known practical method. Fortunately, the productivity of most soils can be increased to a high level without any profound change in their humus content. The extent to which the organic matter and nitrogen contents of the soil are affected by repeated application of practical quantities of manure is shown by data from long-time field experiments at the Ohio Station presented in table 32.

TABLE 32.—Effect of continued manuring upon the organic matter and nitrogen contents of the soil

Ohio Station data

Cropping system	Manure treatment	Period covered	Composition of surface soil			
			Organic matter*		Nitrogen	
			Lb. per acre	*Pct. of original*	*Lb. per acre*	*Pct. of original*
Continuous corn......	None	32 years	12,700	36	825	38
Continuous corn.......	5 tons annually	32 years	18,215	52	1,210	56
Continuous oats......	None	32 years	22,300	64	1,350	62
Continuous oats.......	5 tons annually	32 years	33,980	97	2,020	93
Continuous wheat.....	None	32 years	22,100	63	1,320	61
Continuous wheat.....	5 tons annually	32 years	23,000	94	1,840	85
Corn, oats, wheat, clover, timothy......	None	32 years	26,700	76	1,546	71
Corn, oats, wheat, clover, timothy....	8 tons in rotation	32 years	32,570	93	1,900	87
	16 tons in rotation	32 years	35,870	102	1,980	91
Corn, wheat, clover....	None	29 years	29,650	84	1,918	88
Corn, wheat, clover....	8 tons in rotation	29 years	34,200	97	2,140	98
Original soil (1894)....	....	....	35,100	100	2,176	100

*Organic carbon × 1.724.

Since soil humus contains close to 5 per cent of nitrogen, additions to soil organic matter and nitrogen from manuring occur approximately in the proportion of 20 to 1. Thus, changes in organic matter content may be assumed to be 20 times as great as those taking place in nitrogen. By comparing the difference between the amounts of nitrogen present in comparable manured and unmanured soils with the amount applied in the manure, an idea is gained of the fraction of the nitrogen applied (also of the organic matter) that remains residual in the soil. Actually, the total gain attributable to manure is made up of two parts. One part is the actual residue from the manure applied, and the other, sometimes the larger part, is contributed by the root and stubble residues of the increased crops produced by the manure. Data from a number of long-time field experiments showing the "apparent" recovery of the nitrogen supplied in manure are shown in table 33.

TABLE 33.—Residual nitrogen left in soil by manuring in long-time field experiments

Location	Cropping system	Manure applied, average amount per year	Period	Total nitrogen in manure	Nitrogen in soil, increase over unmanured	Apparent recovery of nitrogen
		Tons	*Yr.*	*Lb.*	*Lb.*	*Pct.*
Rothamsted Station, England (83)	Continuous wheat	14	71	14,200	3,020	21
Woburn Station, England (86)	Continuous wheat	....	56	5,962	459	8
	Continuous barley	....	56	5,962	810	14
Ohio Station	Continuous corn	5.0	32	1,440	385	27
	Continuous wheat	5.0	32	1,440	520	36
	Continuous oats	5.0	32	1,440	670	47
	5-year rotation, limed	3.2	32	908	333	37
	5-year rotation, unlimed	3.2	32	908	493	54
	3-year rotation, limed	2.7	29	684	320	47
Missouri Station, (Sanborn field) (45)	4-year rotation	1.5	40	540	897	166
	6-year rotation	1.0	40	378	1,265	334

A surprisingly small part (8 to 21 per cent) of the heavy applications of manure nitrogen in the Rothamsted (83) and Woburn (86) experiments has accumulated in the soil. This is even more surprising when it is considered that in the Rothamsted work, the increased wheat crops accounted for only about 17 per cent of the nitrogen applied. The total recovery of nitrogen in soil and crop was, therefore, about 48 per cent, and there was a total loss of more than half of the nitrogen applied.

The figures for "apparent" recovery of nitrogen in table 33 do not differentiate between nitrogen left as residue from the manure and that accumulated in crop remains. In the Missouri (45) data, the latter must have been relatively large, since the "apparent" recovery greatly exceeds the amount applied; hence much must have been added by the clover residues or fixed from the air by free-living nitrogen-fixing bacteria. In the Ohio Station experiments, it is possible to estimate the two component parts of the residual nitrogen by assuming that the contribution of crop residues on the manure plots was the same as that observed on chemically fertilized plots producing equivalent crop yields. The data are given in table 34.

TABLE 34.—Effects of manure on soil nitrogen content, showing comparative amounts residual from manure and left as crop residues

Ohio Station data

Cropping system*	Apparent recovery of nitrogen of manure	Estimated portion from crop residues	Difference—actual recovery from manure
	Pct.	*Pct.*	*Pct.*
Continuous corn	26.7	3.2	23.5
Continuous wheat	36.1	13.6	22.5
Continuous oats	46.5	14.6	31.9
5-year rotation—Corn, oats, wheat, clover, timothy			
Limed	36.6	16.4	20.2
Unlimed	54.3	33.4	20.9

*For amounts of nitrogen applied and recovered in soil see table 33.

Excepting the continuous oats experiment, the nitrogen residual from the manure itself falls in a narrow range of 20.2 to 23.5 per cent, indicating that under these conditions four-fifths to three-fourths of the nitrogen applied was either lost or taken up by the crop. Presumably, a similar proportion of the organic matter applied was lost through decomposition.

The value of manure as an agent for conserving soil humus and nitrogen depends considerably upon the crops benefiting by its use. When it is used on cultivated crops, such as corn, potatoes, or tobacco, the indirect gains from root and stubble residues are very meager (see data for continuous corn in table 32). When the rotation includes sod legumes, clover, alfalfa, etc., and the manure is used in a manner to benefit these crops, its maximum total effect on the soil humus and nitrogen is realized. This fact is of great importance in evaluating manure in soil conservation.

Effect of manure on mineral composition of the soil.—Depending upon the amounts and composition of manure applied and the removals occurring in crops and drainage, changes are produced in the mineral composition of the soil. Chief interest centers in the changes occurring in the more active mineral components. Data showing the reaction, content of exchange bases, and total exchange capacity in the surface soils of unmanured and manured plots in the 5-Year Rotation Experiment at the Ohio Station, before and after 32 years of cropping, are given in table 35 (96).

Comparing the data for the manured and untreated plots after 32 years of cropping shows that manure has increased considerably the amounts of active calcium, magnesium, potassium, sodium, and manganese in the soil. However, in most cases even the heavier application of manure has not maintained them at the original levels found in 1894. (The increases in calcium and magnesium on the limed plots come from the lime.)

The reaction of the unlimed soil measured in pH appears to be slightly less acid in the manured compared with the unmanured plots, although the lime requirement (exchange hydrogen) is not much affected. All plots have become considerably more acid than at the beginning.

The exchange capacity is increased by manure on both unlimed and limed soil, reflecting, no doubt, the contribution to exchange capacity of the humus added.

TABLE 35.—Mineral composition of soil as affected by manure

Ohio Agricultural Experiment Station. Data of Schollenberger and Dreibelbis (96)

Treatment	Exchange bases in surface soil (0–6⅔ in.) per acre						Exchange hydrogen (CaCO3 equivalent)	Exchange capacity (CaCO3 equivalent)	Reaction
	Calcium	Magnesium	Potassium	Sodium	Manganese	Aluminum			
	Lb.	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*pH*
Original soil (1894)	1,054	151	160	159	178	32	4,600	9,290	5.03
Unlimed plots after 32 years of cropping									
Average of untreated plots	491	60	76	19	149	51	6,100	8,010	4.72
8 tons of manure per rotation	585	98	106	24	174	17	6,580	8,950	4.86
16 tons of manure per rotation	585	124	168	50	205	20	6,180	8,840	4.92
Limed plots after 32 years of cropping									
Average of untreated plots	3,232	330	70	9	17	...	...	9,870	7.50
8 tons of manure per rotation	3,416	398	110	10	17	...	...	10,670	7.60
16 tons of manure per rotation	3,248	365	124	16	25	...	...	10,360	7.55

Effect on physical properties of soil.—Beneficial effects of manure upon the physical properties of the soil are for the most part limited to cases in which larger additions to the humus content are effected than occur with the usual rates of application possible in general farming. In the long-time field experiments at the Ohio Station, seven applications of 16 tons of manure divided between corn and wheat in a 5-year rotation increased the humus content of the Wooster silt loam soil 34 per cent compared with untreated check plots but did not raise it above the original level of 1894. Samples of soil taken in 1925 showed no significant differences between manured and unmanured plots in field moisture-holding capacity (moisture equivalent), volume weight, or plasticity (Atterberg constants). Moreover, a field plow draft test revealed no significant difference between manured and unmanured plots.

On the other hand, heavy applications of manure may notably affect the physical properties of the soil. On the Broadbalk continuous wheat plots at Rothamsted the plot receiving 14 tons of manure per acre annually since 1843 now contains about 5 per cent of organic matter in the upper 9 inches of soil compared with only 1.5 per cent on continuously untreated soil. Russell (83) states that the soil of the manured plot is normally found to contain 3 or 4 per cent more water than that of the unmanured plot. He also states that the Rothamsted mangold plots, receiving no animal manure since 1876, "get into so sticky and unkindly state that the young plants have some difficulty in surviving, however much food is supplied, and may fail altogether in a dry spring", whereas the dunged plots (14 tons annually since 1876) "are much more favorable to the plant and never fail to give a crop." It should be kept in mind, however, that such effects as these are the result of heavy manure treatments, long continued. They are well known in old gardens and in greenhouse culture, but seldom observed in general field cropping in this country.

Effect of manure on soil erosion.—Manure incorporated with the soil may aid in reducing soil erosion in two ways: (a) by increasing somewhat the permeability of the soil to water, thus cutting down the surface runoff, and (b) by increasing the density of crop cover, thereby slowing down surface runoff and favoring water absorption. Permeability to water appears in some cases at least to have been more largely affected by manure than other physical soil properties. Lemmermann and Behrens (57) found the permeability of a soil receiving about 9 tons of manure per acre every 2 years from 1902 to 1933 to be two to eight times as great as that of similar unmanured soil. However, on another soil receiving about 5½ tons of manure annually with rye grown each year since 1879, the permeability was only 39 per cent as great as on comparable unmanured land.

Musgrave and Norton (66), in studies of the runoff and soil losses from control plots at Clarinda, Iowa, found manure effective in reducing both water and soil losses. Some of their data are presented in table 36.

At the Ohio Station measurements of the amount of surface soil lost by erosion have been made on a number of the long-time fertility plots. A comparison of the losses taking place on manured and unmanured plots is shown in table 37.

OBJECTIONABLE FEATURES OF MANURE

Flies.—Fresh manure, especially that from horses, is the preferred breeding place of the common house fly and similar insects. According to Howard and Bishopp (38), hog manure is second as a favorable medium, followed by

TABLE 36.—Effect of manure on water and soil losses (from Marshall silt loam, 9 per cent slope, August 31, 1932, to December 31, 1935)

Data of Musgrave and Norton (66)

	Runoff	Soil lost from 1 acre
	In.	*Tons*
Fallow, no treatment	17.5	190.7
Fallow, 8 tons of manure per acre	14.6	145.9
Fallow, 16 tons of manure per acre	11.5	114.0
Continuous corn, no treatment	9.3	77.4
Continuous corn, 8 tons of manure per acre	6.3	32.0
Continuous corn, 16 tons of manure per acre	3.4	17.9

TABLE 37.—Effect of manure in reducing soil erosion losses

Ohio Agricultural Experiment Station

Cropping system	Period covered	Average annual application of manure	Average slope	Soil lost
	Yr.	*Tons*	*Pct.*	*In.*
Continuous wheat	42	None*	3.5	7.6
Continuous wheat	42	2.5	3.0	6.6
Continuous wheat	42	5.0	2.8	5.5
Continuous oats	42	None*	4.0	6.7
Continuous oats	42	2.5	4.0	6.4
Continuous oats	42	5.0	4.0	5.6
Continuous corn	42	None*	3.3	9.7
Continuous corn	42	2.5	3.7	10.5
Continuous corn	42	5.0	3.5	9.5
Corn, oats, wheat, clover, timothy	42	None†	5.2	7.6
Corn, oats, wheat, clover, timothy	42	1.6	5.7	6.4
Corn, oats, wheat, clover, timothy	42	3.2	6.0	6.3

*Average of check plots, Nos. 4 and 7.
†Average of check plots, Nos. 16, 19, and 22, Sec. C.

hen manure, etc. Comparatively few house flies are reared in cow manure. Howard (37) cites data indicating that a million flies may develop in a ton of fresh horse manure. Some of the means of fly control recommended by these authors are precisely the same as those which have been shown to be most effective in conserving the fertilizer values in manure, viz., cement floors in stalls, prompt removal and spreading upon the field when possible, otherwise compact storage under as nearly anaerobic conditions as possible.

Temporary storage in a pit or bin with flyproof cover, with wire screen traps attached at small openings to which the matured flies are attracted by the light, is an effective means for reducing the number of flies bred in manure. In England, advantage is taken of the tendency for matured maggots to migrate from compacted manure for pupation. The manure is made into a rectangular pile which is carefully compacted by beating with a shovel. The surrounding earth is also compacted and smoothed, and covered by a ring of straw a few inches from the manure. About twice a week at the height of the fly season and less frequently in cool weather, this straw is cleanly swept up and burned to destroy the pupae and larvae hidden in it. Another effective means of destroying practically all the maggots developing in manure is to heap the manure upon a slatted platform over water; the fully developed larvae leave the manure for pupation, fall into the water, and are drowned. The manure should be moistened daily and kept as compact as possible to drive the maggots out; otherwise conditions may be favorable for their pupation and complete development in it. A platform 10 by 20 feet is stated to be sufficient to hold the manure produced by four horses in 4 months if the pile is made 5 feet high (38). The excessive leaching and exposure to air, as well as the attention necessary to keep the manure compacted and moistened and sufficient water below, make this plan less desirable; losses of fertility elements and nuisance from odors would probably be greater than with storage in a pit screened to prevent the escape of flies.

Treatment of fresh manure with larvicides has been investigated extensively (13). Mixing in Cyanamid and superphosphate, ½ pound of each per bushel of manure, gave a 98 per cent kill of larvae; used alone, superphosphate had practically no effect, and Cyanamid was considerably less effective than in combination (38). These materials are inexpensive and increase the value of the manure by direct addition of fertility elements, although a considerable part of the ammonia nitrogen developed from the Cyanamid is likely to be lost. The lime contained in it would increase this tendency and reduce the value of the superphosphate. A decoction of powdered hellebore, ½ pound stirred into 10 gallons of water and let stand 24 hours, added to fresh manure at the rate of 1 gallon per cubic foot is very effective in killing larvae and harmless to poultry, etc., working over the manure (38). The sole objection to this treatment is expense, as hellebore costs about 50 cents a pound. According to Cook et al. (13), the most effective treatment is with powdered borax or calcined colemanite mineral (calcium borate), as this prevents the hatching of fly eggs as well as kills larvae. The application recommended is 10 ounces of borax or 12 ounces of calcined colemanite per 10 cubic feet (8 bushels) of manure immediately upon removal from the stable. Most of this should be sifted upon the outer part of the pile, where flies will deposit their eggs and larvae will congregate, and watered in. The cost of treatment is about 1 cent per horse per day with borax, less with colemanite. Experiments have shown that manure treated as described is not toxic to crops if applied at a rate not exceeding 15 tons per acre, but there is always some risk in the use of borax-treated manure, probably less on limed soils. On the other hand, boron is one of the elements essential for plant growth sometimes deficient in soils, and where it is known to be beneficial might well be added to manure.

Howard (38) states that sulfate of iron ($FeSO_4 7H_2O$), 2 pounds dissolved in water to drench the daily production of manure by one horse, or 2½ pounds if the dry chemical is mixed with the manure, kills over 90 per cent of the fly larvae in manure. At lower rates, it was found ineffective, although it did deodorize the manure (13). Treatment with sulfate of iron will undoubtedly conserve ammonia and influence the natural course of fermentation in manure, because the sulfate of iron is strongly acid. It is less likely to make the manure toxic to plants than is borax.

According to Knipling (51), as little as 0.0025 per cent of phenothiazine added to cattle manure prevents the development of horn fly larvae. If this material should prove equally effective in killing house fly larvae in horse manure, it would solve the problem of expense; the chemical costs 35 to 50 cents per pound, but the minute addition required would amount to only 2 or 3 cents per ton of manure treated. It is not poisonous to higher animals.

Infections.—There is no doubt that diseases and parasites may be spread among animals by manure; allowing hogs and chickens to work over cattle manure may be responsible for the spread of tuberculosis among them. Manure known to be infected by the highly contagious foot-and-mouth disease or anthrax, etc., should be burned. The heating effect of natural fermentation cannot be relied upon to destroy the organisms.

Odors.—The most practical method for minimizing odors from manure is probably compact storage in a pit or in heaps without access of air. The methods adapted to storage of manure with minimum losses in general are those which will be attended by least nuisance from odors.

Weed seeds.—The general presence of viable weed seeds in farm manure is well known, and is a serious objection to its use for top-dressing alfalfa seedings, etc. The probability that many seeds will be killed if the manure is allowed to ferment and heat is frequently urged as an advantage of such procedures. However, by no means all weed seeds are killed, as shown by tests of Korsmo (52) with fresh and fermented manure from horses, cows, and pigs.

MANURE AS AN ECONOMIC ASSET ON THE FARM

Used on general field crops, ordinary farm manure may be expected to have an average crop-producing value of about $2.50 per ton at present crop prices. Averaging 9 to 11 years' results for seven experimental fields in Ohio gives a return of $22.09 from 9 tons of manure used alone, or $2.47 per ton. On the same fields and for the same period, an average application of 6.5 tons used in conjunction with chemical fertilizers has returned $10.67, or $1.64 per ton, over and above the returns from fertilizer. Averaging data for 13 experiment fields in Indiana (117) gives $2.61, with a range of 96 cents to $4.11. Data from 16 experiment fields in Iowa (102) average $1.97, and range from 96 cents to $3.84. Five experiment fields in Kentucky (78) give $2.45. An average for several fields in Missouri (16) gives $2.40. For 36 tests in Maryland (59) the average reported is $5.28, with crop prices figured 20 to 100 per cent higher than in the foregoing tests. When used on higher-acre-value crops (tobacco, potatoes, truck crops, etc.), manure produces even larger returns. The average for a large number of tests with a variety of truck crops in Maryland was $8.67 per ton of manure. For sugar beets under irrigation, the calculated value per ton of manure applied has ranged from $1.00 to $5.49; over a 24-year period, the mean value was $2.77 (29). Even the minimum value indicated in this work was measurably in excess of the estimated cost of application, so that manuring was always profitable.

If an average value of $2.50 per ton and a manure recovery of two-thirds of the potential production from feeding all crops except wheat grain are assumed, the value of the manure produced from 100 acres of cropland producing the following crops and yields—corn, 50 bushels; oats, 40 bushels; wheat, 25 bushels; and hay, 2 tons—would be $500. By better care of the manure to avoid losses in storage and application, by thinner spreading over a larger area of crops, and by more intelligent use of chemical supplements, this value might be materially increased.

MANURE IN A COMPLETE FERTILITY SYSTEM

The greatest benefit from manure is only realized when it is combined with the other elements that constitute good soil management. It will not take the place of good crop rotations, lime on soils that need it, phosphate fertilizers, high-quality seed, proper drainage, and good tillage practices. Combined with these, maximum returns from manure are assured. Data from long-time field experiments in which manure has been so used are presented in table 38.

TABLE 38.—Results from complete fertility systems including manure

Ohio Agricultural Experiment Station Special Circular 46, page 85. Purdue Agricultural Experiment Station Soils and Crops Experiment Farm, Report of Progress, 1915-1936

Location	Soil type	Period	Treatment	Average crop yields				Average annual value of crops*	Annual cash cost†	Annual net value
				Corn	Oats or soybeans	Wheat	Hay			
		Yr.		*Bu.*	*Bu.*	*Bu.*	*Tons*	*Dol.*	*Dol.*	*Dol.*
Wooster, Ohio‡	Wooster silt loam	31	Corn: 10 tons of manure, 150 pounds of 4-12-4 in hill‖ Wheat: 400 pounds of 2-14-4‖ Limed to pH 7.0 Tile-drained	73.7	60.8 (oats)	34.5	3.1***	35.25	3.00	32.25
Lafayette, Indiana§	Miami, Crosby, and Brookston silt loams	13	Corn: Manure** 100 pounds of 2-12-6 in hill Wheat: 300 pounds of 2-12-6 Tile-drained	70.1	31.0 (soybeans)	35.8	2.5****	35.18	2.00	33.18

*Values employed: corn, 60 cents; wheat and soybeans, $1 00, oats, 40 cents, hay, $10.00.
†Fertilizers and lime figured at present market price.
‡Data are for 45-acre variety range.
§Data are for plot 12 in Grain and Livestock System Experiment.
‖Prior to last 8 years, 400 pounds of 0-16 0 used on both corn and wheat.
**Manure equal to weight of crops excluding wheat grain.
***Mixed alfalfa, clover, timothy.
****Alfalfa.

In both of the experiments cited in table 38 the amount of manure used was about two-thirds of the potential production with all crops fed except wheat grain. This recovery of manure should not exceed that possible on the well-managed livestock farm. The soil in the Ohio test is a naturally acid soil of only fair productivity; that in the Indiana test is mixed light and dark limestone soil, typical of much land in the eastern corn belt states. The yields in both tests are nearly double the average yields for the respective regions. They represent a goal which is not beyond attainment on the livestock farm where manure is well cared for, efficiently handled, and its use combined with the other elements of good farming.

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