THE EFFECTS OF MANURE, COMPOST, AND AMMONIUM NITRATE ON THE MAINTENANCE OF SOIL FERTILITY AND CROP PRODUCTION

by

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ABSTRACT OF THESIS

Daniel Mireku Osafo, THE EFFECTS OF MANURE, COMPOST, AND AMMONIUM NITRATE ON THE MAINTENANCE OF SOIL FERTILITY AND CROP PRODUCTION. Master's Thesis, Department of Agricultural Chemistry and Soils, University of Arizona, 1963.

Laboratory analyses were done on the soils of 18 plots on the University of Arizona Agricultural Experiment Station farm at Mesa, Arizona. The 18 plots represented six replicates of the following three treatments: manure, compost, and ammonium nitrate as three different sources of nitrogen. Composited soil samples, taken to a depth of four feet, were analyzed to determine their nutrient levels and attempt to explain why the organic fertilizers were proving to be superior to ammonium nitrate, as measured by yields of seed cotton and alfalfa hay.

It was concluded that the reason for the superiority of the organic fertilizers could be that they contained more nitrogen and, probably, more phosphorus as well and that these nutrients were being returned to the soil in the form of crop residues.

In order to determine which of the three treatments was the most economical, it was found that the ratios of gross income to cost of fertilizers were the best indices in a study of this nature, assuming several important factors such as cost of application and handling of the fertilizers to be the same in all three cases.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

INTRODUCTION

The early Chinese, Greek and Roman civilizations are known to have recognized the beneficial effects of increased organic matter content of soils for improving plant growth. From these ancient days until now, the beneficial effects of organic matter have been demonstrated in several ways the world over (39, 48).

The literature abounds with the names of naturalists, plant physiologists, agricultural chemists and soil scientists who, from the 15th century to the present time, have studied and are still studying soil organic matter and its effects on crop production. Having recognized the apparent superiority of organic matter applied to soil as farm manure, composted materials and green manure to commercial fertilizers in increasing crop yields, most of these workers contend that in order to maintain soil fertility, there is a need for building up the organic matter content of soils by any of the above methods or by fallowing, especially where, due to natural conditions or by continuous cropping, the organic matter content of the soil is very low (39).

A point of the utmost importance which has come out of their researches is the existence of positive correlations between soil organic matter and the nitrogen and phosphorus contents of soils (1, 2, 35, 39).

Hans Jenny (25) has pointed out the importance of soil forming factors in influencing the nitrogen and organic matter contents of medium-textured soils in the United States. He lists these in their order of importance, namely, climate, vegetation, topography, parent material, and age. Areas having high ambient temperatures, which are conducive to the rapid oxidation and loss of soil organic matter, and very low annual precipitation, which, with evaporation exceeding precipitation, support only a scanty natural vegetation, necessarily have very low amounts of soil organic matter.

With regard to the climatic conditions of southwestern United States, particularly southern Arizona, it is found that the high mean ambient temperatures which obtain in nearly all the agriculturally important valleys, coupled with the very low annual rainfall and the natural desert vegetation produced, give rise mostly to alkaline calcareous soils with very low amounts of organic matter, generally less than 1 percent (31).

The Laveen loam located on the University of Arizona Agricultural Experiment Station at Mesa, Arizona, which is the soil studied, is a typical example of such alkaline calcareous soils. Records over a 38-year period, 1917-1954, show that the Mesa Farm has a mean annual temperature of 68° F and mean annual rainfall of about 8 inches (40).

Breazeale and Burgess (4), McGeorge (32), and Fuller and McGeorge (13, 14), in studying some alkaline calcareous soils of southern Arizona, including the Laveen loam, characterize the soil as follows:

1. The phosphate reserves of the soils are relatively high but their availability to plants is naturally low, being reduced by solid phase calcium carbonate and sodium and calcium salts in solution.

2. Apart from this fixation of phosphate, there is evidence of biological fixation of phosphates by soil microbes.

3. The soils contain, especially in their surface layers, a considerable amount, about 25 percent, of organic phosphorus relative to the total phosphorus content.

4. As evidenced by results of work done on experiment station plots and private farms, the soils respond to phosphorus fertilizers.

Clearly, then, nitrogen and phosphorus fertilizers are very important if soil fertility and high crop production are to be maintained on these soils. Important aspects of these findings are the kinds of fertilizers, as nitrogen and phosphorus carriers, that must be used and their performance, with respect to their costs of application, the crop responses they produce and their residual effects. These must be seriously considered in all farming enterprises if crop production is to be economically profitable.

In a trial involving the use of barnyard manure, compost and ammonium nitrate as three different sources of nitrogen, it has been found on the Mesa farm that the organic fertilized soil, since the second year of the trial, consistently produced better yields of the cotton and alfalfa that are significant on the 5 percent level over the NH_4NO_3 fertilized borders.

The purpose of the project was to study the effects of the various treatments on the nutrient level of Laveen loam and to determine the total nitrogen and phosphorus contents of alfalfa currently growing in an attempt to explain the reason why the organic fertilizers are proving to be better than ammonium nitrate and which of the specific treatments is the most economically profitable.

REVIEW OF THE LITERATURE

Attempts to clarify the role of organic matter in increasing plant growth occupied the minds of philosophers, scholars, and scientists from the early Greek and Roman times through the 19th century. In our modern times, the chemical nature of soil organic matter and its effects on crops are fields of study being actively pursued by many workers.

Naturalists and plant physiologists of the 16th and 17th centuries, notably Van Helmont (1577-1644) and Robert Boyle in 1661, in their efforts to find the "principle" of vegetation, thought plants obtained their nutrients from water and that humus played a part in plant growth by supplying moisture and fire (39, 48).

In the 18th century, various workers, for example, H. Boerhaave in 1727, Jethro Tull in 1731 and J. A. Kulbel in 1741 contributed to certain ideas that became vogue in those days. To them, humus acted favorably on plant growth by supplying heat and moisture and acting as a source of organic nutrients which were absorbed directly by plants and underwent chemical changes in plant tissue to become part of the plant (39, 48).

As a result of advances made in the field of agricultural chemistry towards the end of the 18th century and in the 19th century, agricultural scientists began to change their ideas about the actual functions of soil organic matter in plant growth. Organic matter, although still regarded by most workers of this period, for example, J. G. Wallerius, the Swedish chemist, A. von Thaer of Germany and J. J. Berzelius of Brussels, as the important material on which soil fertility depended, through its influence on soil moisture and as a supplier of plant nutrients including carbon or as plant food as such, was shown to exert its influence best while putrefying (7).

In 1804, Theodore de Saussure, a Swiss plant physiologist who first demonstrated plant respiration and photosynthesis, found that plant roots absorbed more water than dissolved salts and that different dissolved salts were absorbed to different extents. He concluded that plants obtained their carbon and oxygen from the atmosphere and soil water, respectively, that fixation of atmospheric carbon dioxide and water led to synthesis of dry matter and that the soil furnished only a small part of plant food in the form of dissolved salts (39).

de Saussure's work stimulated J. B. Boussingault of France to start his famous field experiments in Alsace in 1834. Introducing the modern analytical and agricultural techniques of weighing, chemical assays and crop rotations, he demonstrated the beneficial effects of manure on crops and the extent to which the soil, rain, and air contributed to plant growth. He found that air and rain (water) supplied carbon, hydrogen and oxygen to plants and that manure afforded more mineral matter than the crop removed, the balance remaining in the soil. He argued that, other things being equal, the best rotation is one which yields the greatest amount of organic matter over and above what is present in the soil (39).

Justus von Liebig's delineation (28) of the role of soil organic matter in plant nutrition was a major breakthrough in that field of study. He established that plants obtained their carbon from the atmosphere and that only alkalis and phosphoric acid were obtained from the soil. He, however, erred in claiming that the atmosphere was also the source of nitrogen supply to plants, a claim which became controversial.

The controversy stirred up by Liebig's deductions caused Lawes and Gilbert to start their famous field experiments in Rothamsted, England, in 1843, in an attempt to learn more about factors governing soil fertility and their effects on crops. By 1854, they had accumulated enough data to show that crops require phosphates and salts of alkalis, and that the composition of plant ash does not indicate reliably the quantities of the nutrients required. They also concluded that crops require more nitrogen than the amount obtained from the atmosphere, if they are to show any increase in growth, and that soil fertility may be maintained for some years by means of artificial manures and that the beneficial effects of fallowing lay in the increase in nitrogenous compounds in the soil (19).

With the advent of soil microbiology and the work of such pioneer microbiologists as Mitscherlich, Louis Pasteur, Beijerinck, Winogradsky, Robert Kock and Ferdinand Cohn, to mention a few names, it was established that various groups of soil microorganisms, in the process of decomposing soil organic matter for energy for their metabolism, are able to mineralize or liberate inorganic forms of nutrients from organic forms, a continuous supply of carbon as carbon dioxide for their own use, nitrogen in the form of ammonia and nitrate, phosphorus and sulfur as phosphates and sulfates, respectively, and that without these nutrients, plant growth would not occur (49).

There is a wealth of published literature on the functions of organic matter in soils and their relationship to plant growth. However, knowledge of the composition of soil organic matter is a necessary prerequisite to the understanding and evaluation of these functions and their effects on plant growth.

Soil organic matter consists of plant residues at various stages of decomposition and the corresponding decomposition and excretory products of the organisms--both macro and micro--living on acid in the soil. Thus, at one stage, its composition approximates that of plants which form the major raw material for its formation. The major constituents are given as follows (11, 12):

1. Carbohydrates which form the major structural material of plants and are composed of

a.	Sugars and starches	1 - 5%
b.	Hemicelluloses	10 - 28%
c.	Celluloses	20 - 50%

2. Fats, waxes and resins which consist chiefly of oils and fats, glycerides of fatty acids and of long chain fatty acids and alcohols, and form 1 percent to 8 percent of plants on dry weight basis.

3. Proteins which form the greater part of the living cell contents and are polymers of α-amino acids united by peptide linkages--CO-NH--and are composed of water soluble and crude fractions which together may form 1 percent to 15 percent of the plant.

4. Lignins, the structure of which is believed to be repeating units of coniferyl alcohol or some closely related compound with methoxy groups usually present and ortho to the phenolic hydroxyl group. Lignins form about 20 percent to 30 percent of the dry weight of plants.

In composts and soils of low mineral contents, such as peats, these substances come out in definite fractions when subjected to the treatments shown in the following tables (11).

On being added to soil, the organic material undergoes decomposition and the above components become transformed into simpler forms by various groups of microorganisms, principally the bacteria, fungi

Table 1. Fractionation of organic matter.

	Treatment	Fraction
1a	Ether extraction	Oils, fats and waxes
1b	Cold water extraction	Salts, sugars and some soluble polysaccharides
2.	Alcohol extraction	Resins
3.	Hot water extraction	More soluble polysaccharides
4.	Dilute acid (2% HCl) hydrolysis	Hemicelluloses
5.	Concentrated acid (80% H_2SO_4) hydrolysis	Cellulose
6.	Residue	Lignin and protein

Table 2. Chemical composition of alfalfa at different stages of decomposition.

Original material (gm)	'	'	'	'	'
Total organic matter	260	70	58	46	39
Ether extraction	7	--	40	12	13
Water (cold) extraction	32	70	52	34	34
Hemicelluloses	32	51	44	39	37
Cellulose	69	59	36	26	23
Protein	21	72	52	58	43
Lignin	28	98	80	78	57
Days of decomposition		27	68	205	405

and actinomycetes, which, depending on the composition of the material, act in a more or less definite sequence (46, 47).

Decomposition Processes

Carbohydrates

Carbohydrate decomposition by microorganisms depends on its nature, the nature of the organisms, and conditions of decomposition, mainly moisture, oxygen supply and pH (49).

Sugars can be completely oxidized by fungi to carbon dioxide and water, when the oxygen is adequate. At various oxygen tensions, this process can go through other pathways with citric and oxalic acids formed as intermediate products and carbon dioxide and water as end products.

Under anaerobic conditions, bacteria can oxidize glucose to carbon dioxide and water through lactic and butyric acids and alcohol stages.

Starch is hydrolyzed to produce dextrins by microbial diastatic enzymes. Dextrins are then further hydrolyzed maltose and glucose which become oxidized to carbon dioxide and glucose. Bacteria and fungi predominate in these processes.

Hemicellulose

Hemicelluloses are attacked by a variety of bacteria and fungi, some more readily than others. They are first hydrolyzed by enzymes to produce polyuronides and certain sugars, depending on the types present. Thus, pentosan gives pentose sugar, hexosans produce hexose sugars, galactan yields galactose and mannan gives rise to mannose. Polyuronides are rather complex. An example is pectin which is made up of galactose, arabinose galacturonic and acetic acids and methyl alcohol, which are the hydrolytic products and are further hydrolyzed and oxidized (49).

Cellulose

Cellulose is believed to be hydrolyzed to simpler components by a wide variety of organisms, including aerobic bacteria (15), myxobacteria, anaerobic bacteria, actinomycetes, filamentous fungi, higher fungi and protozoa (34). The predominance of any of these organisms depends on factors like moisture content, pH, oxygen supply and temperature. Under anaerobic conditions, bacteria can decompose cellulose with the formation of various organic acids and alcohols. The current theory is that cellulose is hydrolyzed by a group of hydrolytic enzymes termed cellulase to cellubiose and then another group of enzymes (or probably, one single enzyme) termed cellubiase takes it on to glucose which is then oxidized to carbon dioxide and water (16).

Proteins and other nitrogenous compounds

These compounds vary in nature, but generally, proteins are hydrolyzed by specific enzymes or by chemical reagents, splitting into various polypeptides and finally simple amino acids. Many soil organisms are capable of attacking proteins, and the amount of nitrogen transformed from proteins depends on the nature of the organism, nature of the protein presence of available carbohydrates and soil conditions.

Other nitrogenous compounds include urea, purine and purimidine bases, and lecithins which undergo various changes, depending on the organisms and conditions of decomposition, to yield ammonia (49).

Lignins

The microbial decomposition of lignins is still not properly understood. However, lignins are known to be resistant to microbial attack. They are slowly decomposed, resulting in a decrease of the methoxy groups and an increase in the carboxylic groups.

Addition of organic matter to soils stimulates the decomposition of both the added and native soil organic matter (20). Nitrogen is needed by the organisms to enable them to utilize the carbonaceous materials for energy for their metabolism, growth and reproduction. It is in this process that the organisms liberate simple inorganic compounds that are utilized by plants. Apart from nitrogen, other essential nutrients like phosphorus, sulfur and calcium are also needed. Hausenbuiller (22) and Chandra and Bollen (5) have shown that when the soil nitrogen and phosphorus supplies are not adequate, the organisms utilize what is present in the soil for their metabolic processes in the initial stages of decomposition. After a time, the nutrients mineralized in the processes start appearing and may accumulate, and thus represent a measure of their availability (2).

As a result of microbial action, a number of products are liberated.

Table 3. More common simple products that result from activity of soil microorganisms.*

Carbon	CO_2, $CO_3^{=}$, HCO_3^-, CH_4 and elemental carbon
Nitrogen	NH_4^+, NO_3^-, NO_2^- and elemental nitrogen
Phosphorus	$H_2PO_4^-$, $HPO_4^{=}$ and $PO_4^{=}$
Sulfur	S, H_2S, $SO_3^{=}$, $SO_4^{=}$ and CS_2
Others	O_2, H_2, H_2O, H, OH^-, K^+, Ca^{++}, Mg^{++}

* Lyon, Buchman, and Brady (29).

Functions of organic matter in soil

The beneficial effects or organic matter on plant growth are generally classified under four main functions.

1. As a source of plant nutrients.
2. As a material with a high cation exchange capacity.
3. Its favorable effects on soil physical properties.
4. Growth regulating substances.

Organic matter has been demonstrated in various ways as an important source of certain plant nutrients. In this respect Table 3 is illustrative, with particular regard to nitrogen and phosphorus. It is now established that as a result of microbial action on organic matter in the soil, nitrogen and phosphorus compounds, among others, capable of being absorbed and utilized by plants, are liberated.

Soil organic matter has acidic properties, due to the dissociation of hydrogen ions from uronic and carboxylic groups, and from various hydroxyl groups as the pH increases from acid to slightly alkaline region. With lignin, for example, which forms the major part of humified soil organic matter, the greater the degree of oxidation, the greater the number of carboxylic groups (49). When cations are present, on dissociation of hydrogen ions, they will be adsorbed and held to the organic matter on exchangeable sites (3, 39).

The physical properties of soils believed to be enhanced by soil organic matter include moisture retention, aggregation and aeration which are, to some extent, interrelated.

Humified organic matter displays the typical properties of hydrophilic colloids. It will thus absorb considerable quantities of moisture when present, and thus increase the water-holding capacity of the soil. However, its greatest contribution to the water-holding capacity is through its effect on the structure and pore space of the soil (3, 39).

The proposed mechanisms of aggregate formation believed to be a function of soil organic matter are:

1. Living bacteria, fungi and actinomycetes, whose presence and numbers are directly related to organic matter content of the soil and its nature, binding soil particles together.

2. Gelatinous organic materials such as gums, resins, and waxes which are thought to surround soil particles and hold them together by a cementing or encapsulating action.

Thus, increased soil aggregation and the stabilization of the aggregates as a result of increased soil organic matter content could be due to the mechanical binding of soil particles by microbial filaments during the period of intense microbial activity, the presence of binding or cementing agents in the organic residues and/or synthesized by the organisms, and organic waste products formed during decomposition of the original material, dead microbial cells or secondary decomposition products (10, 18, 30). The relationship between aggregation and aeration is that aggregation ensures the presence of pore spaces of such size as permit good aeration in the soil after drainage of excess water under field conditions (3).

OBJECTIVES OF THE INVESTIGATION

A continuing project on the effects of organic and mineral fertilizers on the maintenance of soil fertility and crop production has been underway at the University of Arizona Agricultural Experiment Station farm at Mesa, Arizona, since 1956. Crop yields have been measured and the cost of the various treatments computed, but no laboratory work has, hitherto, been attempted to evaluate this project.

The trial was carried out on eighteen plots numbered 48 to 65, on the northeastern part of the farm. There were 3 treatments and 6 replicates, the treatments being:

1. Barnyard manure at the rate of 9 tons per acre.
2. Compost at the rate of 6 tons per acre.
3. Ammonium nitrate at 300 lbs. per acre.

In 1956-1957, plot numbers 49, 51, 55, 59, 60 and 65 were fertilized with manure; plot numbers 50, 52, 54, 57, 61 and 63 were treated with compost, and ammonium nitrate was applied on plot numbers 48, 53, 56, 58, 62 and 64.

In 1958-1959, ammonium nitrate was applied on all the plots at rate of 300 lbs. per acre, with the inorganic nitrogen plot receiving extra ammonium nitrate in 1959.

In 1960-1961, all the plots received a uniform treatment of triple superphosphate at the rate of 200 lbs. P_2O_5 per acre.

From 1956 to 1959, all eighteen plots were planted to cotton (Acala) and then to alfalfa (Moapa) in 1960 and 1961.

The purpose of this project was to study the effects of the various treatments on the soil nutrient level by soil analyses and to determine the amounts of total nitrogen and phosphorus in the alfalfa crop currently growing on the plots as an indication of the nutrient availability to the crop. Yield figures and the cost of the various treatments are included to indicate the most economical of the three treatments.

MATERIALS AND METHODS

Soil studied

The experiment was conducted on one soil type, Laveen loam, which is the dominant soil on the Experimental Station farm at Mesa.

The Laveen soils are light colored calisols of the Red Desert region. The parent materials consist of alluvial fan deposits mainly from granitic rocks, but include some materials derived from other geologic sources. These soils are dominantly of sandy loam or loam texture with smaller areas of clay loam. They are associated geographically with Mohave, Rillito and Pinal series. They are somewhat similar to the Adelanto series, but differ mainly in that the Laveen soils are strongly calcareous and usually lime nodules occur on and in the surface soil. These are numerous in the subsoil compared with practically none or very few nodules in and throughout the Adelanto surface and subsurface soils.

Laveen soils are differentiated from Rillito soils in having a lower content of lime, less cementation and fewer nodules in the Cca horizon. Pinal soils have an indurated lime hardpan.

Soil profile: Laveen very fine sandy loam

Ap. 0-12" Pale brown (10 YR 6/3 dry, brown 4.5/3 moist) very find sandy loam; massive; slightly hard when dry, very friable when moist; very strongly calcareous with much disseminated lime and a few lime nodules that range up to about 1/2 inch in diameter; moderately permeable with few plant roots, gradual, smooth lower boundary.

Cca. 12"-20" Very pale brown (10 YR 7/3 dry, brown 5/3 moist) loam, massive; hard and slightly lime cemented when dry; friable when moist; very strongly calcareous with much disseminated lime and an estimate of 5 to 10 percent lime nodules that range up to 1/2 inch in diameter; moderately permeable; few plant roots; gradual, smooth lower boundary.

Cca2. 30"-60" Similar in color, texture and structure to the horizon above, but high in disseminated lime and contains an estimate of 10 to 15 percent lime nodules; very hard, and may be softly lime cemented when dry, friable when moist; moderately permeable with a few plant roots.

Characteristics: The surface soil is strongly calcareous, but the content of nodules may range from a few to as much as 10 percent by volume.

Depth of the Cca horizon is quite variable, owing to agrading or degrading erosion. Unusual departures in such depths are designated as phases. In many places, the Cca horizon continues to depths of more than 6 ft., and, elsewhere limy, but less nodular C material occurs at depths ranging from 3 to 4 1/2 ft. Light brown and reddish brown colors are included.

Topography: Alluvial fans and desert valley plains. The surface is smooth to gently undulating. Slopes range from nearly flat to about 3 percent. In some places where erosion has been severe, the surface is ridged or hummocky.

Drainage: Surface run-off ranges from slow to rapid, depending on slope; internal drainage is moderate and adequate under irrigation.

Vegetation: Creosote bush, bursage, desert sage, cacti, and after spring rains, a number of short-lived annuals, the most important of which for grazing are six-weeks grama, alfilaria and Indian wheat.

Use: Virgin areas are used only for limited grazing. The carrying capacity in much of southern Arizona is one animal unit to a section for year long grazing, plus 10 animal units for a period of 90 days following spring rains. Under irrigation, good yields of alfalfa, grain, cotton, truck crops and sorghums are obtained.

Distribution: In the Red Desert region of southern Arizona and southeastern California.

Type Location: One mile west of Laveen, Arizona.

Series Established: Salt River Valley area, Arizona, 1926.

Source of Name: Name of town southwest of Phoenix, Arizona.

Soil Survey--Soil Conservation Service, U.S.D.A.

Revised: 3/1/56 by W. G. Harper.

A profile description of that particular area of the Mesa Station made available by the Soil Conservation Service* follows.

0"-12"	A calcareous light brown loam.
12"-20"	A light brown calcareous fine sandy loam.
20"-42"	A fine sandy loam with a few lime nodules.
42"-60"	A fine sandy loam or loam with numerous nodules and spots of lime.

Experimental methods

Soil samples, taken with an auger, at one-foot intervals to a depth of four feet from the lower, middle and upper portions of each of the 18 borders, were composited on a piece of canvas, for each foot, placed in paper bags and brought to the laboratory in June of 1962.

All 72 samples were air-dried, ground to pass a number 10 mesh sieve and the following determinations made on them, using the

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* Information provided through the courtesy of Mr. Milo S. James, Arizona State Soil Scientist, S.C.S., U. S. Department of Agriculture.

methods indicated. Most of the experimental methods employed are standard and only brief descriptions and references are given. Where other methods were used, a more detailed description is provided.

1. Total nitrogen was determined by Kjeldahl's method, using the Gunning-Hibbard modification as outlined by Wright (51).

2. CO_2-soluble nitrate was determined by the phenyldisulfonic acid method on the carbonic acid extract as outlined by Jackson (24).

3. CO_2-soluble phosphate was determined by the Denige's colorimetric method for phosphate as modified by Truog and Meyer and outlined by Jackson (24).

4. pH values of both the soil paste and the 1:5 suspension were determined as outlined by Richards (38), using a Beckman Glass Electrode pH meter.

5. The electrical conductivity of the saturation extract was determined by the Bridge and Cell method outlined by Richards (38).

6. Cation exchange capacity was determined by leaching the soil samples with 1.00 N. CH_3COONH_4, pH 7.0, according to the method outlined by Chapman and Pratt (6).

7. EDTA titration values were determined by titrating 1 ml of the saturation extract with 0.01 N. EDTA solution as outlined by Richards (38).

8. Calcium carbonate was determined by a method currently in use at the Soil and Water Testing Laboratory, Department of Agricultural

Chemistry and Soils, University of Arizona, and recommended by the U. S. Soil Conservation Service. A 2 gm. sample of soil screened through a 40 mesh sieve was weighed into a 250 ml. beaker, 10 ml. of exactly 1.0 N. H_2SO_4 were added, and the mixture diluted to bring the volume to 100 ml. The mixture was then stirred, covered with a watch glass, and gently boiled for 10 minutes on a hot plate. Two drops of phenolphthalein were added to the cooled mixture which was titrated to a pink color with a standard solution of NaOH having a strength of about 0.5 N. Two blank determinations were made to standardize the NaOH solution.

Calculation:

Normality of H_2SO_4 solution = 1.0

$$\frac{10\ (\text{ml. } H_2SO_4)}{\text{Titre (blank)}} = \text{Normality of NaOH solution}$$

10-(ml. NaOH [sample] x normality of NaOH)

= ml. H_2SO_4 neutralised $CaCO_3$

ml. H_2SO_4 neutralised x 2.482 = % $CaCO_3$.

where 2.482 is a factor specific for the method.

9. Organic carbon was determined by Walkley and Black's (50) rapid titration method, using electrometric indicator (17).

The organic carbon percentage was then multiplied by the empirical factor 1.724 to give the organic matter percentage.

From the total nitrogen and organic carbon contents, the carbon/nitrogen ratios were calculated.

10. Mechanical analysis of the soil was determined by the Bouyoucos hydrometer method as modified by Day (8).

11. Moisture retention was determined, using the pressure membrane apparatus as developed by Richards (36). Richards and Weaver (37) have shown that a tension equivalent to 15 atmospheres corresponds to the wilting percentage of soils and a tension of about 1/3 atmosphere is equal to the moisture equivalent, which, for a fine-textured soil such as Laveen loam, gives a fairly good measure of field capacity.

The two tensions were therefore used, the difference in moisture contents at the two tensions being used as a measure of the moisture retention. Only samples of the first two feet were used in this determination.

Six handfuls of the alfalfa crop on each plot were clipped one inch from the soil surface with a pair of scissors and placed in paper bags which were brought to the laboratory. Each of the 18 samples was dried in the oven at 70° C, ground to pass a 40 mesh sieve and the following determinations made on duplicate samples.

a. Total nitrogen was determined by the method used in the soil analysis (51).

b. Total phosphorus was determined by the molybdivanadophosphoric acid method as outlined by Chapman and Pratt (6) after digestion of the samples with nitric and perchloric acids.

RESULTS AND DISCUSSION

Certain assumptions had to be made for purposes of discussion and interpretation of the experimental results.

It is well known that the colloidal clay fraction of the soil, together with the soil organic matter fraction, forms the colloidal complex which is the seat of such physico-chemical reactions as ion exchange and moisture retention which determine the fertility of the soil, other things being equal. From the results of the mechanical analysis, it is evident that within the limits of experimental error, all the experimental plots showed uniform particle size distribution at the various depths, slight differences existing from depth to depth rather than from plot to plot at a given depth. It was, therefore, assumed that that part of the reactivity of the soil due to specific surface of the mineral matter was the same throughout the experimental area and that any differences in nutrient content and other soil properties observed in the course of the experiment were due to differences in the organic fraction content of the soils as a result of the various treatments.

It was also necessary to assume that any effects of previous agronomic practices on the experimental area were the same. Thus, apart from the initial differential treatments of manure, compost and ammonium nitrate in 1956-1957, and the extra nitrogen applied to the inorganic nitrogen plots in 1959, all the other treatments were uniform and any differences in the results obtained were attributed to the 1956-1957 treatments.

Irrigation water used on the Mesa Station is known to contain dissolved plant nutrients. These vary in kind and amount, depending on which of the two sources, surface or pump water, is used in the nearby Salt River Project which provides the irrigation water for the station. McGeorge (33) points out that most pump waters in Arizona contain considerable quantities of dissolved plant nutrients. He estimates the nitrate content, for example, to be between 10 to 50 ppm. The third assumption was that irrigation water affected all the plots to the same extent and its effects could, therefore, be ignored in this study.

The analytical data obtained on the soils were statistically analyzed for each foot. The results showed that there were significant differences in some nutrient levels in the first foot, but none in the second, third, or fourth foot. In order to make any meaningful comparisons on the treatment effects, the discussion is therefore limited to nutrients in the first foot. Data for the remaining three feet have, however, been included for comparative purposes.

Table 4. Results of the mechanical analysis.

Plot no.	1st Foot			2nd Foot			3rd Foot			4th Foot		
	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay	Sand	Silt	Clay
	percent											
48	40	40	20	43	40	17	37	42	21	34	42	24
49	41	39	20	43	41	16	39	41	20	37	40	23
50	41	38	21	41	43	16	40	40	20	38	39	23
51	39	40	21	44	40	16	39	41	20	34	42	24
52	41	39	20	42	42	16	38	41	21	34	42	24
53	41	38	21	41	42	17	40	40	20	37	40	23
54	37	42	21	42	41	17	37	42	21	34	43	23
55	39	40	21	42	41	17	39	44	20	37	40	23
56	40	40	20	41	42	17	39	40	21	34	42	24
57	38	41	21	43	40	17	40	40	20	34	41	25
58	40	39	21	43	41	16	41	39	20	37	40	23
59	39	40	21	41	42	17	38	41	21	33	43	24
60	39	40	21	42	42	16	39	40	21	34	43	23
61	39	40	21	40	43	17	40	40	20	34	42	24
62	40	40	20	44	39	17	39	41	20	37	40	23
63	40	40	20	41	42	17	40	39	21	37	39	24
64	41	38	21	42	42	16	40	40	20	34	42	24
65	39	40	21	43	40	17	40	40	20	34	42	24

Data represent single determinations.

Table 5. Results of soil analysis--first, second, third, and fourth feet.

Treatment	Organic matter	Total nitrogen	C/N ratio	CO_2-soluble PO_4	CO_2-soluble NO_3	Conductivity of the Saturation extract	EDTA titration	pH values Paste	pH values 1:5	Cation exchange capacity	$CaCO_3$	Moisture retention**
	%	%		ppm.	ppm.	mmhos/ cm.	ml.			meq./ 100 gm.	%	%
						First foot						
Manure	0.876	0.069	7.36	4.91	16.50	1.10	0.50	7.82	8.61	11.2	8.5	10.3
Compost	0.873	0.069	7.33	4.98	15.66	1.03	0.49	7.81	8.66	11.1	8.5	10.2
NH_4NO_3	0.843	0.067	7.27	4.80	15.29	1.14	0.52	7.78	8.62	11.1	8.5	9.6
Level of signif.	5%	1%		NS	5%	5%	NS			NS	NS	NS
C.V-%	2.9	1.5		6.1	6.1	8.1	16.2			3.5	2.9	8.7
Duncan's multiple range:-												
P*=2	0.023	0.001			0.88	0.08						
P*=3	0.024				0.92	0.09						
						Second foot						
Manure	0.261	0.028	5.39	1.59	9.0	1.04	0.49	8.04	8.81	8.3	12.2	8.4
Compost	0.257	0.028	5.32	1.50	9.0	1.00	0.44	7.93	8.83	8.2	12.3	7.5
NH_4NO_3	0.260	0.027	5.55	1.41	8.8	1.02	0.48	7.91	8.78	8.1	12.3	8.0
C.V.-%	14.8	4.5		13.9	5.8	20.0	17.0			3.9	3.4	23.6

Data represent the means of twelve replicates.

* Number of means for range being tested.

** Means of six replicates.

Table 5. (Continued).

Treatment	Organic matter	Total nitrogen	C/N ratio	CO_2-soluble		Conductivity of the saturation extract	EDTA titration	pH values		$CaCO_3$
				PO_4	NO_3			Paste	1:5	
	%	%		ppm	ppm	mmhos/cm	ml			%
					Third foot					
Manure	0.18	0.022	4.74	1.12	6.8	1.13	0.51	7.99	8.90	17.6
Compost	0.18	0.022	4.74	1.02	6.6	1.14	0.51	7.96	8.90	17.6
NH_4HO_3	0.16	0.021	4.42	0.96	6.5	1.12	0.51	7.97	8.91	17.6
C.V.-%	15.9	5.5		14.5	7.0	10.8	16.7			1.6
					Fourth Foot					
Manure	0.17	0.018	5.47	0.32	5.5	1.31	0.55	8.06	8.98	22.8
Compost	0.16	0.018	5.15	0.30	5.4	1.18	0.53	8.07	8.99	22.7
NH_4NO_3	0.15	0.018	4.83	0.27	5.2	1.19	0.53	8.06	8.99	22.7
C.V.-%	10.3	6.7		19.3	11.8	14.7	21.0			2.2

Data represent the means of twelve replicates.

Organic matter content

Statistical analysis of the data showed a significant difference in the organic matter content of the differently treated plots at the 5 percent probability level. There was no significant difference between the manure and compost treatments, but both were significantly higher than the inorganic nitrogen treatment in organic matter content.

The explanation advanced for this is that the manure and compost plots received 9 tons of manure and 6 tons of compost per acre, respectively, for two years, over and above the native organic fraction of the soil present, prior to the application of the organic materials. Even though conditions obtained for the rapid oxidation and loss of the organic materials in the soil, and the organic additions might have stimulated the decomposition of both the added and the native organic matter, the products mineralized slowly and continuously in the process were utilized by the crops, with the result that they showed increase in growth. This accelerated growth in turn supplied more numerous and vigorous roots and other crop residues which contributed to a buildup of soil organic matter (27).

Total nitrogen content

There was a highly significant difference--at the 1 percent probability level--between the organic treated plots and the inorganic nitrogen plots in total nitrogen content. However, there was no difference between the manure and compost treatments in their effects on the total nitrogen content.

Calculation of the total amounts of nitrogen applied to the soil in the course of the experiment shows that the manure plots received a total of 944 pounds nitrogen per acre, the compost plots received a total of 630 pounds--based on 2.04 percent and 1.75 percent nitrogen in the manure and compost, respectively,* while the inorganic nitrogen plots received a total of 502 pounds nitrogen per acre.

It is apparent that the organic treated plots received more nitrogen than the inorganic plots. It is to be expected that, in spite of the leaching of soluble nitrogenous compounds by irrigation water and the uptake of nitrogen by the crops, there would still be more nitrogen in the organic plots, especially since they contain more organic matter than the inorganic nitrogen plots. Also, analysis of the alfalfa showed that the hay from the manure plots contained more nitrogen than the hay from the compost and the inorganic plots; thus, assuming, that litter fall occurred at the same rate on all the plots, more nitrogen was contributed to the manure plots this way than to the compost and the inorganic plots.

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* Information provided through the courtesy of the Arizona Testing Laboratories, Phoenix, Arizona, which carried out chemical analysis of the materials.

Since the manure contained more nitrogen than the compost, its rate of oxidation in the soil might have exceeded that of the compost. It is possible that, with time, both materials would have uniform composition and the same rate of oxidation. This could account for the fact that both the manure and compost plots contained the same level of total nitrogen, even though the manure plots received more nitrogen.

CO_2-soluble phosphate

Statistical analysis of the data did not show any significant differences in the CO_2-soluble phosphate. It is possible that the organic phosphorus contained in the manure and compost might have played a part in increasing crop yields from 1957 to 1959. However, with the application of triple superphosphate at the rate of 200 pounds P_2O_5 in 1960 and 1961 to all the plots, the amounts of phosphorus from the organic sources would be expected to be insignificant, relative to the amounts applied in the two years. This would explain why the CO_2-soluble phosphate levels did not show any significant differences.

CO_2-soluble nitrate

The manure plots showed a higher level of CO_2-soluble nitrate than the compost and inorganic plots, but there was no significant difference in the levels of nitrate nitrogen between the compost and inorganic nitrogen treatments. This appears to be rather unusual since the manure and the compost plots contained the same amounts of total nitrogen and organic matter. There seems to be no reasonable explanation for this, other than the fact that with a C/N ratio of 7.36 as against 7.33 for the compost plots, the manure plots contained more carbon which, on oxidation by the microorganisms, would be expected to lead to the mineralization of more nitrogen.

Electrical conductivity of the saturation extract

Statistical analysis of the data showed that there were treatment differences in the electrical conductivities of the soil saturation extracts from the different plots. There was no difference due to the application of compost as compared with manure, or manure as compared with ammonium nitrate. However, there was a significant difference between the compost and the ammonium nitrate treatments. There seems to be no explanation for this finding, other than that the slightly lower figures for the organic treated plots may be due to the solubilization of calcium and magnesium salts by the carbonic and organic acids produced during the decomposition of the organic materials and their subsequent leaching out of the first foot (26), since this determination provides a measure of the total salt content of soil.

EDTA titration values

Statistical analysis did not show any significant difference in the EDTA values for the differently treated plots. However, the values for the manure and compost treatments were slightly lower than those for the ammonium nitrate treatment. The reason could be the same as shown by Kelley (26), since this determination is an index to the calcium and magnesium contents of soil.

Cation exchange capacity

It was expected that the higher organic matter content of the organic matter treated plots would lead to a higher cation exchange capacity in these plots, but statistical analysis of the data did not show this. This might have been due to the inherent errors in the method used for this determination on such a calcareous soil, and its inability to show such small differences as could be ascribed to differences in the organic matter content of the order of 0.03 percent.

Moisture retention

The plots which received the organic materials were expected to hold more available moisture than those which received ammonium nitrate. However, statistical analysis of the data did not show this, and the reason could be the same as that discussed in the preceding section on cation exchange capacity.

Table 6. Results of the alfalfa analysis.

Treatment	Total nitrogen	Total phosphorus
	%	%
Manure	4.58	0.356
Compost	4.56	0.347
NH_4NO_3	4.47	0.341
Level of significance	1%	5%
C.V.-%	1.5	3.4
DMR.*		
P = 2	0.08	0.010
P = 3	0.09	0.011

Data represent the means of twelve replicates.

* Duncan's Multiple Range with P as number of means over the range being tested.

Total nitrogen content of the alfalfa hay

Statistical analysis of the data showed a highly significant difference between the organic and the inorganic treatments in the total nitrogen content of the alfalfa hay, but no significant difference between the two organic treatments. Although the level of CO_2-soluble nitrate in the compost plots was not statistically different from the level in the ammonium nitrate plots, the alfalfa hay showed a statistical difference in nitrogen content. The reason for this might be a slower mineralization of nitrogen from the organic matter in the compost treated plots than in the manured plots. The C/N ratio seems to indicate this. The different rate of mineralization apparently was enough to make more nitrate available for plant utilization in the compost plots than in the inorganic nitrogen plots, which resulted in the higher level of total nitrogen in the hay from the compost plots than from the inorganic nitrogen plots.

Total phosphorus of the alfalfa hay

There was a significant difference, at the 5 percent level, in the total phosphorus content of the alfalfa hay between the manure plots and the plots of the other two treatments. There was no difference in phosphorus content between the compost and ammonium nitrate treatments. Since the levels of CO_2-soluble phosphate in the plots did not show any significant differences, and the manure borders showed a higher level of CO_2-soluble nitrate than the plots which received the other treatments, it would appear that the higher phosphorus content shown by the hay from the manure plots was strictly a function of the higher level of nitrate and the consequent better growth rate, causing more phosphate to be absorbed by the alfalfa. Trumble and Shapter (45) have demonstrated such a phenomenon for Wimmera rye grass and subterranean clover which received different applications of phosphorus and nitrogen.

<u>Yields of seed cotton and alfalfa hay</u>

In 1956, there were no statistical differences in seed cotton yield among the treatments, even though the organic treatment yields were higher, as shown in Table 7. This could be due to the fact that with the application of the carbonaceous materials to the organic plots, there occurred a nitrogen depression and, possibly, a phosphorus depression as well prior to the mineralization and accumulation of nitrate and phosphate. Sufficient nitrate and phosphate must have been present to prevent this depression on the application of more organic materials in 1957, with the result that the expected treatment differences became manifest starting from 1957.

In 1958, all borders showed increases in yield over the previous year due to the ammonium nitrate applied. It is possible that the

Table 7. A summary of the mean yields of seed cotton and alfalfa hay for the three treatments and the corresponding years.

Year	Treatments and mean yields			Level of significance
	Manure	Compost	NH_4NO_3	
	-------------	lbs./A	-----------------	
		Seed cotton		
1956	3,904	3,895	3,503	NS
1957	3,851	3,414	3,081	5% ≠
1958	4,190	4,063	3,299	5% ≠
1959	3,803	3,751	3,162	5% ≠
		Alfalfa hay		
1960	12,876	12,994	10,943	5% ≠
1961	17,676	16,919	16,088	5% ≠

Data represent means of six replicates.

≠ No statistical difference between manure and compost treatments.

decreased yield over all the treatments in 1959 was due to lack of nutrients other than nitrogen.

The substantial increase in the yields of alfalfa hay in 1961 over the 1960 yields was largely due to the second application of triple superphosphate.

As indicated already, the manure plots received more nitrogen than the compost plots, which, in turn, received more than the inorganic nitrogen plots. It is obvious, then, that the organic matter treated plots should yield more cotton and alfalfa hay than the inorganic nitrogen plots. Moreover, other nutrients like phosphorus, potassium, calcium and magnesium known to be contained in manures and composts (44) might possibly have contributed to the higher yields of the organic plots. This seems to support Thorne's (42) view that

> When manure has been compared with chemical fertilizers, the manure usually has been used in such amounts as to carry far larger quantities of the essential elements of fertility than those given in the chemicals and without stopping to consider this point, the carbonaceous matter of the manure has been credited with the superior effect produced.

<u>Other possible treatment effects</u>

The organic matter treatments might have had an effect on the pH values of the plots which received them during the period of active decomposition of the materials (6). The time of sampling for the analysis was five years after the last application of the organic materials.

Also, according to Thorne (43), a soil containing 5 percent or more lime has a high buffer capacity which must be overcome before any appreciable change in pH value of the soil is produced. With the surface foot having a calcium carbonate content of 8.47 percent and, therefore, a very high buffering capacity, it was assumed that the effects of the treatments on the pH values of the plots at the time they were sampled would be negligible and is, therefore, not discussed.

Since the effect of treatments on the calcium carbonate content of the borders is inconsequential to crop performance and statistical analysis of the data did not show any significant differences, this is also not discussed.

The pH values and the calcium carbonate content of the plots, however, serve to indicate that the soil studied is indeed an alkaline calcareous soil and quite uniform in composition

Gross income and costs

In order to determine which of the three treatments was the most economical, the yields of lint, in the case of cotton, and of alfalfa hay for each treatment and each year were computed. Prices for the two commodities in the United States were then obtained for each year. Assuming that factors like the cost of handling the fertilizers, applying the fertilizers, harvesting and handling of the crops were the same for all treatments, the gross income for each treatment and year was divided by the cost of the fertilizers applied.

The gross income per cost of fertilizer ratios obtained were then averaged for each crop over the six-year period. The results showed that for cotton production, the ammonium nitrate treatment was the most economical and the manure treatment was the least economical. For alfalfa hay production, the results showed that the manure treatment was the most economical and the ammonium nitrate treatment the least economical, although differences in the ratios are rather small. However, averages of the ratios for the two crops over all years showed that the ammonium nitrate treatment was the most economical and the manure treatment the least, as shown in Tables 7 and 8.

Table 8. Yield of cotton, cost of fertilizers, and gross income.

Item	1956			1957		
	Manure	Compost	NH_4NO_3	Manure	Compost	NH_4NO_3
Yield of seed cotton lbs./A	3,904	3,895	3,503	3,851	3,414	3,081
Yield of lint*--tons/A	0.703	0.701	0.631	0.693	0.614	0.555
Price per ton--$	643.80	643.80	643.80	674.20	674.20	674.20
Gross income--$	452.60	451.30	406.20	467.20	413.90	374.20
Cost of fertilizer-$	35.00	30.00	14.00	34.00	26.00	15.00
Gross income/cost	12.9	15.0	29.0	13.7	15.9	24.9

* Ginning percentage of 36%.

Gross income per cost ratios averaged over years

Manure	Compost	NH_4NO_3
14.8	15.7	19.7

Table 8. (Continued).

Item	1958			1959		
	Manure	Compost	NH_4NO_3	Manure	Compost	NH_4NO_3
Yield of seed cotton lbs./A	4,190	4,063	3,299	3,803	3,758	3,162
Yield of lint*-- tons/A	0.754	0.731	0.594	0.684	0.676	0.569
Price per ton--$	694.00	694.00	694.00	640.00	640.00	640.00
Gross income--$	523.30	507.30	412.20	437.70	432.60	364.20
Cost of fertilizer-$	28.00	28.00	28.00	31.00	31.00	35.00
Gross income/cost	18.7	18.1	14.7	14.1	13.9	10.4

* Ginning percentage of 36%.

Gross income per cost ratios averaged over years

Manure	Compost	NH_4NO_3
14.8	15.7	19.7

Table 8. (Continued).

Item	1960			1961		
	Manure	Compost	NH_4NO_3	Manure	Compost	NH_4NO_3
Yield of hay--tons/A	6.438	6.497	5.472	8.838	8.460	8.044
Price per ton--$	26.33	26.33	26.33	23.80	23.80	23.80
Gross income--$	169.50	171.10	144.10	210.30	201.30	191.40
Cost of fertilizers	8.46	8.46	8.46	8.46	8.46	8.46
Gross income/cost	20.0	20.2	16.7	24.8	23.8	22.6

Gross income per cost ratios averaged over years

Manure	Compost	NH_4NO_3
22.4	22.0	19.7

Table 9. Ratios of gross income to cost of fertilizers.

Year	Manure	Compost	NH_4NO_3
1956	12.9	15.0	29.0
1957	13.7	15.9	24.9
1958	18.7	18.1	14.7
1959	14.1	13.9	10.4
1960	20.0	20.2	16.7
1961	24.8	23.8	22.6
Average	18.6	18.8	19.7

SUMMARY AND CONCLUSIONS

In this study involving such deep-rooted crops as cotton and alfalfa, soil samples were taken to a depth of four feet and analyzed to determine their nutrient levels in an attempt to explain why the organic fertilizers were proving to be superior to ammonium nitrate in increasing crop yields. The soil properties determined were those known to be enhanced by organic matter and to improve crop performance.

Statistical analysis of the data obtained showed that differences in plant nutrient levels and other soil properties due to treatment were significant in only the surface foot of the soil. This was rather interesting because the organic materials were spread with a manure spreader and plowed 12 inches under the soil. This, however, does not preclude the possibility that some of the plant nutrients were leached, from time to time, from the first foot to lower depths, by irrigation water and might have contributed to the increases in crop yields noted on the organic plots.

The organic materials were superior to the ammonium nitrate because they contained more nitrogen, and, probably, phosphorus, sulfur, calcium, magnesium and potassium which they are known to contain. Their sustained superiority over the years could be due to their residual effects and the contribution of the increased litter fall and root mass to the soil organic matter level, so that differences in the soil nutrient levels were a function of the differences in the soil organic matter levels in the plots.

Although the organic materials produced increases in crop yields over the ammonium nitrate plots, the ratios of gross income to cost of fertilizers, assuming other factors to be constant, indicated that the ammonium nitrate treatment was the most economical over the years.

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