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Factors influencing the rate of decomposition of different types of plant tissue in soil, and the effect of the products of plant growth

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FACTORS INFLUENCING THE RATE OF OXIDATION
OF DIFFERENT TYPES OF PLANT TISSUE IN
AND THE EFFECT OF THE PRODUCTS ON PLANT

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FACTORS INFLUENCING THE RATE OF DECOMPOSITION
OF DIFFERENT TYPES OF PLANT TISSUE IN SOIL,
AND THE EFFECT OF THE PRODUCTS ON PLANT GROWTH

By

Major Franklin Spaulding

Presented in Partial Fulfillment of the
Requirements for the Degree of Doctor of
Philosophy at the Massachusetts State
College, Amherst, Massachusetts, May
1935.

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INTRODUCTION

This study is devoted particularly to decomposition of decaying plants which yield the fertilizing constituents so necessary to the proper growth of other plants: and it will become evident that the rate of decomposition of a plant is governed by the proportion in it of carbohydrates to nitrogenous compounds, and that the proportion of carbohydrates to nitrogenous compounds in its make-up depends, in turn, upon the typical chemical make up of the species and upon the stage of growth of a plant at the time it is cut down and left to decay. (The proportions of pentosan and nitrogenous compounds in various plants might be made the basis of a classification of plants. For, although, there appears not to be a clear increase of nitrogenous content in the evolutionary series -- fungi have a small nitrogen content, for example: ferns show somewhat larger proportions: and the dicotyledons have still more: but with the monocotyledons there appears a diminution of nitrogenous content: -- yet the proportion of pentosans rises steadily through the series.)

Generally speaking the older the plant, the larger the proportion of carbohydrates in its composition: and the carbohydrates resist decomposition under the chemical influences of fungi, bacteria, and enzymes for longer than nitrogenous compounds. Furthermore, a large ratio of carbohydrates to nitrogenous compounds delay the time at which the latter -- the fertilizing constituents of the decaying plant -- are avail-

able for the sustenance of other plants: for so long as the bacteria and fungi of decay find carbohydrates to feed upon, they will come between the growing plant and the nitrogenous compounds in order to consume these latter in themselves.

OBJECT

The object of the investigation was to establish by experimental methods principles by which the characteristics and relative values of natural fertilizer (humus) could be estimated in advance of use from their known or discoverable chemical constituents. Such principles would help the agriculturist to maintain the fertility and increase the yield of his land by proper use of his own resources rather than by recourse to commercial fertilizers. With this principal object are combined certain incidental objects growing logically out of the results of the investigation.

In more detail these objects may be stated thus:

1. To discover the rates of decomposition in both soil and sand cultures of various plants widely used by agriculturists, this rate to be determined in two distinct ways:

- a. By determining the total content of carbon, nitrogen, pentosans, and lignic acid of each plant at a certain stage of growth: and then determining the amount of ammonia and nitrates liberated in the soil or sand culture at given intervals during the period of rotting by the various plants.
- b. By determining the total content of carbon, nitrogen, pentosans, and lignic acid of each plant at a certain stage of growth: and estimating the rate at which ammonia and nitrates are successively liberated by

the various plants in the soil or sand culture by their effects upon the growth of barley. In both these methods of determining the rate of decomposition, the following factors were kept constant for all samples and tests:

(1) the significant chemical constituency of soil and sand cultures: and (2) the amount of nitrogen in each sample of plant tissue left to decay (whatever the total bulk of the sample). The first constant was the result of determinations of the amount of nitrogen and carbon in the soil cultures (none of either was permitted in the sand cultures): the second constant was the result of determinations of the percentage of nitrogen normally present in each of the samples which were to be rotted in the cultures. But in method (a) the amount of ammonia and nitrates liberated were measured in the laboratory: while in method (b) the amounts of ammonia and nitrate liberated were measured by plant growth in the greenhouse.

2. To compare the relative proportions of certain constituents (especially pentosans) of the plants with their relative positions in classifications of Bessy, Clements, and Conrad, who arrange plants in an evolutionary series determined by morphological rather than chemical considerations: that is, to show a correlation between classification of plants in accordance with their relative contents of pentosans or nitrogen and classifications in accordance with the evolution of their forms.

3. To determine the relation of the nitrogenous content of a plant to the proportion of silica and lime in the tissue thereof.

4. To show that correlations (either positive or negative) exist among all the characteristics of plants studied in this experiment.

- a. Rates of decomposition (especially liberation of ammonia and nitrates).
- b. Rates of beneficial effects of these plants when allowed to rot, upon other living plants.
- c. Proportions of nitrogenous compounds to carbohydrates (especially pentosans and lignic acid) in the original make-up of plants.
- d. Proportions of silica and lime in the tissues of plants.
- e. Classifications of plants in evolutionary series.

LITERATURE REVIEW

When the agricultural sciences began to emerge in a recognizable form at the beginning of the last century, the importance of organic material to soil fertility was already known and generally accepted. Humus, the decomposed residue of plants and animals, was supposed to be the direct food of plants. The ^{Nu}tritive effect of this residue, though generally known to agriculturists, was not precisely demonstrated in the laboratory until about 1838. This demonstration aroused interest, but was soon overshadowed by the famous pronouncement of Leibig in 1840, "that crops in a field increase or decrease in exact proportion to the increase or decrease of mineral substances conveyed to them in manure", and by the rapid development on the part of Lawes and Gilbert of the Rothamstead Experiments in nutrition of plants.

One of the essential differences between a soil and a mass of rocky fragments lies in the organic content of the former. Organic matter is necessary to that chemical decomposition of minerals (usually in the form of rocks) which produce a soil capable of growing crops successfully. The physical condition of the soil also depends largely on the presence of organic matter. In an average soil there will be found organic matter existing in an almost infinite number of stages of decomposition, organic matter which includes not only all complex compounds contained in the as yet unspoiled vegetable and animal tissue, but also those simpler compounds of which the partially decayed portion of such material is composed.

The source of practically all organic matter is plant-tissue. Lyon

and Buckman (26) demonstrate the preponderance of plant-tissue over animal-tissue by assuming one bacterial cell to weigh .000,000,002 milligram, and assuming further that there were some 100,000,000 such organisms in each gram of soil: even at this density of bacteria only 400 to 800 pounds of the total weight (2,000,000 pounds) of an acre of six inch soil is made up of microscopic life. Another 1200 to 1600 pounds of molds, fungi, algae, actinomyces, insects, and earthworms. But the remainder of the roughly 400,000 pounds of organic material in a soil weighing 2,000,000 pounds to the acre (of six inch depth) consists of plant-tissue in various stages of decay. In short, although the bacteria perform a very important function in the making of a fertile soil, they actually compose a very small fraction by weight of its organic content. The much larger proportion of plant-tissue is made up partly of the exposed portion of vegetation: and the remainder is the result of root extension and subsequent decay.

Since the organic matter in soil has its origin very largely in the higher plants, it is advisable to consider the general chemical nature of such plants. About 75 percent of the average green plant is water. The remaining 25 percent is made up roughly of carbon, oxygen, hydrogen and mineral materials in the approximate ratio of 6-5-1-1. (As can be seen from the partial analysis recorded in Table I of some few plants, the preponderant part of normal plant-tissue is carbon). The chemical constituents of plants are usually more specifically classified under the following heads: (I) Carbohydrates, which include sugars, starch, cellulose, lignins, inulin, gums, pectins, and pentosans: (II) fixed oils and waxes, which include castor oil, corn oil, cottonseed oil, linseed oil, and the like: (III) volatile oils and resins, which include such oils as those of

mustard, cloves, and peppermint, as well as such related materials as rosin, myrrh and balsam: (IV) organic acids and their salts, such as citric, malic, tannic, and tartaric acid: and (V) nitrogenous compounds such as nitrate ammonias, amides, ammonio-acid, alkaloids, and proteins.

Some of the compounds of the first group are unusually resistant to decomposition: for although sugars and starches disappear fairly soon, the other compounds listed under this heading decompose slowly. Lignin, indeed, is by far the most resistant of all the constituents of a plant, being the principal contributor to humus.

Of the five groups, the nitrogenous compounds are probably the most complicated chemically, for they contain not only carbon hydrogen, oxygen, and nitrogen, but also practically all of the mineral elements such as sulfur, phosphorus, calcium, and iron that exist in the plant. (The nitrogenous compounds are probably the most complicated chemically because the molecular weight and exact composition of many of them are not yet certainly established). To be sure, the nitrogenous compounds are not all equally complex: there are, for example, simple proteins such as globulins, albumin, and protamines, besides such derivative proteins as proteose, and peptones. In addition to all these, there is a host of other nitrogenous compounds that have no small influence on the composition of the soil. All these compounds exist in the living forms, especially of plants: which tend to accumulate in varying amounts in the upper level of the soil, and are present in all stages of decomposition and of solubility. All the chemical transformations in the soil thus far referred to are brought about by the microorganisms which are normally present in soils, and which are known to bring about or influence indirectly numerous physical and chemical changes therein.

The average of analyses shows that in ordinary fertile soils 95 percent of the nitrogen, 33 percent of the phosphorus, and appreciable amounts of the potassium, sulfur, and calcium which it contains are embodied in the organic matter. In other words, by far the most important natural source of the nitrogen available to the farmer for the production of crops is plant-tissue.

But the function of organic matter is cumulative, for when the plant decomposes, it returns to the soil not only the mineral nutrients that it has taken therefrom and utilized by metabolism, but also carbohydrates which with the aid of sunlight, it has synthesized from the carbon dioxide of the air. When the plant decomposes, the carbon thus synthesized serves as a source of energy for organisms of the soil that tie up atmospheric nitrogen and return it to the soil. Consequently, the plant yields, upon decomposition, not only the nitrogen it extracted from the soil as it grew, but, through bacteria feeding on its carbon, also nitrogen from the air.

Because the residue of plants increases the capacity of soil to hold water, retards erosion, absorbs (by means of the acidoid colloids in organic material) the ions of mineral elements which would be otherwise leached out of the soil, and reduces both the plasticity and the cohesion of soils, plant-tissue helps in still other ways to form and maintain the agricultural usefulness of soil. All these purposes are served as well by plants that grow out of season or that are otherwise economically worthless as by plants which are grown to be used as fertilizer.

THE ROLE OF CELLULOSE

Scott (54), Collison and Conn (7), Newton and Daniloff (3), and Gilbert and Pember (13) have all noted that when straw containing little nitrogen and much cellulose was applied to the soil, there resulted a diminution of nitrates, with a consequent falling off in the yield of crops: but that these effects could be overcome by the addition of sufficient nitrates in the form of nitrogen and manure.

Doryland (11) stated that a given soil can absorb and hold only so much ammonia and nitrate: that when it is saturated, attempts to force more of these compounds into it are vain. But he found, too, that the addition of dextrose or straw temporarily increased the power of the soil to absorb ammonia and nitrate: and when large quantities of straw were added to the soil, there was a marked increase in this power. Although their effect is less marked the residues of plants other than the small grains affect the soil in the same way.

Patrick (40) found that the amount of carbon dioxide evolved from a soil fertilized with plant tissue reflects the relative carbon-nitrogen ratios of the plants used: timothy (which has a high proportion of carbon): and corn gave off more than clover (which has a still smaller proportion of carbon). But when fertilizer was added to a neutral soil in such quantities as to insure an equal amount of carbon in the several samples, the total evolution of carbon-dioxide was much greater from soil treated with clover than from soil treated with timothy to make its nitrogen-carbon ratio the same as that of clover, the timothy plus the sodium-nitrate invariably yielded more free nitrate than did the clover.

Wilson (67) explained the depression of nitrate in soils when timothy and clover were turned under as follows: carbon-dioxide evolution followed the growth of organisms, which was greater under clover soon after turning under, but soon dropped. Whereas the growth of organisms where the timothy was turned under were not so rapid, but were more prolonged. The decomposition of timothy extended over a longer period of time than did that of the clover residue.

Norman (38) reported that carbon-dioxide closely paralleled the production of heat, and heat production was shown to correspond to a rapid loss of hemicelluloses. Patrick (39) in studying the influence of crop residue on nitrate found that in the roots and stubble of sweet clover there was added 61⁴⁴ pounds with a carbon nitrogen ratio of 22.9:1, timothy 126⁵² pounds with a carbon nitrogen ratio of 81:1, corn 978 pounds with a carbon nitrogen ratio of 58:1. He observed that the carbon-dioxide evolution was in the order of the carbon-nitrogen ratio, timothy, corn and clover. Hill (19) found that the depression of crop growth from the addition of cellulose to the soil was in proportion to the amount of cellulose added. Varying the amount of nitrates added up to 8 tons did not counteract these ill effects. Rye in a green stage depressed growth on a heavy clay soil and gave an increase on a more open type of soil which was well aerated. Corn yields were depressed over a period of 12 years where rye was turned under, and corn and wheat gave a much smaller yield where clover and soybeans were cut for hay than where they were turned under. The carbon-nitrogen ratio was much wider in non-legumes than it was in legumes, and decay was much slower.

Viljoen and Fred (60) reported that the unfavorable action of wood on plant growth is due to a lack of nitrates in the soil. This loss

may be due to a greater assimilation of nitrates by soil micro-organisms. Diminution of nitrification is caused by a group of organisms which make use of cellulose, rather than an inhibition of nitrification.

Salter and Green (148) reported that the accumulation and losses of organic material are affected by the nature and size of the crop in field soils. Corn is about twice as destructive of organic carbon and nitrogen as is a crop of wheat or oats.

Smolik (56) found a relative accumulation of fats, waxes, and oils to take place in the humification of alfalfa roots and tops. The amount of soluble protein, sugars, amino acids and starches decrease. Hemicelluloses decrease almost half and celluloses 22 percent. Proteins in the green parts as well as the roots decrease, but lignins and lipoids increase considerably.

Heck (18) found that when energy material was simple, decomposition is largely bacterial, with the liberation of large amounts of nitrate nitrogen, when it is of a high cellulose content, the action is to a great extent fungus, with the liberation of little or no mineral nitrogen. The structure of the carbonaceous energy-material governs somewhat the type of decomposition curves and the amount of nitrogen liberated as nitrate. Decomposition is rapid and their effects soon lost if simple; if they are of a high cellulose content, the decomposition is much slower and continues over a longer period. He also found that the nitrogen content of fungus tissue was influenced by the nitrogen content of the substrate. The decrease in the amount of fungus tissue begins when its carbon nitrogen ratio reaches 10 or 12 to 1. The average percentage of nitrogen for field forms of fungus tissue is 4 percent and that of carbon 40 to 44 percent. Rudolf (146) found that soil algae acted as indicators of soil properties.

He drew his conclusions from a study of the algae present in the end in like soils over a period of 13 years which had the same fertilizer treatment. The treatment was as follows: no fertilizer, complete fertilizer, nitrogen, and phosphorus, nitrogen and potash, phosphorus and potash. He found that the different types of algae in the soils were different for the different treatments. The plot receiving the complete fertilizer contained 26 times as many algae as the unfertilized plots. The former had 43 different types where the latter had only 9.

Norman (38) found that the distribution and arrangement of hemicelluloses in plant tissue are not shielded so as to be hindered in their attack by microorganisms as in the case of cellulose, by the presence of a more resistant lignin barrier.

ROLE OF PENTOSAN

Redge(44) found in studying the decomposition of rice, oats, wheat, barley, straw, rushes, corn, and white ash that if pentosan are much in excess of lignin, the material will be easily decomposed, the rate decreasing as the ratio to lignins decreased. A high lignin content of any cellulose material is detrimental to decomposition. Pentosans form the important microbial food and may be assumed to control decomposition of a material.

Schmidt and others (49) found that about 50 percent of the pentosans of corn was destroyed in 100 days, and about 35 percent of that of rye straw in about 300 days. Fraps (12) in studying the organic constituents of the soil reported that the average percentage of pentosans increased with the average nitrogen content of the soil. They are slightly higher

in the surface than in the subsoil in proportion to the nitrogen content. Pentosans in cotton seed meal disappeared rapidly from the soil during the first week, and at the end of the eighth week 7 percent of the original pentosans were present; from sudan grass 31 percent; from rice bran 61 percent, from sheep excrement 75 percent.

THE INFLUENCE OF SOLUBLE MATERIAL ON DECOMPOSITION

Martin (3) determined the decomposition of alfalfa and sweet clover at 30-210- and 270 day intervals after incorporating them in the soil and measured the rate of decomposition as indicated by carbon-dioxide evolution and nitrate accumulation. Plant tissue low in nitrogen yielded little ammonia and nitrogen, even though decay took place. He found that fat in alfalfa and corn stalks decomposed quickly while fat in straw resisted disintegration. More than 50 percent of the cold water soluble fractions (sugar amino acids, soluble protein, starches, organic acids, ash, etc.) had gone in 30 days in alfalfa tops and was nearly complete in 90 days. In sweet clover the decrease was not so rapid and at the end of 9 months was not as complete as was in alfalfa at the end of 90 days.

Wakeman(52) found that the removal of the alcohol and water soluble fractions had but little effect on the decomposition of barley straw but greatly reduced the decomposition of alfalfa meal. He found further from the study of rye at different stages of growth that there was a gradual decrease of the nitrogen, ash, and fat content also of the water soluble portion with an advance in age, and a gradual increase in the content of lignin, pentosans, and cellulose. He concluded that the rate of decomposition depends upon the amount of water soluble constituents,

nitrogen, and lignin content.

Whiting and Richmond (66a) reported that the first season's growth of biennial white sweet clover contained less nitrogen than the leaves and stems, though they nitrified more readily. He explained this on the basis of the higher water soluble nitrogen content.

THE ROLE OF NITROGEN

Shunk (55) found that the addition of nitrates speeded up the decomposition of cellulose, as evidenced by the evolution of carbon-dioxide. This increase was probably due to an increase in fungus activity. He is of the opinion that the decomposition of cellulose depends on the available nitrogenous content. The work of Martin (3) showed an increase in the number of molds from the addition of alfalfa in excess of that of sweet clover. Tenny and Waksman (61) report from their study of corn stalks, rye straw, oak leaves, and alfalfa plants that the rate of decomposition was influenced by their chemical composition. Plant materials with a nitrogen content between .2 percent and 1.7 percent their decomposition was marked by an increase in crude protein content, due to the synthesizing activities of the soil organisms. They further report that the addition of available inorganic nitrogen salts hastens the decomposition of celluloses and hemicelluloses. The rapidity of liberation of nitrogen in an available form depends upon the nitrogen content of the plant.

THE ROLE OF LIGNIN

Iwanoff and Zwetkoff (24) found that addition of lignin to protein being decomposed by pure cultures of bacteria and fungi checked

the decomposition considerably, due to the formation of compounds that are resistant to decomposition by bacteria. Waksman (63) found that among the various ingredients of such materials as straw the lignins are the most resistant to the action of soil fungi and bacteria. The accumulation of lignin in the soil accounted for a large part of the soil humus which was formed as a result of the decomposition of straws. The removal of the lignin from straw and alfalfa meal increased the rate and the amount of decomposition.

Tenny and Waksman (61) found from their studies of the decomposition of corn stalks, rye straw, oak leaves, and alfalfa plants under optimum temperature and moisture after 12 to 14 months the residue possessed all the conditions and properties of soil humus. This humus was made up of lignin or modified lignin complexes largely of plant origin: of proteins and other complex organic nitrogenous compounds largely of microbial origin: of a small amount of cellulose undergoing decomposition and of varying concentrations either in the process of decomposition or products of decomposition.

Boruff and Buswell (3) studied the anaerobic fermentation of lignin from cornstalks and reported that after 136 days pentosans had fermented 54 percent, cellulose 57 percent, and lignin 42 percent. After 600 days pentosans 71 percent, cellulose 85 percent, and lignin 54 percent. He concluded that isolated lignin fermented very slowly and incompletely under aerobic conditions.

Russell (47) gives the comparative percentages of carbon in plant constituents as follows: Sugars and starches 40 percent

Celluloses and hemicelluloses 45 percent

Fats, waxes, oils, 45 to 60 percent

Lignin 63 percent

Proteins 50 percent

Based on the carbon content the lignins would be the last to decompose.

THE EFFECT OF DRYING

Whiting and Schoonover (66) found that the drying of green manures retarded the rate of decomposition as evidenced by ammonification and nitrification, and carbon-dioxide evolution in both green house and laboratory experiments. Green clover produced nitrates very rapidly with a maximum transformation of 35.8 percent at the end of 43 days, while the dried yielded 15.7 percent for the same period. Hutchinson and Milligan (21a) reported that at the end of 8 weeks green manure from *Crotalaria juncea* had nitrified 68 percent, dried for 24 hours 45.3 percent, dried 48 hours 39.1 percent. Hill (19) reported that the drying of green manures retarded the decomposition as evidenced by the carbon-dioxide evolved during the first ten days. This retardation was thought to have been due to the soluble hemicelluloses and other polysaccharides having been changed to less soluble forms.

SOIL ACIDITY AND DECOMPOSITION

Thom and Smith (59) found that the total number of micro-organisms in a limed soil to be about 2 to 3 times that of an acid soil. Organic materials break down by aerobic action, which involves enormous numbers of bacteria fungi and other organisms, without correlated effects upon the micro-population of the underlying soil. Green manures plowed into the soil in good tillable condition are broken down principally by bacterial activity. Growing root systems surrounded by very narrow zones of microbic activity give acidity tests at least partially independent of adjacent soil, hence present biological conditions are determined by their own acidity, rather than that of the soil.

Jensen (26) submitted a group of organic materials with a carbon-nitrogen ratio from 1 to 85, to 1 to 10, to nitrification tests in acid and alkaline soil for six months. In acid soil only pea meal with a carbon-nitrogen ratio of 13.3 to 1 showed an increased in inorganic nitrogen over the control: in alkaline soil the limit above which no nitrification in six months was 26-1. Below this limit the rate of nitrification increased rapidly with decreasing carbon nitrogen ratio. All of these materials tended to increase the content of "alpha" humus but not to the same extent: more was produced in alkaline than in acid soil. The mycelium of Polyporus contains a fraction possessing the properties of humic acid, rich in nitrogen but devoid of methoxyl which persists in the soil. The carbon nitrogen ratio is a factor which exerts an influence on nitrification as profound as that of the soil reaction.

Aso and Yoshida (1) found that the decomposition of green manures in soils of ph of 5.30 and low in water soluble phosphorus was increased by applications of superphosphate or potassium sulfate. The affect of the former was the greater.

WEEDS AS FERTILIZERS

All plants during the process of their growth extract from the earth and air such elements of food as they may require for their subsistence, or if they fail to do so, die or fail to reach maturity. It is just as essential for weeds to be properly fed as it is for crop plants as far as plants themselves are concerned. They extract from the soil their due portion of those food ingredients necessary for proper growth and productiveness of paying crops. If these weeds are burned or removed from the soil the question naturally arises as to the how, the

when, and the what is the best method for returning these elements that have been removed from the soil by vegetation that is useless, except from the standpoint of prevention of erosion and the tying up of plant food elements as organic matter that might have been lost to the soil.

In the case of many of the well established grasses and legumes they are cut and fed to livestock and then returned to the soil as barn-yard manure, but in the case of the useless weeds that are unpalatable to livestock this has not been practiced.

Every plant, no matter of what nature, that is gathered and removed from the fields in which it grew, takes with it more or less of the food elements needed by the next plants to be grown thereon. In order that the natural fertility of the soil be maintained and that the soil fertility elements be preserved for crops yet to follow, it is essential that we return to the soil not only the principal nutrient losses, but that other factors affecting plant growth be properly maintained. Commercial fertilizers aim in general to return to the soil the three essential elements of Nitrogen, Phosphorus, and Potassium, but with the exception of the few organic fertilizers, they in no wise directly return the humus and organic acids produced by decaying organic matter.

Information concerning the chemical composition of plants and natural vegetation is very limited as compared with the total number of plants which have been studied, and the major portion of the investigations which have been conducted have been confined to weeds and grasses which grow in competition with cultivated crops.

Ince (23) determined the amount of nitrogen in 13 common weeds which occurred in the cultivated fields of North Dakota and found that 24 out of

27 weeds which were analyzed contained a larger amount of nitrogen and phosphorus than wheat, oats, barley, or flax. The average nitrogen content of these weeds was 2.53 percent and the phosphorus content was 0.29 percent on the dry matter basis.

Snyder (57) analyzed 15 different weeds for their nitrogen and found that on the average they contained 3.01 percent of this element. There was found more protein in the dry matter of these weeds than in either alfalfa or clover. Portulaca contained the largest amount which was 4.40 percent. Because of the large amount of mineral matter which they contain, he suggests the weeds are not delicate feeders, and when they are burned or removed from the land a large amount of the nitrogen and mineral matter is lost.

Pickell (40) determined the protein content in 9 Florida weeds and found that most of the plants were relatively low in nitrogen as compared with the results of the two previous investigators, although Portulaca oleariacea contained 4.05 percent nitrogen, which is similar to the results secured by Snyder. .

Campbell (5) studied the nitrogen content in the tops of 11 winter annuals which were collected in the fall and again in the spring. He found that the spring growth contained on the average 3.53 percent nitrogen as compared to 2.63 percent which occurred in the leaves and stems which grew in the fall. A comparison of the nitrogen content of nine annual plants at different stages of growth indicated that a rapid decrease in the nitrogen content occurs between the blooming period and maturity. Six weeds growing in rye contained about the same amount of nitrogen as the rye plants when harvested at different periods during

the growing season. The roots of certain weeds contained smaller amounts of nitrogen than the leaves and the stems were usually higher in plant food elements than the roots.

Millsbaugh (33) analyzed 49 different plants for total nitrogen, phosphorus, and potash and his results indicate that the composition of weeds and grasses are very similar to that of the cultivated crops although a marked variation occurs in certain species.

Cooper (9) found that the nitrogen phosphorus and calcium content of *Poa pratense*, *Danthonia spicata*, and *Andropogon virginicus* were all low when these plants were in full bloom. Cruickshank (10) and others have shown that the nitrogen and phosphorus content of grasses decrease as the season advances and that young grass is higher in nitrogen.

Stutzer and Seidler (58) analyzed seven important weeds for nitrogen, phosphorus, potassium, sodium, and calcium. These weeds contained larger amounts of plant food than ordinary field crops, and in some instances plants which contained large amounts of calcium were low in potassium.

Kling (2) made a survey of the German literature on the chemical composition of weeds and reported the analysis of 6 common weeds, all of which were very high in plant food. The average nitrogen content was 3.64 percent, phosphorus 0.52 percent, calcium 2.35 percent, and potassium 6.20 percent. These analyses were much higher than those secured by Stutzer and Seidler on the same kind of plants.

Harper (16) and others made a study of the nitrogen, phosphorus and calcium content of common weeds and native grasses growing in Oklahoma. Two hundred and twenty nine composite samples were collected and analyzed. This collection included 50 different species of plants. Weeds were higher in nitrogen, phosphorus and calcium than the grasses, and plants growing

on good soil were higher in nitrogen than similar plants growing on poor soil. Young plants were higher in mineral nutrients and nitrogen than older plants. The stems were lower in nitrogen phosphorus and calcium than the leaves. Plants growing on the same soil were found to be different in mineral analysis. This was explained on the difference in the feeding power of plants.

Harper and Daniel (17) made an analysis of the vegetation in ponds and lakes near Stillwater, Oklahoma. for nitrogen, phosphorus, and calcium. The nitrogen content was higher than that which is found in weeds and grasses. This was also true for the phosphorus content. All samples of *Elodea canadensis* were high in calcium while those of *Typha latifolia* were very low.

Greenhill and Page (14) analyzed pasture grasses representing from five weeks growth under intensive systems of grass land management and found that the lime content varied during the season, but there were no indications of a seasonal trend. The average seasonal content was practically the same in all cases. The phosphoric acid content showed a definite seasonal trend, decreasing during drought or the early summer flush period and increasing again after the flush period. There was a significant correlation between the phosphoric acid and the nitrogen content. Variations in the total ash and silica contents were less definite during the season. Good quality untreated samples contained less total ash and phosphorus than the intensive pastures, but similar amounts of lime and silica.

Mitchell (33a) found that phosphorus content of plants was increased by fertilization. Applications of lime aided in the assimilation of phosphorus by legume plants. Three hundred pounds of ammonium sulfate

per acre increased the nitrogen content of rye and clover from 28 to 40 percent. Copper, zinc, and manganese showed no effects.

Maschaupt (29) studied the effect of the different kinds of soil and fertilizer, sodium nitrate, potassium nitrate, and ammonium sulfate on the content of nitrogen and ash in barley, rye, beets, oats, and potatoes. The influence of the kind of soil was greater with straw, beet and potato leaves than with grain or roots and was greatest in silica content of straw. The average silica content of straw from clay soil was five times that of straw from heather soils. The kind of fertilizer had no marked influence upon the nitrogen content and ash of crops on these soils. The soils were heather, moor, swamp, loam, and clay.

Hepner (20) studied the chemical composition of 63 samples of Wyoming grasses, rushes and sedges from different altitudes ranging from 6,900 feet to 10,000 feet. The average nitrogen content of all crops grown below 8,000 feet was 1.385 percent. A complete analysis of 25 soils failed to reveal any correlation between the nitrogen content of the plants and any of the soil constituents. He thinks that other factors play a much more important role than does the soil in causing increased storage of nitrogen by high altitude plants. Hoagland (20a) is of the opinion that the intake of mineral nutrients may be influenced by several factors such as the ratio of anions to anions, cations to cations, and anions to cations: the power of the soil to supply mineral elements and the conditions surrounding the top together with conditions favorable to the expansion of the root system.

Cruickshank (10) analyzed samples of some different species of plants collected from the same field and found that there was a natural difference in the mineral composition of different species, the most

outstanding of which was between the legumes and the grasses. Legumes tend to be richer than the grasses in minerals, especially in calcium content. The grasses are relatively richer in phosphorus than the legumes. A ratio of calcium to phosphorus was found to be 1 to 0.3 in alfalfa, 1 to 3.8 in timothy, 1 to 0.45 in clover, as compared to 1 to 1.6 in rye grass.

Orr (39) reported four main conditions under which the mineral content of the plant may vary, namely: the species of the plant: the stage of growth: climatic conditions: and the nature of the soil. A rich soil favors the spread of those species which are naturally rich in minerals and also tends to enrich the individual plant whatever its species.

Iljin (22) studies the composition of plants under different conditions. He reported that the amount of one or the other elements in plants depends on the composition of the soil or upon the ability of the plant to accumulate some certain preferred ion. The influence of the soil on the accumulation of potassium is very weak. With most plants the more calcium present in the soil the more they take up, especially is lime taken up on limestone soils. The drier the climate and the stronger the transpiration of the plants the more calcium is found in species living on limestone soils. Many species regulate their calcium content by accumulating a constant amount on many different types of soils. On one and the same soil the calcium intake of different plants may be different.

SUMMARY FROM LITERATURE REVIEW

Material of a high cellulose content or a wide carbon nitrogen ratio when added to the soil are attacked mostly by soil fungi with little or no mineral nitrogen liberated, and a depression of soil nitrates.

Pentosans are relatively easily decomposed, but their resistance to decomposition varies with the source.

Plant materials that have a high water soluble nitrogen fraction are retarded in their rate of decomposition by the removal of this fraction, indicating that decomposition may be controlled by the amount of water soluble nitrogen present. If the total nitrogen content is less than 1.7 percent, decay will be marked by a reduction in the nitrate content of the soil.

Lignin is the greatest contributor to soil humus of the various plant products. It is of a higher carbon content and is attacked but slightly by soil bacteria and fungi.

Drying of plant tissue or green manures retards decomposition probably due to a retarding effect on the entrance of soil organisms and a change in the solubility of the products.

Carbon-dioxide evolution indicate that an alkaline soil provides a larger number of soil organisms than an acid soil, and decomposition is more rapid. Biological activities are not wholly independent of soil reaction.

The mineral content of plants may vary according to the species of plant: stage of growth: climatic condition: and the nature of the soil. Weeds in general are higher than the grasses in nitrogen, phosphorus, calcium, and potassium.

METHOD

The plant parts used were finely ground and incorporated into sand and into soil in one gallon stone jars. The experiment was carried on over a period of 8 weeks and in a few instances to 9 weeks. During this period an analysis was made to determine the rate of decomposition as indicated by the amount of ammonia and nitrate nitrogen formed.

The soil used was a Merrimac sandy loam from the experiment station farm. It was allowed to dry out considerably so as to be easily screened and pulverized. In the case of the sand, glass sand was secured from the Berkshire Sand Company and treated similar to the soil. In the lime treatments the equivalent of 2 tons per acre was used.

A sufficient amount of soil was weighed to provide 8 pounds for each pot used in the series. To it was added the required monocalcium phosphate and potassium sulfate which was constant throughout the investigation. After a thorough mixing 16 pounds was weighed and into it was put the ground plant tissue. The mixture was then divided equally into two pots.

Each pot contained 8 pounds of slightly moist soil with a total nitrogen content of 0.143 percent, which was 5.19 grams of nitrogen per pot. The carbon content of this soil was 1.63 percent which was 59.15 grams of carbon per pot. The total nitrogen content of the plant tissue was determined and equivalent quantities of nitrogen added from each source to make 0.41 gram. It was unfortunate that in this investigation equivalent quantities of carbon, lignin, cellulose, etc. could not be added, and at the same time have an equivalent quantity of nitrogen. This factor should be kept in mind in making deductions from this work.

All materials were collected in the fall or in their green stage and dried immediately. Oat straw, rye straw, and corn stover were secured from farmers north of the College. All others except cottenseed hulls, buckwheat hulls, sorghum and seaweed (*Ascophylum nodosum*) were secured locally, either supplied by the department or collected locally. Only the above ground parts were used.

PREPARATION OF MATERIALS

The materials were prepared by first passing them through an ensilage cutter, which cut them into lengths from a fraction of an inch to 1 inch or longer. They were then dried in a steam heated air drier at to to 70°C. After they were thoroughly dried they were ground in a Hanse Brothers and White burr mill which ground them into a coarse meal. They were then put in a Wiley mill and chopped until fine enough to pass a 1 millimeter sieve. This material was then mixed thoroughly and a composite sample taken for making determinations. The sample was placed in a Little Trojan Ball mill and pounded for a day or overnight which ground them to a very fine powder, except in the case of the monocotyledonous group which were very hard to powder. The material as taken from the Wiley mill was used for incorporation in the soil.

The organic nitrogenous materials were incorporated in the soil, and the soil placed in 1 gallon stone jars and moistened to about 20 to 25 percent moisture on the dry basis and allowed to set for one week.

DETERMINATIONS

Total nitrogen determinations were made by the method of Ranker (42), for making total nitrogen determinations in plant tissue.

Carbon was determined by combustion in a stream of oxygen. The carbon-dioxide was absorbed by ascarite and weighed.

Pentosans were determined by the official methods of The Association of Official Agricultural Chemists (39a).

Lignins were determined by the method of Mehta (32) (alkali method) at 30 pounds pressure and the results multiplied by 3.7⁴³ as 26.72 percent of the lignocellulose was resolved at this pressure.

Nitrates were determined colorimetrically by the use of phenoldisulfonic acid in an alkaline solution (described in Bureau of Soils Bulletin #31, 1906) (50).

Ammonia was determined by the method of Harper (15).

RESULTS

The different plant materials are listed on page 27. and a partial chemical analysis in Table I shows the nitrogen, carbon, pentose, and liquid content. The results are averages of duplicate determinations. In cases where the duplicate did not check favorably a third determination was made and the two which most nearly checked were used for averages.

The accumulation of ammonia and nitrate nitrogen in sand and in soil for treatments 1 to 12 inclusive both with and without lime are expressed as parts per million of nitrogen as listed in Tables 3, 5, and 7. Alfalfa treatment in sand and in soil was taken as control. The corresponding moistures for the ammonia and nitrate determinations are listed in Tables 4, 6 and 8.

Barley growth produced from similarly treated pots are listed in Table 10, in dry weights and as percentage of control. The control was an equivalent quantity of nitrogen from nitrate of soda.

The accelerating or retarding effect of the soil was not taken into account, as this factor was constant throughout the investigation for all treatments.

LIST OF PLANT MATERIALS TESTED, ARRANGED IN THE
ORDER IN WHICH THE INVESTIGATION WAS MADE

1. Sudan grass - *Sorghum sorghum*, var *sudanense* P.
2. Millet German - *Setaria italica* L.
3. Oat straw - *Avena sativa* L.
4. Rye straw - *Secale cereale* L.
5. Timothy - *Phleum pratense* L.
6. Corn stover - *Zea maize* L.
7. Red Clover - *Trifolium pratense* L.
8. Alfalfa - *Medicago sativa* L.
9. Buckwheat hulls - *Fagopyrum esculentum* Moench.
10. Cottonseed hulls - *Gossipium* var. L.
11. Andropogon sorghum, var. L.
12. Tobacco (stems and leaves) *Nicotiana tabacum* L.
13. Fungi-*Polyporus betulinus* Micheli.
14. Seaweed-*Ascorphyllum nodosum*
15. Club moss - *Lucopodium complanatum* L.
16. Horsetails - *Equisetum arvense* L.
17. Fern - *Osmundae cinnamomea* L.
18. Buttercup-*Ranunculus acris* L.
19. Buckwheat - *Fegonyrum esculentum* Moench.
20. Knotweed - *Polygonum aviculare* L.
21. Smartweed - *Polygonum persicaria* L.
22. Pepper - *Capsicum annum* R.
23. Potato top - *Solanum tuberosum* L.
24. Tomato top - *lucopersicum vulgare* Mill.
25. Artichoke - *Helianthus tuberosus* L.
26. Bidens - *Bidens frondosa* L.
27. Ragweed - *Ambrosia artemesifolia* L.
28. Xanthium - *Xanthium canadense* Mill.
29. Pursley -*Portulaca oleariaceae* L.
30. Amaranth - *Amaranthus retroflexus* L.
31. Cabbage - *Brassica oleariaceae* L.
32. Onion - *Allium cepa* L.
33. Orchard grass - *Dactylis glomerata* L.
34. Lambs quarter - *Chenopodium album* L.
35. Kentucky blue grass - *Poa pratense* L.
36. Turnip top - *Brassica compestris* L.
37. Canadian blue grass - *Poa compressa* L.
38. Sweet clover - *Melilotus alba* D.
39. Sedge - *Carex lupulinus* Muhl.
40. Sedge - *Juncus effusus* L.
41. Moss (Hairs Cap) - *Polytrichum commune* L.
42. Sedge - *Carex stricta* Lam.
43. Witch grass - *Agropyron repens* L (Beauv)
44. Gladiolus var.
45. Red Top - *Agrostis alba* L.

TABLE I - Results of partial chemical analyses of materials.
Arranged in the order of decreasing nitrogen content,
expressed in percentage of dry wt.

Materials	Nitrogen	Carbon	N-C-R	Pentosan	Lignic acid
Pursley	4.48	35.98	1-8	8.90	9.36
Amaranth	3.62	38.01	1-11	9.88	6.66
Cabbage	3.58	41.07	1-12	5.10	4.08
Tomato	3.33	40.89	1-12	7.45	11.34
Tobacco	2.99	38.17	1-13	22.70	4.42
Onion	2.63	41.64	1-15	9.74	4.38
Pepper	2.56	38.25	1-15	8.32	4.23
Bidens	2.55	45.22	1-18	13.30	11.40
Orchard grass	2.54	47.17	1-19	12.14	7.67
Alfalfa	2.43	47.84	1-20	16.93	10.89
Lambs quarter	2.43	40.05	1-17	8.62	4.45
Kentucky Blue Grass	2.41	46.16	1-19	19.41	1.76
Turnip top	2.32	44.66	1-19	10.98	5.74
Canadian Blue Grass	2.29	45.84	1-20	13.70	14.15
Knot weed	2.21	40.13	1-18	8.12	10.18
Buttercup	2.17	50.64	1-23	12.51	13.74
Ragweed	2.15	45.16	1-21	14.82	2.06
Xanthium	2.12	44.28	1-21	9.17	6.44
Smartweed	1.94	47.22	1-24	9.27	16.58
Seaweed	1.92	35.88	1-19	10.17	9.55
Red clover	1.76	46.79	1-27	15.53	13.28
Sweet clover	1.67	47.55	1-29	10.59	5.61
Carex lupulinus	1.62	50.69	1-31	23.32	11.34
Millet German	1.56	46.19	1-30	26.45	14.84
Juncus effusus	1.52	50.23	1-33	25.54	30.24
Buckwheat	1.50	44.08	1-29	9.76	9.47
Potato top	1.48	35.75	1-25	8.31	10.22
Moss hairs cap	1.42	43.47	1-27	6.89	16.47
Carex stricta	1.41	50.18	1-35	25.74	21.26
Witch grass	1.36	50.46	1-36	16.96	15.08
Sudan grass	1.36	46.63	1-34	22.91	13.96
Gladiolus	1.21	48.02	1-40	19.73	14.41
Horsetails	1.19	32.89	1-28	6.89	6.40
Fern	1.13	48.71	1-43	7.56	12.76
Fungi	1.09	47.48	1-44		19.24
Oat straw	1.03	49.71	1-48	26.90	18.53
Corn stover	1.02	45.94	1-45	27.17	9.84
Timothy	0.86	49.90	1-58	18.70	13.96
Red top	0.86	47.68	1-55	21.32	5.20
Club moss	0.83	46.32	1-56	8.82	4.19
Artichoke	0.67	45.87	1-68	11.85	3.97
Sorghum	0.62	46.23	1-75	22.06	13.92
Cottonseed hulls	0.57	47.18	1-83	31.63	17.26
Rye straw	0.53	47.20	1-89	27.36	15.16
Buckwheat hulls	0.52	49.76	1-96	24.33	20.62

TABLE II - Grams of materials added to maintain 41gm. nitrogen arranged in the order of increasing quantities. The calculated additional amounts of carbon in grams in the parallel column.

Organic source	Grams of material added per 8 # soil	Grams of carbon added.
Pursley	10.7	4.0
Amaranth	12.1	4.6
Cabbage	13.2	5.4
Tomato	13.7	5.6
Tobacco	14.9	5.7
Pepper	17.6	6.8
Bidens	17.7	8.0
Lambs quarter	17.8	7.1
Alfalfa	18.2	8.7
Onion	18.5	7.7
Orchard grass	18.6	8.8
Kentucky blue grass	19.0	8.7
Canadian blue grass	19.8	9.1
Ragweed	20.9	9.4
Xanthium	21.0	9.3
Turnip top	21.8	9.7
Buttercup	23.4	11.9
Seaweed	23.5	8.4
Red clover	25.2	11.8
Sweet cover	27.2	12.9
Millet	28.4	13.1
Carex Lupulinus	28.5	14.5
Buckwheat	30.2	13.3
Juncus effusus	30.2	15.2
Potato top	30.3	10.8
Moss hairs cap	31.1	13.5
Sudan grass	32.0	14.9
Carex stricta	32.1	16.1
Witch grass	32.9	16.6
Horsetails	36.7	12.0
Gladiolus	38.5	18.5
Knotweed	40.8	16.4
Fungi	41.8	19.8
Corn stover	42.6	19.6
Fern	42.6	20.7
Oat straw	45.5	22.6
Smartweed	48.1	22.7
Timothy	49.3	24.6
Red top	53.5	25.5
Club moss	54.2	25.1
Artichoke	66.9	30.7
Sorghum	73.3	33.9
Cottonseed hulls	80.9	38.2
Rye straw	81.5	38.5
Buckwheat hulls	84.1	41.8
Soil industry of carbon and nitrogen present	5.19	59.15
Added in the organic	.41	

TABLE III - Parts per million of ammonia and nitrate nitrogen produced in soil from the addition of .41 of nitrogen from the plants listed.

Time in days	7		14		21		28	
p.p.m.	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃
1. Sudan grass		13	1	15	1	30	1	22
2. German millet		25	2	28	1	64	1	48
3. Oat straw		-	1	-	-	T	1	T
4. Rye straw		-	-	-	2	-	-	-
5. Timothy		T	1	-	-	-	-	-
6. Corn stover		-	2	-	-	-	-	T
7. Red Clover		33	1	25	2	51	2	82
8. Alfalfa		61	1	81	-	118	-	115
9. Buckwheat hulls		-	-	-	4	-	-	-
10. Cottonseed hulls		-	2	T	1	-	-	-
11. Sorghum		-	-	-	1	-	-	-
12. Tobacco stems & leaves		77	1	97	3	236	-	137
13. Fungi			5	-	4	-	8	-
14. Seaweed			4	58	4	56	4	57
15. Club moss			2	-	3	-	5	-
16. Horsetails			3	-	6	13	5	21
17. Fern			2	-	2	-	4	-
18. Buttercup			3	-	2	9	4	14
19. Buckwheat			2	-	2	-	3	-
20. Knotweed			3	77	3	58	3	51
21. Smartweed			4	-	3	11	2	20
22. Pepper			3	23	6	84	4	47
23. Potato tops			3	52	2	61	2	70
24. Tomato tops			1	48	1	75	3	67
25. Artichoke			1	-	-	-	2	T
26. Bidens			2	27	1	34	1	45
27. Ragweed			2	28	1	50	1	43
28. Xanthium			-	53	3	37	3	60
29. Pursley	5	78	6	95	1	101	3	82
30. Amaranth	6	43	4	85	2	88	2	85
31. Cabbage	-	26	3	80	2	78	3	76
32. Onion	4	20	3	37	3	46	3	47
33. Orchard grass	2	13	5	9	2	12	2	20
34. Lambs quarter	5	14	4	94	2	75	6	100
35. Kentucky blue grass	3	34	3	33	5	37	5	45
36. Turnip top	4	14	4	24	1	22	5	28
37. Canadian blue grass	1	T	5	27	4	29	3	40
38. Sweet clover	7	T	5	23	4	34	2	45
39. Carex lupulinus	-	T	3	-	2	-	3	-
40. Juncus effusus	-	T	5	-	3	-	4	-
41. Moss (Hairs cap)	2	T	3	32	5	31	-	38
42. Carex stricta	-	-	3	-	1	-	-	-
43. Witch grass	2	-	3	-	-	-	2	-
44. Gladioli	-	-	3	-	1	-	3	-
45. Red top	-	-	1	-	-	-	2	-

TABLE III (Cont.) - Parts per million of ammonia and nitrate nitrogen produced in soil from the addition of .41 of nitrogen from the plants listed.

Time in days	35		42		49		56		63		Av. p.p.m		% of Con- trol
ppm.	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	
1.	6	37	1	54	-	37			2	34	36		39
2.	2	42	1	72	1	69			1	46	50		55
3.	4	8	1	14	-	9			1	23	9		10
4.	3	5	-	-	2	-			1	-	2		2
5.	3	-	-	-	2	6			-	13	4		5
6.	2	10	3	26	-	2			2	32	13		14
7.	3	16	1	92	1	62			1	60	48		52
8.	2	75	-	141	-	78			1	58	91		100
9.	2	-	-	T	-	-			1	-	2		2
10.	-	-	-	T	1	-			-	-	1		1
11.	2	-	-	-	2	-			2	-	1		1
12.	7	117	-	208	1	117			2	85	136		149
13.	4	T	-	-	5	-	11	-			6		7
14.	1	64	3	86	1	87	8	89			74		81
15.	1	T	2	9	-	5	8	10			7		7
16.	2	23	1	46	-	45	10	41			31		34
17.	4	8	1	15	3	15	8	13			10		11
18.	7	31	1	30	2	46	7	36			27		30
19.	3	13	1	21	1	22	6	31			15		17
20.	3	45	1	73	2	66	5	57			64		70
21.	2	36	1	34	4	45	8	53			32		35
22.	2	47	1	49	1	75	9	79			61		67
23.	2	84	3	124	2	141	7	129			97		107
24.	1	83	1	93	3	96	6	99			82		91
25.	2	-	1	-	5	-	9	-			3		3
26.	1	41	-	56	2	84	7	99			57		63
27.	2	59	1	55	1	64	8	55			53		58
28.	3	53	1	85	1	102	8	100			73		79
29.	3	87	1	78	5	133	-	106			98		107
30.	3	88	2	94	-	129	-	93			91		99
31.	4	79	-	80	1	118	-	109			86		94
32.	2	49	-	49	1	85	-	71			52		57
33.	3	30	-	30	2	39	3	59			31		33
34.	3	92	2	89	1	133	2	108			91		100
35.	2	59	1	69	-	46	2	80			53		58
36.	3	38	3	37	-	54	3	68			38		42
37.	1	60	1	40	1	74	-	66			44		48
38.	1	45	2	57	-	101	3	84			51		56
39.	2	-	2	-	-	-	-	10			4		4
40.	-	-	2	-	1	-	1	-			2		2
41.	3	37	3	38	1	52	1	50			37		40
42.	1	-	2	-	-	-	-	-			1		1
43.	3	-	-	-	2	-	5	8			3		1
44.	3	-	4	-	1	-	5	-			3		3
45.	2	-	3	-	2	-	4	-			2		3

TABLE IV - Percentage moisture content of soil on which ammonia and nitrate nitrogen determinations were made, as indicated in Table III.

Days	7	14	21	28	35	42	49	56	63	Av.
1. Sudan grass	22	21	23	24	24	21	20		27	23
2. German millet	18	19	22	22	20	18	18		25	19
3. Oat straw	18	27	28	25	22	24	22		27	24
4. Rye straw	19	25	27	22	20	21	21		25	22
5. Timothy	22	20	24	23	21	22	22		24	22
6. Corn stover	25	27	29	25	24	23	22		25	24
7. Red clover	20	21	22	20	21	19	19		22	20
8. Alfalfa	25	23	25	22	21	20	19		22	22
9. Buckwheat hulls	17	21	24	25	23	21	20		23	22
10. Cottonseed hulls	20	22	24	22	20	22	20		23	21
11. Sorghum	31	33	32	33	33	28	27		25	29
12. Tobacco	19	24	24	22	23	22	28		21	22
13. Fungi		21	24	18	23	25	25	31		24
14. Seaweed		17	23	16	17	17	17	24		19
15. Club moss		26	31	24	27	30	22	34		29
16. Horsetails		25	30	23	24	27	24	28		26
17. Fern		23	30	21	22	21	20	21		22
18. Buttercup		20	26	19	24	27	24	24		23
19. Buckwheat		19	24	17	23	26	25	25		23
20. Knotweed		17	21	15	22	17	17	17		18
21. Smartweed		22	26	21	21	19	17	21		21
22. Pepper		21	24	17	18	17	16	21		19
23. Potato		22	29	21	23	22	22	30		24
24. Tomato		20	25	17	18	19	18	25		20
25. Artichoke		23	29	22	20	25	24	27		24
26. Bidens		20	24	17	20	21	17	18		19
27. Ragweed		17	22	15	17	17	16	17		17
28. Xanthium		20	24	17	20	21	19	19		20
29. Pursley	20	20	24	21	23	23	18	20		20
30. Amaranth	20	20	23	20	23	31	20	24		22
31. Cabbage	19	19	26	24	28	24	22	25		23
32. Onion	20	18	22	23	26	22	21	18		21
33. Orchard grass	20	21	27	23	27	23	21	21		23
34. Lambs quarter	21	23	29	25	28	25	22	20		24
35. Kentucky blue grass	23	24	30	28	26	25	23	21		25
36. Turnip top	19	20	26	28	26	25	25	22		24
37. Canadian blue grass	21	19	26	24	25	27	21	23		24
38. Sweet clover	21	22	27	24	27	27	20	23		24
39. Carex lupulinus	19	21	27	24	27	33	21	22		23
40. Juncus effusus	18	21	26	24	29	31	21	20		24
41. Moss (Hairs cap)	19	22	27	24	28	28	22	21		24
42. Carex stricta	19	22	29	24	28	24	22	22		24
43. Witch grass	18	21	26	25	29	23	21	20		23
44. Gladioli	21	24	29	27	27	23	26	24		25
45. Red top	20	21	26	24	27	26	22	28		23

TABLE V - Parts per million of ammonia and nitrate nitrogen produced in soil from the addition of .41 grams of nitrogen from the plants listed plus the equivalent of 2 tons of limestone per acre.

Days	7		14		21		28	
	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃
1. Sudan grass	2	-	4	-	5	5		
2. German millet	1	9	2	14	6	30		
3. Oat straw	2	T	2	-	6	T		
4. Rye straw	2	T	3	16	2	-		
5. Timothy	2	-	3	-	6	-		
6. Corn stover	2	-	1	-	3	-		
7. Red clover	3	-	4	-	5	18		
8. Alfalfa	2	54	3	97	4	46		
9. Buckwheat hulls	2	-	1	-	6	-		
10. Cottonseed hulls	1	-	5	-	7	-		
11. Sorghum	1	-	1	-	7	-		
12. Tobacco	1	52	1	80	7	81		
13. Fungi	4	-	6	-	6	-	6	-
14. Seaweed	4	T	25	23	4	40	-	61
15. Club moss	2	T	2	10	2	T	3	T
16. Horsetails	1	T	4	9	3	T	3	T
17. Fern	-	-	2	-	2	-	1	T
18. Buttercup	1	T	2	T	3	T	4	T
19. Buckwheat	-	-	3	-	3	-	3	-
20. Knotweed	1	10	1	16	4	34	2	48
21. Smartweed	-	-	4	-	1	-	2	-
22. Pepper	-	-	3	T	2	24	3	37
23. Potato tops	5	28	4	42	1	62	1	37
24. Tomato tops	3	28	1	52	-	63	1	82
25. Artichoke	1	-	1	-	3	-	-	-
26. Bidens	3	-	2	T	1	20	1	39
27. Ragweed	2	13	1	19	1	25	2	37
28. Xanthium	2	19	2	29	2	49	2	57

TABLE V (cont.) - Parts per million of ammonia and nitrate nitrogen produced in soil from the addition of .41 grams of nitrogen from the plants listed plus the equivalent of 2 tons of limestone per acre.

Days	35		42		49		56		63		ppm Av.	% of control
	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃		
1.	2	18			4	40			2	25	18	24
2.	2	44			3	43			2	65	37	50
3.	2	-			3	T			3	-	3	4
4.	-	-			3	T			2	-	6	8
5.	-	-			3	T			2	-	3	4
6.	-	-			3	6			3	13	10	14
7.	2	54			4	-			2	47	23	31
8.	1	81			3	75			3	73	74	100
9.	0	-			3	-			3	-	2	3
10.	1	-			1	-			2	-	3	4
11.	1	-			1	-			2	-	3	3
12.	1	100			2	75			2	123	87	118
13.	7	-	5	-	3	-	3	T			5	7
14.	-	49	5	78	1	87	4	120			61	83
15.	2	T	5	T	3	-	1	-			4	5
16.	1	T	4	T	5	19	3	22			9	12
17.	2	T	2	-	2	-	1	-			2	2
18.	2	T	3	23	2	30	2	40			14	19
19.	3	T	3	-	1	-	1	19			5	7
20.	3	39	3	46	1	61	2	57			41	55
21.	-	T	2	T	1	33	2	50			13	18
22.	1	31	2	52	1	56	1	81			37	50
23.	2	79	1	97	1	144	1	150			82	110
24.	1	85	1	96	2	131	1	118			87	113
25.	4	-	1	-	2	-	1	-			2	2
26.	2	28	2	45	1	48	2	52			31	42
27.	2	31	1	67	2	66	1	62			41	56
28.	1	45	1	78	1	55	-	59			50	68

TABLE VI - Percentage moisture content of soil plus lime on which ammonia and nitrate nitrogen determinations were made, as indicated in Table V.

Days	7	14	21	28	35	42	49	56	63	Av.
1. Sudan grass	34	23	25		18		19		16	22
2. Berman Millet	33	25	26		17		18		22	23
3. Oat straw	26	17	25		19		21		24	22
4. Rye straw	29	23	28		19		21		26	24
5. Timothy	26	24	27		19		17		24	22
6. Corn stover	33	28	32		21		19		30	27
7. Red clover	32	26	29		19		15		24	24
8. Alfalfa	25	20	24		23		16		17	20
9. Buckwheat hulls	29	23	25		18		16		19	21
10. Cottonseed hulls	21	20	22		18		19		21	20
11. Sorghum	31	30	33		24		23		25	27
12. Tobacco	29	19	25		18		17		17	20
13. Fungi	23	25	21	31	31	29	28	29		28
14. Seaweed	26	17	20	23	31	26	24	25		25
15. Club moss	23	26	22	28	34	29	26	26		27
16. Horsetails	27	28	14	23	26	23	24	26		24
17. Fern	23	23	18	29	36	29	28	32		27
18. Buttercup	24	22	17	25	33	26	21	24		24
19. Buckwheat	24	25	19	27	33	28	27	28		26
20. Knotweed	26	26	19	25	24	17	22	22		23
21. Smartweed	27	30	22	32	31	24	29	27		28
22. Pepper top	22	22	18	27	30	22	19	22		23
23. Potato top	27	24	19	25	28	24	20	31		25
24. Tomato top	25	24	18	27	29	22	17	21		23
25. Artichoke	22	27	23	37	41	33	25	27		29
26. Bidens	23	25	18	27	23	19	17	18		21
27. Ragweed	25	24	17	29	25	20	22	26		24
28. Xanthium	22	23	17	25	25	27	18	19		22

TABLE VII - Ammonia and nitrate nitrogen produced in sand with and without lime from the addition of .41 grams of nitrogen from the plants listed.

Sand										
Days	7		14		21		28		35	
	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃
1. Sudan grass	-		3	-	1	-	2	-	4	T
2. German Millet	5		5	-	4	-	4	T	8	-
3. Oat straw	-		1	-	1	-	-	-	3	-
4. Rye straw	-		-	9	1	-	-	-	3	-
5. Timothy	5		-	6	1	-	-	-	4	-
6. Corn stover	-		2	-	1	-	-	-	4	T
7. Red clover	18		1	-	1	-	-	-	6	-
8. Alfalfa	11		15	-	28	T	1	T	29	T
9. Buckwheat hulls	-		-	28	T	1	T	-	3	-
10. Cottonseed hulls	-		2	-	1	-	-	-	3	-
11. Sorghum	-		2	-	1	-	1	-	6	-
12. Tobacco	21		15	15	21	24	11	14	22	45

Sand-Lime Treatment

Days	19		35		49	
	NH ₃	NO ₃	NH ₃	NO ₃	NH ₃	NO ₃
1. Sudan grass	6	-	4	-	2	-
2. German Millet	1	-	5	-	5	-
3. Oat straw	3	-	4	-	3	-
4. Rye straw	2	-	0	-	2	-
5. Timothy	1	-	1	-	2	-
6. Corn stover	2	-	-	-	2	-
7. Red clover	2	-	2	-	3	-
8. Alfalfa	6	-	8	-	4	-
9. Buckwheat hulls	1	-	1	-	2	-
10. Cottonseed hulls	1	-	0	-	2	-
11. Sorghum	2	-	-	-	1	-
12. Tobacco	3	-	-	-	3	-

TABLE VII (Cont.) - Ammonia and nitrate nitrogen produced in sand with and without lime from the addition of .41 grams of nitrogen from the plants listed.

Sand						Av.	% of Control	
Days	42		49		63			
	<u>NH₃</u>	<u>NO₃</u>	<u>NH₃</u>	<u>NO₃</u>	<u>NH₃</u>	<u>NO₃</u>		
1.	4	-	6	-	5	-	4	16
2.	8	-	6	-	7	-	6	25
3.	2	-	-	-	1	-	2	7
4.	1	-	-	-	2	-	3	14
5.	1	-	-	-	1	-	3	13
6.	-	-	1	-	1	-	1	6
7.	8	-	2	-	9	-	7	29
8.	29	6	23	-	24	18	23	100
9.	-	-	1	-	2	-	1	6
10.	-	-	-	-	-	-	2	7
11.	9	-	2	-	2	-	3	14
12.	9	31	12	28	5	30	38	166

Sand-Lime Treatment

Days	63			
1.	2	-	4	74
2.	3	-	4	77
3.	1	-	3	58
4.	1	-	1	29
5.	2	-	1	31
6.	-	-	1	22
7.	2	-	2	52
8.	1	-	5	100
9.	0	-	1	27
10.	1	-	1	22
11.	2	-	1	23
12.	1	-	2	37

TABLE VIII - Percentage moisture content of sand with and without lime on which ammonia and nitrate nitrogen determinations were made in Table VII.

	Sand										
	Days	7	14	21	28	35	42	49	56	63	Av.
1. Sudan grass		5	10	9	9	10	8	7		11	9
2. German millet		5	9	11	9	7	5	7		11	8
3. Oat straw		6	11	11	10	9	7	9		14	10
4. Rye straw		8	11	16	11	12	7	11		15	11
5. Timothy		8	8	12	11	9	7	8		10	10
6. Corn stover		8	10	10	10	10	5	10		12	10
7. Red clover		9	9	11	11	8	6	8		9	10
8. Alfalfa		9	8	9	9	7	5	8		10	8
9. Buckwheat hulls		7	7	13	8	8	5	10		11	9
10. Cottonseed hulls		7	8	13	9	9	8	10		11	10
11. Sorghum		7	14	12	18	16	12	15		22	15
12. Tobacco		5	10	9	11	8	5	6		10	8

Sand and Lime											
1. Sudan grass			8		4		8			12	8
2. German millet			6		5		6			9	7
3. Oat straw			8		7		8			12	9
4. Rye straw			10		7		9			18	11
5. Timothy			8		7		9			15	10
6. Corn stover			7		7		7			17	10
7. Red clover			6		5		5			7	6
8. Alfalfa			7		5		5			7	6
9. Buckwheat hulls			9		6		6			11	8
10. Cottonseed hulls			7		8		13			12	10
11. Sorghum			10		11		11			14	12
12. Tobacco			5		4		4			10	6

TABLE IX - A classification based on average p.p.m. of ammonia and nitrate nitrogen produced per week, also comparative amounts of ammonia and nitrate calculated in terms of p.p.m. using the amount of these forms of nitrogen evolved from control as 100. Included are groups with lime and without lime.

Soil	Av.		%		Soil and Lime		%
	p.p.m. NH ₃	NO ₃			p.p.m. NH ₃	NO ₃	
1. Tobacco	136		149	✓ 1. Tobacco	87		118
2. Pursley	98		107	2. Tomato top	83		113
3. Potato top	97		107	3. Potato top	82		110
4. Alfalfa	91		100	4. Alfalfa	74		100
5. Lambs quarter	91		100	5. Seaweed	61		83
6. Amaranth	91		100	6. Xanthium	50		68
7. Cabbage	86		94	7. Ragweed	41		56
8. Tomato top	82		91	8. Knotweed	41		55
9. Seaweed	74		81	9. Pepper	37		50
10. Xanthium	73		79	10. German millet	37		50
11. Knotweed	64		70	11. Bidens	31		42
12. Pepper	61		67	12. Red clover	23		31
13. Bidens	57		62	13. Sudan grass	18		24.
14. Kentucky blue grass				14. Buttercup	14		19
	53		58	15. Smartweed	13		18.
✓ 15. Ragweed	53		58	✓ 16. Corn stover	10		14
16. Onion	52		57	17. Horsetails	9		12
17. Sweet clover	51		56	18. Rye straw	6		8
18. German millet	50		55	19. Buckwheat	5		7
19. Red clover	48		52	20. Fungi	5		7
20. Canada blue	44		48	21. Club moss	4		5
21. Turnip top	38		42	✓ 22. Timothy	3		4
22. Moss hairs cap	37		40	23. Oat straw	3		4
23. Sudan grass	36		39	24. Cottonseed			
24. Smartweed	32		35	hulls	3		4
25. Horsetails	31		34	25. Sorghum	3		3
26. Orchard grass	30		33	26. Buckwheat hulls	2		3
27. Buttercup	27		30	27. Fern	2		2
28. Buckwheat	15		17	28. Artichoke	2		2
29. Corn stover	13		14				
30. Fern	10		11				
31. Oat straw	9		10				
32. Club moss	7		7				
33. Fungi	6		7				
✓ 34. Timothy	4		5				
35. Carex stricta	4		4				
36. Fitch grass	3		4				
37. Artichoke	3		3				
38. Gladiolus	3		3				
✓ 39. Red top	2		2				
40. Juncus effusus	2		2				
41. Rye straw	2		2				
42. Buckwheat hulls	2		2				
43. Carex stricta	1		1				
44. Sorghum	1		1				
45. Cottonseed hulls	1		1				

TABLE IX -(Cont.) A classification based on average p.p.m. of ammonia and nitrate nitrogen produced per week, also comparative amounts of ammonia and nitrate calculated in terms of p.p.m. using the amount of these forms of nitrogen evolved from control as 100. Included are groups with lime and without lime.

Sand			Sand and Lime		
	Av. p.p.m. NH ₃ NO ₃	%		Av. p.p.m. NH ₃ NO ₃	%
1. Tobacco	37.86	166.05	1. Alfalfa	4.56	100.00
2. Alfalfa	22.80	100.00	2. German millet	3.49	76.54
3. Red clover	6.50	28.51	3. Sudan grass	3.37	73.90
4. German millet	5.76	25.26	4. Oat straw	2.66	58.33
5. Sudan grass	3.56	15.61	5. Red clover	2.37	51.97
6. Rye straw	3.22	14.12	6. Tobacco	1.68	36.84
7. Sorghum	3.08	13.51	7. Timothy	1.39	30.48
8. Timothy	2.99	13.11	8. Rye straw	1.30	28.51
9. Cottonseed hulls	1.54	6.75	9. Buckwheat hulls	1.21	26.54
10. Oat straw	1.51	6.62	10. Sorghum	1.11	24.34
11. Buckwheat hulls	1.50	6.01	11. Cottonseed hulls	1.01	22.15
12. Corn stover	1.33	5.83	12. Corn stover	1.00	21.93
Av.	7.64	33.45		2.10	45.96

TABLE X - Dry weight in grams of barley plants grown in soil and in sand with and without lime to which had been added quantities of plant tissue in proportions to furnish equal quantities of nitrogen.

Soil			Soil and Lime		
	Av. dry wt. in g	% of control		Av. dry wt. in g	% of control
1. Sudan grass	2.56	16.46	1. Sudan grass	4.82	37.00
2. German millet	4.69	30.19	2. German millet	10.21	78.20
3. Oat straw	1.51	9.74	3. Oat straw	2.47	18.90
4. Rye straw	1.44	9.28	4. Rye straw	1.43	10.95
5. Timothy	2.13	13.69	5. Timothy	1.36	10.42
6. Corn stover	1.36	8.73	6. Corn stover	1.82	12.94
7. Red clover	3.38	21.11	7. Red clover	4.32	33.10
8. Alfalfa	9.01	58.08	8. Alfalfa	11.39	83.79
9. Buckwheat hulls	1.48	9.53	9. Buckwheat hulls	1.96	15.00
10. Cottonseed hulls	1.93	12.41	10. Cottonseed hulls	1.55	11.87
11. Sorghum	1.30	8.34	11. Sorghum	1.17	9.00
12. Tobacco	12.37	79.90	12. Tobacco	14.60	107.62
13. Fungi	0.62	9.00	13. Fungi	0.75	20.10
14. Seaweed	5.99	87.80	14. Seaweed	4.61	123.60
15. Club moss	1.73	24.8	15. Club moss	1.06	28.40
16. Horsetails	3.03	44.1	16. Horsetails	1.22	32.70
17. Fern	1.37	19.9	17. Fern	0.69	18.50
18. Buttercup	3.05	44.3	18. Buttercup	2.12	56.80
19. Buckwheat	1.52	22.0	19. Buckwheat	0.72	19.30
20. Knotweed	5.69	82.0	20. Fungi	3.15	84.50
21. Smartweed	2.86	41.5	21. Smartweed	2.17	58.20
22. Pepper	5.02	73.0	22. Pepper	2.70	72.40
23. Potato top	6.13	88.9	23. Potato top	5.80	155.50
24. Tomato top	6.45	93.6	24. Tomato top	2.20	59.00
25. Artichoke	0.76	11.0	25. Artichoke	0.40	10.70
26. Bidens	4.85	70.4	26. Bidens	2.51	67.30
27. Ragweed	5.31	77.0	27. Ragweed	2.62	95.70
28. Xanthium	5.77	83.7	28. Xanthium	3.57	
29. Pursley	8.77	57.55	Sand		
30. Amaranth	9.38	61.55	All died.		
31. Cabbage	9.28	60.90			
32. Onion	7.61	49.93			
33. Orchard grass	6.10	40.03			
34. Lambs quarter	5.26	34.51	Sand and Lime		
35. Kentucky Blue grass	7.11	46.55	1. Sudan grass	1.26	64.30
36. Turnip top	6.68	43.83	2. German millet	1.53	78.40
37. Canadian blue grass	8.58	54.99	3. Oat straw	1.02	52.50
38. Sweet clover	6.23	40.88	4. Rye straw	1.11	56.70
39. Carex flupifinus	3.70	24.28	5. Timothy	1.31	66.80
40. Juncus effusus	1.15	7.55	6. Corn stover	1.31	66.80
41. Moss (Hairs cap)	5.36	35.17	7. Red clover	1.44	74.00
42. Carex stricta	2.10	13.78	8. Alfalfa	1.14	58.10
43. Witch grass	1.27	8.33	9. Buckwheat hulls	1.50	76.50
44. Gladiolus	1.37	8.99	10. Cottonseed hulls	1.12	57.10
45. Red top	1.18	7.74	11. Sorghum	0.89	45.70
			12. Tobacco	5.63	287.20

TABLE XI - Relative growth of barley plants in soil and in sand with and without lime to which had been added equal quantities of nitrogen from different plant tissues.

Soil Unlimed	% of Control	Soil Limed	% of Control
1. Tomato	94	1. Potato	156
2. Potato	89	2. Seaweed	124
3. Seaweed	87	3. Tobacco	108
4. Xanthium	84	4. Xanthium	96
5. Knotweed	82	5. Alfalfa	87
6. Tobacco	80	6. Knotweed	85
7. Ragweed	77	7. Ragweed	78
8. Pepper	73	8. German millet	78
9. Bidens	70	9. Pepper	72
10. Amaranth	62	10. Bidens	67
11. Cabbage	61	11. Tomato	59
12. Alfalfa	58	12. Smartweed	58
13. Pursley	58	13. Buttercup	57
14. Canada blue grass	55	14. Sudan grass	37
15. Onion	47	15. Red clover	33
16. Kentucky blue	44	16. Horsetails	33
17. Buttercup	44	17. Club moss	28
18. Horsetails	44	18. Fungi	20
19. Turnip top	44	19. Buckwheat	19
20. Smartweed	42	20. Oat straw	19
21. Sweet clover	40	21. Fern	18
22. Orchard grass	40	22. Buckwheat hulls	15
23. Moss Hairs cap	35	23. Corn stover	14
24. Lambs quarter	35	24. Cottonseed hulls	12
25. German millet	30	25. Rye straw	11
26. Carex lupulinus	25	26. Artichoke	11
27. Club moss	24	27. Timothy	10
28. Buckwheat	22	28. Sorghum	9
29. Red clover	21		
30. Fern	20		
31. Sudan grass	16		
32. Timothy	14		
33. Carex stricta	14		
34. Cottonseed hulls	12		
35. Artichoke	11		
36. Oat straw	10		
37. Buckwheat hulls	10		
38. Rye straw	9		
39. Fungi	9		
40. Cladiolus	9		
41. Corn stover	9		
42. Sorghum	8		
43. Witchgrass	8		
44. Red top	8		
45. Juncus effusus	8		
		Sand Limed	
		1. Tobacco	287
		2. German millet	78
		3. Buckwheat hulls	76
		4. Red clover(dead)	74
		5. Timothy	67
		6. Corn stover	67
		7. Sudan grass	64
		8. Alfalfa	58
		9. Cottonseed hulls	57
		10. Rye straw	57
		11. Oat straw	53
		12. Sorghum	46

Table III shows the results of treatments 1 through 12 inclusive. Where the dash appears it indicates that there was less than .5 p.p.m. of nitrogen present. The results show that tobacco, alfalfa, and red clover were readily decomposed, ranking in the order given. The grams of carbon added were in the order listed 5.7, 8.7, and 11.8. German millet and sudan grass were slower in decomposition, though in the end approaching red clover. Oat straw, timothy and corn stover treatments were much slower in comparison with the others mentioned, and hardly reached the level of nitrates in the original soil. All other treatments need time in excess of 8 weeks for the nitrates to reappear after disappearing.

In the case of the sand cultures nitrification was much slower as nitrates appeared only in tobacco and alfalfa. Ammonias were higher in the sand than in the soil, probably due to the reaction and insufficient nitrifying organisms.

Fig. I, (Treatments 1 - 12) shows the barley growth in soil from an equivalent quantity of nitrogen from: 1 - sodium nitrate, 2 - tobacco, 3 - alfalfa, 4 - German millet, 5 - red clover, 6 - cottonseed hulls, 7 - sudan grass, 8 - timothy, 9 - oat straw, 10 - buckwheat hulls, 11 - sorghum, 12 - corn stover.

The barley plants in Fig. I were arranged according to height. The plant indications of decomposition follow closely that of the ammonification and the nitrification test. Tobacco and alfalfa treatments were very similar to the check. German millet, red clover, cottonseed hulls, sudan grass and timothy treatments formed an intermediate group between the extremes. Rye straw was unintentionally omitted and would be above or below buckwheat hulls.

Tobacco and alfalfa were as good as the check at the end of 30 days, and were heading at the end of 60 days. All others were dying from the tips back at the end of 30 days. Table X and XI list the data on the barley growth and the percentage of control.

Fig. II (Treatments 1 - 12) shows the barley growth in limed soil arranged according to height from .41 grams of nitrogen from the following: 1 - check sodium nitrate, 2 - tobacco, 3 - German millet, 4 - alfalfa, 5 - sudan grass, 6 - red clover, 7 - oat straw, 8 - corn stover, 9 - timothy, 10 - buckwheat hulls, 11 - cottonseed hulls, 12 - rye straw, 13 - sorghum.

In grams of dry weight, lime reduced growth in the following treatments: rye straw, timothy, cottonseed hulls and sorghum: in all others it increased the grams of dry weight produced. This group could be divided as follows: tobacco, millet, alfalfa and sudan grass treatments approaching the check, all others with red clover treatment first followed by oat straw and corn stover treatments producing intermediate or poor growth.

Fig. III (Treatments 13 to 28 inclusive) shows the barley growth in soil arranged according to height from .41 grams of nitrogen from the plant tissue listed as follows: 0 - control sodium nitrate, 1 - seaweed, 2 - xanthium, 3 - pepper, 4 -tomato, 5 - knotweed, 6 - ragweed, 7 - bi-dens, 8 - potato, 9 - buttercup, 10 - horsetails, 11 - club moss, 12 -smart-weed, 13 - fern, 14 - buckwheat, 15 - fungi, 16 - artichoke.

Tables IX, X, and XI (treatments 12 - 28 inclusive) also figures 1, 2 3 and 4 are showing the same thing in a different way. Table XI shows a

rating in soil based on the ppm. of ammonia as nitrates formed. Table X shows the results of the same treatments from plant growth, and figures 1, 2, 3, and 4 are illustrations of X. Table X also shows the actual dry weights produced in grams. Artichoke, fungi, and club moss did not nitrify in the period of this experiment. Fern, buttercup and buckwheat were found to be marginal, between those that did nitrify and those that did not.

Family relationships in the solanaceae were very similar as to growth indications. Polygonaceae were not as uniform as the solanaceae. Compositae were very uniform eliminating artichokes. Seaweed as good as the check.

Treatments 29 to 45 inclusive were arranged in the order of decreasing nitrogen content. This order was selected in order to illustrate what actually happened in regard to the order of decomposition.

Fig. IV (treatments 29 to 45 inclusive) shows the barley growth in soil arranged according to height from .41 grams of nitrogen from the following plants: 0 - control, 1 - Kentucky blue grass, 2 - cabbage, 3 - turnip top, 4 - onion, 5 - pursley, 6 - orchard grass, 7 - amaranth, 8 - Canada blue, 9 - sweet clover, 10 - moss hairs cap, 11 - carex lupulinus, 12 - lambs quarter, 13 - carex stricta, 14 - juncus effusus, 15 - witch grass, 16 - gladiolus, 17 - red top.

Thirty days after planting treatments 1, 2, 4, 6 and 12 were better than the checks, family correlations showed that Canadian blue was the best of the monocotyledons followed by Kentucky blue and orchard grass in the order given. At harvesting all plants including the controls were dying from the bottom up. Numbers 5 - pursley and 12 - lambs quarter were the greenest of any of the treatments. Growth in all of the monocotyledons were similar, i.e. upright, stiff straw, with little stooling. Pursley, amaranth, cabbage and sweet clover treatments showed a different kind of behavior, weakness of straw and leaves. Orchard grass and turnip tops treatments were beginning to head. Pursley, amaranth, cabbage, and lambs quarter treatments were green and showing signs of excessive nitrogen. Stooling was in the order of the arrangement from pursley to sweet clover treatments with none beyond.

TABLE XII A - A rating of barley growth produced from nitrogen evolved from plant tissue listed.

TABLE XII B - Rating from the ammonification and nitrification test based on ammonia and nitrate nitrogen produced from controls.

A		B	
Vegetation Test		Ammonification and Nitrification Test	
1. Tobacco	158.0	1. Tobacco	118.0
2. Potato top	122.0	2. Potato	109.0
3. Seaweed	105.0	3. Pursley	107.0
4. Xanthium	90.0	4. Tomato	102.0
5. Knotweed	83.0	5. Alfalfa	100.0
6. Ragweed	77.0	6. Lambs quarter	100.0
7. Tomato	76.0	7. Amaranth	99.0
8. Pepper	73.0	8. Cabbage	94.0
9. Bidens	69.0	9. Seaweed	82.0
10. Alfalfa	68.0	10. Xanthium	74.0
11. German Millet	62.0	11. Knotweed	63.0
12. Amaranth	62.0	12. Pepper	59.0
13. Cabbage	61.0	13. Kentucky blue grass	58.0
14. Pursley	58.0	14. Onion	57.0
15. Canadian blue grass	55.0	15. Ragweed	57.0
16. Buttercup	51.0	16. Sweet clover	56.0
17. Onion	50.0	17. Bidens	52.0
18. Smartweed	50.0	18. Canadian blue grass	52.0
19. Kentucky blue grass	47.0	19. German millet	52.0
20. Turnip top	44.0	20. Turnip top	43.0
21. Red clover	43.0	21. Red clover	41.0
22. Sweet clover	41.0	22. Moss hairs cap	40.0
23. Orchard grass	40.0	23. Sudan grass	38.0
24. Sudan grass	39.0	24. Orchard grass	33.0
25. Horsetails	38.0	25. Smart weed	27.0
26. Moss hairs cap	35.0	26. Buttercup	24.0
27. Lambs quarter	35.0	27. Horsetails	23.0
28. Buckwheat hulls	33.0	28. Oat straw	20.0
29. Timothy	30.0	29. Corn stover	14.0
30. Corn stover	30.0	30. Timothy	13.0
31. Oat straw	27.0	31. Rye straw	13.0
32. Cottonseed hulls	27.0	32. Buckwheat	12.0
33. Rye straw	26.0	33. Sorghum	11.0
34. Club moss	25.0	34. Buckwheat hulls	9.0
35. Carex lupulinus	24.0	35. Cottonseed hulls	8.0
36. Sorghum	21.0	36. Fern	7.0
37. Buckwheat	21.0	37. Fungi	7.0
38. Fern	19.0	38. Club moss	6.0
39. Fungi	15.0	39. Carex lupulinus	4.0
40. Carex stricta	14.0	40. Witch grass	4.0
41. Artichoke	11.0	41. Gladioli	3.0
42. Gladioli	9.0	42. Red top	3.0
43. Witch grass	8.0	43. Artichoke	3.0
44. Red top	8.0	44. Juncus effusus	2.0
45. Juncus effusus	8.0	45. Carex stricta	1.0

TABLE XIII - Family grouping based on nitrification and ammonification percentages of the control.

	%	N-C
1 Tobacco	118	1-13
2 Potato top	109	1-25
3 Tomato top	102	1-12
12 Pepper top	59	1-15

Leguminosae

5 Alfalfa	100	1-20
16 Sweet clover	56	1-29
21 Red clover	41	1-27

Compositae

10 Xanthium	74	1-21
15 Ragweed	57	1-21
17 Bidens	52	1-18
43 Artichoke	3	1-68

Others

3 Pursley	107	1-8
6 Lambs quarter	100	1-17
7 Amaranth	99	1-11
8 Cabbage	94	1-12
30 Turnip top	43	1-19
26 Buttercup	24	1-23
35 Cottonseed hulls	8	1-83

Polygonaceae

11 Knotweed	63	1-19
25 Smartweed	27	1-24
32 Buckwheat	12	1-29
34 Buckwheat hulls	9	1-96

Monocotyledonae - Grasses

	%	N-C
13 Kentucky blue grass	58	1-19
14 Onion	57	1-15
18 Canadian blue grass	52	1-20
19 German millet	52	1-30
23 Sudan grass	38	1-34
24 Orchard grass	33	1-19
28 Oat straw	20	1-48
29 Corn stover	14	1-45
30 Timothy	13	1-58
31 Rye straw	13	1-89
33 Sorghum	11	1-75
38 Carex Lupulinus	6	1-31
40 Witch grass	4	1-36
41 Gladioli	3	1-40
42 Red top	3	1-55
44 Juncus effusus	2	1-33
45 Carex stricta	1	1-35

Non Vascular Plants

Seaweed	82	1-19
Moss Hairs cap	40	1-27
Horsetails	23	1-28
Fern	7	1-43
Fungi	7	1-44
Club moss	6	1-56

In the case of Polygonaceae the nitrification rating follows the nitrogen-carbon ratio, this was followed also in the case of the lower forms of plants. In the majority of cases the nitrogen-carbon ratio was not followed.

TABLE XIV - Classification based on average percentages of control from vegetation test and ammonification test.

	$\%$	N-C-R
1. Tobacco	138	1-13
2. Potato	115	1-25
3. Seaweed	98	1-19
4. Tomato	89	1-12
5. Alfalfa	84	1-20
6. Pursley	83	1-8
7. Xanthium	82	1-21
8. Amaranth	80	1-11
9. Cabbage	76	1-12
10. Knotweed	73	1-18
11. Lambs quarter	67	1-17
12. Ragweed	67	1-21
13. Pepper	66	1-15
14. Bidens	61	1-18
15. German Millet	57	1-30
16. Onion	54	1-15
17. Kentucky blue grass	52	1-19
18. Canada blue grass	52	1-20
19. Sweet clover	49	1-29
20. Oat straw	47	1-48
21. Turnip top	43	1-19
22. Red clover	42	1-27
23. Sudan grass	39	1-34
24. Buttercup	38	1-23
25. Smartweed	38	1-24
26. Moss hairs cap	38	1-27
27. Orchard grass	37	1-19
28. Horsetails	31	1-28
29. Corn stover	22	1-45
30. Timothy	22	1-58
31. Buckwheat hulls	21	1-96
32. Club Moss	16	1-56
33. Sorghum	16	1-75
34. Buckwheat	16	1-29
35. Rye straw	14	1-89
36. Carex lupulinus	14	1-31
37. Fern	13	1-43
38. Cottonseed hulls	12	1-83
39. Fungi	11	1-44
40. Carex stricta	8	1-35
41. Artichoke	7	1-68
42. Witch grass	6	1-36
43. Gladioli	6	1-40
44. Red top	5	1-55
45. Juncus effusus	5	1-33

List of materials studied arranged in the order of highest percentages of controls from the nitrification and the ammonification test, without regard to family relationship or chemical composition.

The nitrate and ammonia determinations were carried out in 3 groups as follows: treatments 1 - 12 inclusive under similar conditions of length of day and temperature, treatments 13 to 28 inclusive, and 28 to 45 inclusive.

Under the conditions of the investigation the addition of the following materials need time in excess of the period of the duration of the experiment as can be seen from Tables III, V, and VIII: oat straw, rye straw, timothy, corn stover, buckwheat hulls, cottonseed hulls, sorghum, club moss, fern, buckwheat, artichoke, *Carex lupulinus*, *Juncus effusus*, *Carex stricta*, witch grass, gladiolus, and red top. All other nitrates were formed either immediately or during the duration of the experiment.

Tobacco, seaweed, potato tops, tomato tops, pepper, knotweed, alfalfa, pursley, amaranth, lambs quarter, cabbage, bidens, xanthium, ragweed, decomposed immediately and nitrates appeared in the soil immediately or at the expiration of 1 week.

There were others such as the clovers, millet, sudan grass, the blue grasses, onion, horsetails, smartweed, which were intermediate between the two extremes. The moisture content for the corresponding nitrate and ammonia determinations fluctuated from 17 percent in ragweed treatments to 29 percent in the sorghum treatment.

In the limed soil and sand the addition of limestone reduced the ppm. of nitrates produced in comparison to the unlimed soil. The limed soil treatments included 1 to 29. The moisture for this period fluctuated between 21 percent in bidens and buckwheat hulls to 29 percent in artichoke, which was slightly higher than in soil without lime.

The dry weight of barley produced from these various plant tissues

as nitrogen sources was reduced in treatments 13 to 29, but in treatments 1 to 12 there was an increase in dry weight produced from the addition of lime.

In the Solanaceae, Compositae, and Leguminosae the rank in the family groupings are the same in the vegetation test and the nitrification test. The nitrogen-carbon ratio, however, ranges from 1 to 12 in tomato tops to 1 to 29 in sweet clover (artichoke eliminated as a misnomer as it grew broadcast and was woody and had lost three-fourths of its leaves when collected.) In the Polygonaceae vegetation test buckwheat hulls showed up better than did buckwheat, but the order was reversed in the nitrification test. A nitrogen carbon-ratio of 1 to 96 was better than a nitrogen carbon ratio of 1 to 29. Neither was the carbon-nitrogen ratio nor the total nitrogen content followed in either case.

In the dicotyledonous plants with a total nitrogen content of 2 percent or more the nitrogen-carbon ratio or the total nitrogen content affect but little as nitrates reappear in from 1 week to 1¹/₂ days, when finely ground and incorporated in the soil. In the case of potato tops with a nitrogen content of 1.48 percent nitrates were available the first week but in the case of the monocotyledonous plants, orchard grass with a total nitrogen content of 2.54 percent, the nitrates did not exceed that of the original soil until the 4th week. These results are shown by the weekly fluctuations of ammonification and nitrification in Tables III, V and VII, and in figure 1 to 7 appendix showing the weekly fluctuations in parts per million of nitrogen in individual plants listed.

The results are suggestive of the idea of the structure of the plant and their protective waxes and resins as controlling factors in decomposition associated with the water soluble materials in the plant.

DISCUSSION

The following questions were in mind when this experiment was planned.

Is there a relationship between the characteristics of plants (such as reproductive mechanisms) by which they are at present classified into families, and the rate of their decomposition when they are incorporated in the soil?

Is there a relationship between the total nitrogen-content of plants and the rate of decomposition?

Is there a relationship between the carbon-nitrogen ratio and the rate of decomposition?

Is there a relationship between the lignic-acid content of plants and the rate of decomposition?

Is there a relationship between the content of pentosans and the rate of decomposition?

Is there a relationship between the rate of decomposition and the characteristics of plants (such as their position in the evolutionary series) by which they are sometimes classified into "natural" families?

The results of this experiment also open up many other interesting questions for the solution of which the data obtained is insufficient.

Tables XIII and XV (listing family groupings) show how under the conditions of moisture, temperature, and preparation in this experiment plants of the same family tend to group themselves with respect to

readiness of decomposition. Figure I to Appendix VII shows in a little more detail the weekly fluctuations in the amounts of nitrate and ammonia liberated by these individual members. (Individuals of the same family observed under the conditions of this experiment and cut down under similar conditions by growth and at similar stages of development break down similarly.) The smaller the number of representatives used the narrower is the range of fluctuations: and as a study of the monocotyledonous group shows, the larger the number, the wider is the range of fluctuations. There is, consequently, a narrower range of fluctuations among members of families in the dicotyledonous group than among members of the monocotyledonous group of plants. This relative uniformity may be the result of the fact that fewer representatives of the dicotyledons were observed, or that the conditions under which the members of this family grew were more nearly similar, or that, because they decayed more rapidly, their decomposition was either less complex or less accurately recorded. There are also similarities in the behavior of certain members within families. Thus the blue grasses, sudan grass, orchard grass, and onions, all of which are calciphiles, all broke down very rapidly. But there are, to be sure, other calciphiles such as sorghum and timothy, that required more than eight weeks for complete disintegration.

There is a positive correlation of $.81 \pm .035$ between ammonification tests and total nitrogen-content of the plants studied. The larger the percentage of total nitrogen, the sooner the plant (when finely ground and incorporated in the soil) begins to liberate and add its

nitrates to those of the original soil: and the more rapid thereafter is the rate of liberation. But when the percentage of total nitrogen is more than 1.50 percent in dicotyledonous plants, or 2 percent in monocotyledonous plants, nitrates should appear from them in the soil within approximately 14 days. There was, however, little if any correlation between the total nitrogen-content of the members of families of plants and their position in the usual classification. There was, however, a surprisingly close (probably fortuitious) relationship between the three members of the Compositae studied with respect to total nitrogen-content.

There was some relationship between the groupings of plants into families and the carbon-content of the separate members: this relationship was closest among the dicotyledons, but appeared to be a more or less constant factor for all the plants studied. (The largest percentages of carbon were found in the monocotyledonous plants.) But it seems clear to the writer that a high nitrogen-content is seldom associated with a high carbon-content (there was found, indeed, to be a negative correlation of $.53 \pm .07$ between the two): and as the carbon-content increased, the nitrogen content usually decreased. The larger the carbon-content, the slower was the rate of decomposition: for a large content of carbon was usually to be found with a low content of nitrogen, and a low content of nitrogen in an organic fertilizer always results in a nitrogen depression in the soil, and, of course a consequent falling off in the field of crops.

Under the conditions of this experiment the carbon-nitrogen ratio cannot be relied upon to predict which of two plant-materials or organic substances will be nitrified the more readily. The writer found that plant-tissue with a nitrogen-carbon ratio of 1 to 25 - 30 was very readily

decomposed to yield up its nitrates. As the ratio decreased from 1 to 25 - 30 to 1 to 8 (the normal ratio of nitrogen to carbon in the soils) the balance of organisms in the soil is less violently disturbed, and the nitrates given up in decomposition soon appear. The nitrogen-carbon ratio can be used, however, to predict the relative rapidity at which nitrates given up in decomposition may be expected to appear in the soil: or, vice-versa the relative nitrogen depression, generally speaking, of crops. Table XII and XIV show these relationships.

It will have been observed by the reader of the Review of the Literature that the lignin-content in plants is a large contributor to humus. Now in its process of decay, humus at first noticeably deteriorates: but it soon reaches an equilibrium, after which decomposition is so slow that lignic materials tend to accumulate, and the proportion of lignic-content in the soil to increase. Thus, there was a negative correlation of $.357 \pm .08$ between the lignic content of plants and the parts per million of nitrates formed. The higher the lignic-content, too, the slower is the rate of decomposition: for the lignin as ligno-cellulose tends to shield the cellulose from decomposition by soil organisms. (Waksman has shown that plant tissue from which the lignic content has been removed decays readily.)

So far as the rate of decomposition is concerned, there was also a negative correlation of $.474 \pm .02$ between the results of the nitrification-test and the percentage of pentosans in plants: in other words as the pentosans increased, nitrification decreased. The results are remarkably and significantly similar to those of the carbon and nitrogen tests. There was, on the other hand a positive correlation of $.450 \pm .08$ between

the content of pentosan and the content of lignic acid: as one increased, so did the other. These are precisely the results one would expect, and the two tests seem to substantiate each other. In short, as the total nitrogen-content decreased, the percentage of pentosans increased.

Now, in order to make clear still further applications of the results of this experiment to the "natural" classification of plants, it will be necessary to state one assumption on which all such classifications depend. It is assumed by students of botanical (and other) evolution that various forms have developed on the earth at different rates over the same period of time: for only by such an assumption, apparently, is it possible to explain the contemporaneous presence of simple, unadapted forms on the one hand, and complex, highly specialized forms on the other. Thus, certain plants were at some older epoch forced so to adapt themselves to their environment as to evolve a very high tolerance for nitrogen: while others, living in the same epoch but presumably under other conditions, escaped this necessity altogether. To-day, therefore, the one species contains a relatively large proportion of nitrogen, and the others a relatively small proportion: and it seems evident (granting the original assumption) that a corollary of it must be also true: that the very existence of the first species proves the existence at an earlier epoch of an environment which somehow forced nitrogen upon plants in unusual amounts. If this original assumption and its corollary be admitted, then this experiment shows that as the dicotyledons were developing as a distinct order, there must have been what may be called for the sake of brevity a nitrogenous environment: that that this nitrogenous environment must have faded before the

evolution of the monocotyledons, which contain less nitrogen. It may be inquired, indeed, whether there was not some sort of correlation between the "nitrogenous environment" and the evolution of the two seed leaves of the dicotyledons.) Thus, such low forms as the lichens, the horsetails, and the club moss contain little nitrogen and (at least the last two) much silica: but a dicotyledon like portulaca is rich in nitrogen. With a monocotyledon, like rye, however, the total nitrogen content is exceedingly small.

The mention of the proportion of silica in plants leads to a still further development of the theory of environments at older epochs which were characterized by a predominance of one or a few elements or compounds. It has just been remarked that the "nitrogenous environment" in which the dicotyledons appear to have evolved had faded before the monocotyledons were developed: it will be recalled, too, that as the content of nitrogen decreased, that of the pentosans roughly increased. Now, it seems to follow conversely that if a steady increase in the proportion of the pentosans in the higher members of the evolutionary series can be shown, it is safe to assume (even without analytical proof) that the proportion of nitrogen must be steadily declining: indeed, that the "nitrogenous environment" is waning. The ratio of percentages of silica to nitrogen indicate (as the accompanying table shows) exactly the same recession of nitrogen before the advance of another, opposed constituent of plant-tissue. If, then (as seems likely from the foregoing comparison of nitrogenous content with position in the evolutionary

series) "nitrogenous environments" come and go in cycles. the steady increase of the proportions of silica indicate that the botanical world is now in the downward curve of a cycle. Thus, the proportion of silica in the plants at the bottom of the evolutionary series is negligible: it increases in the higher order of Pteridophytes (such as the horsetails): it decreases, however, in the still higher order of dicotyledons: but gains once more in the monocotyledons, the highest of the orders included in the experiment.

Table of Proportions of Silica and Lime in
Monocotyledons and Dicotyledons

	CaO	Si		CaO	Si
Alfalfa	1.92%	.065	Kentucky Blue Grass	.264%	2.72%
Beans		.820	Canadian Blue Grass	.654	2.72
			Broom Sedge		2.28
Clover	2.90	.238	Corn Plant	.590	1.10
			Oat Plant	.418	2.10
Peas		.250	Orchard Grass	.412	4.40
			Timothy	.285	0.784
Beets		.014	Wheat		2.50
			Rye	.430	
Cabbage	2.42	.184	Average	.44	2.325
Cotton plant		.290			
Lettuce		.538	Fern	1.01	.16
Potato vines (sweet)		.410	Horsetails	2.30	3.65
Potato tops (white)	1.72		Club moss	.27	.31 1.07
Tobacco	4.42	.125	Sphagnum	.29	.16
Tomato	2.77	.519	Marchantia	.94	.09
Lambs quarter	2.93	.200	Fucus	1.62	.03
Buttercup	1.34	.200	Lammaria	1.58	.14
Sunflower	2.45	1.160	Fungi	.03	.04 0.08
Turnip top	3.55	.060			
Average	2.56	.34	Average	.88	.56

(Compiled from analyses made upon ashes of the plants by
Hencamp (19), Wolff (66), and Robinson (43).

In the same table it is clear that there is a positive (though rough) correlation between the proportions in plants of lime and nitrogen. Now while no information has yet been collected to show precisely to tell what the circumstances are that force plants to tolerate more nitrogen (whether the cause relates to climatic conditions, nature or the soil, species of plants or stage of growth, or a combination of these, yet tentative data have been submitted regarding the circumstances which favor the incorporation of lime in plants. It may be assumed that there is some correlation between the two: that conditions which favor a large tolerance of nitrogen are not unlike those which are fairly certain to favor a large tolerance of lime. The conditions which favor a large tolerance of lime relate principally (so far as is known) to the nature of the soil or to climatic conditions: for at least the lower orders of marine plants -- the fucus and the lammaria for example -- of which the absorptive organs subsist in submarine soil, if any) usually contain proportionately more lime than the lower orders of terraneous plants: heavy rainfall (because it dissolves much lime from limestone deposits) renders unusually large amounts of the compound available to plants: and excessive heat (by forcing upon plants the defense of rapid transpiration) makes for the absorption of unusually large amounts of the water in which alone a plant can receive lime. From these tentative principles at least this much may be hazarded about the "nitrogenous environment" in which the dicotyledons evolved: that it was a more moist, probably warmer period than that in which the later monocotyledons developed: for the average percentage of lime in the former order is 2.56, and in the latter, only .44. It will be clear, too, that an analysis of the relative proportions of lime in plants also

substantiate the "natural" classification.

Although the writer feels that the method which he used to determine the lignic content of plants has not yet been perfected (would not serve, for example, in the analysis of a wide range of species), yet the figures for lignic content obtained by the imperfect method used are of considerable use, adding still further substantiations to the various "natural" classifications of plants. For the lignic content of the monocotyledons is higher on the average (4 percent) than that of the dicotyledons (2.50 percent); and, correspondingly, the former stand higher in the evolutionary series than the latter.

But the correlations between proportions of pentosans in plants and their membership in families are not so definite. To be sure, the proportion of pentosans in the grasses range from 12 percent in orchard grass to 27 percent in rye straw; and in the night shade family the proportion of pentosans in three out of four specimens were very close (7 - 8 percent). But tobacco (also a member of the night shade group) contains 23 percent of pentosans. In the polygonum (without seeds and hulls) the percentage of pentosans ranges from 9 to 15 percent. In the leguminosae, the range is from 11 to 17 percent. Yet the dicotyledons are, as a rule, poor in pentosans, the average for the group being but 12 percent; and the monocotyledons were the richest of all the plants tested, their average being 22 percent.

Now, judging from the percentages of pentosans in their make-up alone, one could assume that the monocotyledons are higher than the dicotyledons in the evolutionary series of plants. Indeed, a family

tree could be worked out on the basis of the proportions of pentosans in plants: and on such a tree, the plants would appear in the following order (from the highest to the lowest): The Monocotyledons: In this order rye-straw, oat straw, and corn stover would stand at the top, followed by the careces, juncaces, sorghum, red top, and the blue grasses, which serve as a link connecting the monocotyledons with dicotyledons that follow. Next would come, then the Dicotyledons: Here the Compositae stand highest, with 12 percent of pentosans: next come the leguminosae (11 percent), the polygonaceae (9 percent), and the solanum (8 percent). Intermediate in the arrangement of the dicotyledons would fall the Crucifera, amaranthaceae, portulacaceae, and chenopodiaceae: since only one or two specimens of the families were studied, these groups can be placed only by conjecture and approximately. The lower forms of terraneous plants would fall beneath the solanaceae on the family tree, and would lead at their lower extremity to the aegae.

SUMMARY

The review of the literature on decomposition in the soil has included studies on the various components of the tissue of plants that serve as sources of energy for organisms in the soil, and papers on the fertilizing value of weeds.

A partial chemical analysis (including determinations of the proportions of nitrogen, carbon, lignin, and pentosans) has been made of 43 different plants and two seed parts, the majority of which plants are common weeds or widely cultivated crops.

The decomposition of these plants has been studied in the greenhouse in cultures of four different kinds: soil without lime, soil with lime, (and for treatments 1 through 12) sand without lime and sand with lime. The criteria for the rate of decomposition were the amounts of ammonia and nitrates formed.

The plant-tissue incorporated in these cultures for the purpose of the experiment were all collected in as nearly comparable stages of growth as possible, but were obtained from a wide variety of soils and locations.

It was found that the average proportion of nitrogen was greater in the dicotyledonous than in the monocotyledonous group, ranging in the former from 0.87 percent in the artichoke, to 4.48 percent in pursley, and in the latter from 0.53 percent in rye straw to 2.54 percent in orchard grass. As the nitrogen-carbon ratio widened, the content of

carbon and the pentosans increased, and the rate of decomposition decreased.

The content of pentosans ranged in the dicotyledons from 5 percent in cabbage to 23 percent in tobacco, and in the monocotyledons from 12 percent in orchard grass to 27 percent in rye straw. As the nitrogenous content decreased, the content of pentosans increased.

The proportion of carbon was highest in the monocotyledonous group, ranging from 42 percent in the onion to 50 percent in witch grass. In the dicotyledonous group it ranged from 36 percent in potato tops to 48 percent in alfalfa, increasing with the content of pentosans.

As the proportion of carbon and pentosans content decreased, the rate of decomposition (as shown by the amounts of ammonia and nitrates formed, and by increased plant-growth) increased.

There is not, apparently, a strict correlation between the rate of decomposition and the total nitrogen content of plants or the nitrogen-carbon ratio. Yet the experiment shows very clearly that on the whole the plants containing most nitrogen decompose more readily than those containing less. The structure of plants and their content of such carbohydrates as lignin and pentosans (which resist both grinding and decomposition), were also factors in the rate of decomposition: for plants of the dicotyledonous group were more easily ground than plants of the monocotyledonous group, and were less resistant to decomposition. If the ratio of nitrogen to carbon is no more than 1 to 25 - 30 the plants decompose easily: but if the ratio is wider the incorporation of natural fertilizers in the soil results in a depression of the nitrates.

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LIST OF FIGURES IN APPENDIX

Figure I. Weekly fluctuations in ppm. of ammonia and nitrate nitrogen produced in soils with and without lime from .41 grams of nitrogen from Leguminosae listed.

Figure II. Weekly fluctuations in p.p.m. of ammonia and nitrate nitrogen produced in soil from .41 grams of nitrogen from Solanaceae shown.

Figure III. Same as Figure II except the equivalent of 2 tons of lime per acre added.

Figure IV. Weekly fluctuations in p.p.m. of ammonia and nitrate nitrogen produced in soil from the addition of .41 grams of nitrogen from Gramineae listed.

Figure V. Weekly fluctuations in p.p.m. of ammonia and nitrate nitrogen produced in soil from .41 grams of nitrogen from Compositae listed.

Figure VI. Same as Figure V except from Polygonaceae listed.

Figure VII. Same as V except from all other plants representing different families.

APPENDIX I

TABLE I - Parts per million of ammonia and nitrate nitrogen produced in soil with and without lime also the corresponding percentage moisture for these determinations are listed.

Nitrogen as p.p.m. of NH_3 & NO_3 Alfalfa as check.
Moisture as % DryWt.

	7 days						14 days						21 days					
	Soil		Soil & Lime		: Soil		Soil		Soil & Lime		: Soil		Soil		Soil & Lime		: Soil	
	N	H ₂ O	N	H ₂ O	N	H ₂ O	N	H ₂ O	N	H ₂ O	N	H ₂ O	N	H ₂ O	N	H ₂ O	N	H ₂ O
1. Sudan Grass	13	22	2	34	:	17	21	4	23	:	31	23	10	25				
2. German millet	25	18	2	33		29	19	16	25		65	22	36	26				
3. Oat straw	-	18	2	26		1	27	2	17		-	28	6	25				
4. Rye straw	-	19	2	29		-	25	19	23		2	27	2	28				
5. Timothy	T	22	2	26		1	20	3	24		-	24	6	27				
6. Corn stover	-	25	2	33		2	27	1	28		-	29	3	32				
7. Red clover	33	20	3	32		26	21	4	26		2	22	23	29				
8. Alfalfa	61	25	56	25		81	23	100	20		118	25	50	24				
9. Buckwheat hulls	-	17	2	29		-	21	1	23		3	24	6	25				
10. Cottonseed hulls	-	20	1	21		2	22	-	20		1	24	7	22				
11. Sorghum	-	31	1	31		-	33	1	30		1	32	9	33				
12. Tobacco	77	19	52	29		97	24	81	19		239	24	88	25				
13. Fungi			4	23		5	21	6	25		4	24	6	21				
14. Seaweed			34	26		62	17	33	27		60	23	44	20				
15. Club moss			2	23		2	26	12	26		3	31	2	22				
16. Horsetails			1	27		3	25	13	28		19	30	3	14				
17. Fern			-	23		2	23	2	23		2	30	2	18				
18. Buttercup			-	24		3	20	2	22		11	26	3	17				
19. Buckwheat			-	24		2	19	3	25		2	24	3	19				
20. Knotweed			11	26		80	17	17	26		61	21	38	19				
21. Smartweed			-	27		4	22	4	30		14	26	1	22				
22. Pepper top			-	22		26	21	3	22		90	24	26	18				
23. Potato tops			33	27		55	22	46	24		63	29	63	19				
24. Tomato tops			31	25		49	20	53	24		76	25	63	18				
25. Artichoke			1	22		1	23	1	27		-	29	3	23				
26. Bidens			3	23		29	20	2	25		35	24	21	18				
27. Ragweed			15	25		30	17	20	24		51	22	26	17				
28. Xanthium			21	22		53	20	31	23		40	24	51	17				
29. Pursley	83	20				101	20				101	24						
30. Amaranth	49	20				89	20				90	23						
31. Cabbage	26	19				83	19				80	26						
32. Onion	24	20				40	18				49	22						
33. Orchard grass	15	20				14	21				14	27						
34. Lambs quarter	19	21				98	23				77	29						
35. Kentucky Blue grass	37	23				36	24				42	30						
36. Turnip top	18	19				28	20				23	26						
37. Canadian Blue grass	1	21				32	19				29	26						
38. Sweet clover	7	21				28	22				38	27						
39. Carex Lupulinus	-	19				3	21				2	27						
40. Juncus effusus	-	18				5	21				3	26						
41. Moss(hairs cap)	2	19				35	22				36	27						
42. Carex stricta	-	19				3	22				1	29						
43. Witch grass	2	18				3	21				-	26						
44. Gladiolus	-	21				3	24				1	29						
45. Red top	-	19				1	18				-	26						

APPENDIX I

TABLE I - Parts per million of ammonia and nitrate nitrogen produced in soil with and without lime also the corresponding percentage moisture for these determinations are listed.

Nitrogen as p.p.m. of NH_3 & NO_3 Alfalfa as check
Moisture as % Dry Wt.

	28 days				35 days				42 days			
	Soil N	Soil H_2O	Soil & Lime N	Soil & Lime H_2O	Soil N	Soil H_2O	Soil & Lime N	Soil & Lime H_2O	Soil N	Soil H_2O	Soil & Lime N	Soil & Lime H_2O
1.	23	24			44	24	20	18	57	21		
2.	49	22			44	20	46	17	74	18		
3.	1	25			11	22	2	19	15	24		
4.	-	22			7	20	-	19	-	21		
5.	-	23			3	21	-	19	-	22		
6.	-	25			12	24	-	21	28	23		
7.	84	20			19	21	56	19	92	19		
8.	115	22			78	21	82	23	141	20		
9.	-	25			2	23	-	18	-	21		
10.	-	22			-	20	1	18	-	22		
11.	-	33			2	33	1	24	-	28		
12.	137	22			123	23	100	18	213	22		
13.	8	18	6	31	4	23	7	31	-	25	5	29
14.	61	16	61	23	65	17	49	31	89	17	83	26
15.	5	24	3	28	1	27	2	34	11	30	5	29
16.	26	23	3	23	25	24	1	26	47	27	4	23
17.	4	21	1	29	12	22	2	36	16	21	2	29
18.	18	19	4	25	38	24	2	33	31	27	26	26
19.	3	17	3	27	16	23	3	33	22	26	3	28
20.	54	15	50	25	48	22	42	24	74	17	49	27
21.	22	21	2	32	38	21	-	31	35	19	2	24
22.	51	17	40	27	49	18	32	30	50	17	54	22
23.	72	21	38	25	86	23	81	28	127	22	98	24
24.	70	17	83	27	84	18	86	29	94	19	97	22
25.	2	22	-	37	2	20	4	41	1	25	1	23
26.	46	17	40	27	42	20	30	23	56	21	47	19
27.	44	15	39	29	61	17	33	25	56	17	68	20
28.	63	17	59	25	56	20	46	25	86	21	79	27
29.	85	21			90	23			79	23		
30.	87	20			91	23			96	31		
31.	79	24			83	28			80	24		
32.	56	23			51	26			49	22		
33.	22	23			33	27			30	23		
34.	106	25			95	28			91	25		
35.	50	28			61	26			70	25		
36.	33	28			41	26			40	25		
37.	43	24			62	25			59	27		
38.	47	24			46	27			59	27		
39.	3	24			2	27			2	33		
40.	4	24			-	29			2	31		
41.	38	24			40	28			41	28		
42.	-	24			1	28			2	24		
43.	2	25			3	29			-	23		
44.	3	27			3	27			4	23		
45.	2	26			2	30			3	28		

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TABLE I - Parts per million of ammonia and nitrate nitrogen produced in soil with and without lime also the corresponding percentage moisture for these determinations are listed.

Nitrogen as p.p.m. of NH_3 & NO_3 Alfalfa as check

Moisture as % Dry Wt.

	49 days				54 days				63 days			
	Soil N	Soil H_2O	Soil N	& Lime H_2O	Soil N	Soil H_2O	Soil N	& Lime H_2O	Soil N	Soil H_2O	Soil N	& Lime H_2O
1.	37	20	44	19					37	27	27	16
2.	70	18	46	18					47	25	67	22
3.	9	22	3	21					24	27	3	24
4.	2	21	3	21					1	25	2	26
5.	8	22	3	17					13	24	2	24
6.	2	22	9	19					34	25	16	30
7.	65	19	4	15					61	22	49	24
8.	78	19	78	16					60	22	76	17
9.	-	20	3	16					1	23	3	19
10.	-	20	2	19					-	23	2	21
11.	2	27	1	23					2	25	2	25
12.	117	18	77	17	56 days				85	21	125	17
13.	5	25	3	28	11	31	3	29				
14.	88	17	88	24	97	24	124	25				
15.	5	22	3	26	18	34	1	26				
16.	45	24	24	24	51	28	25	26				
17.	18	20	2	28	21	21	1	32				
18.	48	24	32	21	43	24	42	24				
19.	23	25	1	27	37	25	20	28				
20.	68	17	62	22	62	17	59	22				
21.	49	17	34	29	61	21	52	27				
22.	76	16	57	19	88	21	82	22				
23.	143	22	145	20	136	30	151	31				
24.	99	18	133	17	105	25	119	21				
25.	5	24	2	25	9	27	1	27				
26.	86	17	49	17	106	18	54	18				
27.	65	16	68	22	63	17	63	26				
28.	103	19	56	18	108	19	59	19				
29.	138	18			106	20						
30.	129	20			93	24						
31.	119	22			109	25						
32.	86	21			79	18						
33.	41	21			62	21						
34.	134	22			110	20						
35.	46	23			82	21						
36.	54	25			71	22						
37.	75	21			66	23						
38.	101	20			87	23						
39.	-	21			10	22						
40.	1	21			1	20						
41.	53	22			51	21						
42.	-	21			-	22						
43.	2	26			13	20						
44.	1	24			5	24						
45.	2	22			4	23						

APPENDIX I

TABLE I - Parts per million of ammonia and nitrate nitrogen produced in soil with and without lime also the corresponding percentage moisture for these determinations are listed.

Nitrogen as p.p.m. of NH_4 & NO_3 Alfalfa as check.

Moisture as % Dry Wt. 3

	Soil		Soil & Lime		% of check	% of check
	Av - N	Av H_2O	Av.-N	Av H_2O	Soil	Soil & Lime
1. Sudan grass		23		22	39	24
2. German millet		19		23	55	50
3. Oat straw		24		22	10	4
4. Rye straw		22		24	2	8
5. Timothy		22		22	5	4
6. Corn stover		24		27	14	14
7. Red clover		20		24	52	31
8. Alfalfa		22		20	100	100
9. Buckwheat hulls		22		21	2	3
10. Cottonseed hulls		21		20	1	4
11. Sorghum		29		27	1	3
12. Tobacco		22		20	149	118
13. Fungi	6	24	5	28	107	7
14. Seaweed	74	19	61	25	91	83
15. Club moss	7	29	4	27	81	5
16. Horsetails	31	26	9	24	79	12
17. Fern	10	22	2	27	70	2
18. Buttercup	27	23	14	24	67	19
19. Buckwheat	15	23	5	26	63	7
20. Knotweed	64	18	41	23	58	55
21. Smartweed	32	21	13	28	35	18
22. Pepper top	61	19	37	23	34	50
23. Potato tops	97	24	82	25	30	110
24. Tomato tops	82	20	83	23	17	113
25. Artichoke	3	24	2	29	12	2
26. Bidens	57	19	31	21	7	42
27. Ragweed	53	17	41	24	7	56
28. Xanthium	73	20	50	22	3	68
29. Pursley	98	20			107	
30. Amaranth	91	22			99	
31. Cabbage	86	23			94	
32. Onion	52	21			57	
33. Orchard grass	31	23			53	
34. Lambs quarter	91	24			100	
35. Kentucky blue grass	53	25			58	
36. Turnip top	38	24			42	
37. Canadian blue grass	44	24			48	
38. Sweet clover	51	24			56	
39. Carex lupulinus	4	23			4	
40. Juncus effusus	2	24			2	
41. Moss (hairs cap)	37	24			40	
42. Carex stricta	1	24			1	
43. Witch grass	3	23			4	
44. Gladiolus	3	25			3	
45. Red top	2	25			3	

TABLE II - Parts per million of ammonia and nitrate nitrogen produced in sand with and without lime also the parallel moistures for those determinations.

Nitrogen as p.p.m. of NH_3 & NO_3
Moisture on percentage of dry wt.

	7 days		14 days		19 days	
	Sand N H ₂ O	Sand & Lime N H ₂ O	Sand N H ₂ O	Sand & Lime N H ₂ O	Sand N H ₂ O	Sand & Lime N H ₂ O
1. Sudan grass	- 5		3 10		6 8	
2. German millet	5 5		5 9		1 6	
3. Oat straw	- 6		1 11		3 8	
4. Rye straw	- 8		9 11		2 10	
5. Timothy	5 8		6 8		1 8	
6. Corn stover	- 8		2 10		2 7	
7. Red clover	18 9		1 9		2 6	
8. Alfalfa	11 9		15 8		6 7	
9. Buckwheat hulls	- 7		- 7		1 9	
10. Cottonseed hulls	- 7		2 8		1 7	
11. Sorghum	- 7		2 14		2 10	
12. Tobacco	21 5		30 10		3 5	
	21 days		28 days		35 days	
	Sand N H ₂ O	Sand & Lime N H ₂ O	Sand N H ₂ O	Sand & Lime N H ₂ O	Sand N H ₂ O	Sand & Lime N H ₂ O
1. Sudan grass	1 9		2 9		4 10	4 4
2. German millet	4 11		4 9		8 7	5 5
3. Oat straw	1 11		- 10		3 9	4 7
4. Rye straw	1 16		- 11		3 12	- 7
5. Timothy	1 12		- 11		4 9	1 7
6. Corn stover	1 10		- 10		4 10	- 7
7. Red clover	1 11		- 11		6 8	2 5
8. Alfalfa	28 9		1 9		29 7	8 5
9. Buckwheat hulls	1 13		- 8		3 8	1 6
10. Cottonseed hulls	1 13		- 9		3 9	- 8
11. Sorghum	1 12		1 18		6 16	- 11
12. Tobacco	48 9		25 11		67 8	- 4
	42 days		49 days		63 days	
	Sand N H ₂ O	Sand & Lime N H ₂ O	Sand N H ₂ O	Sand & Lime N H ₂ O	Sand N H ₂ O	Sand & Lime N H ₂ O
1. Sudan grass	4 8		6 7	2 8	5 11	2 12
2. German millet	8 5		6 7	5 6	7 11	3 9
3. Oat straw	2 7		- 9	3 8	1 14	1 12
4. Rye straw	1 7		- 11	2 9	2 15	1 18
5. Timothy	1 7		- 8	2 9	1 10	2 15
6. Corn stover	- 5		1 10	2 7	1 12	- 17
7. Red clover	8 6		2 8	3 5	9 9	2 7
8. Alfalfa	35 5		23 8	4 5	42 10	1 7
9. Buckwheat hulls	- 5		1 10	2 6	2 11	- 11
10. Cottonseed "	- 8		- 10	2 13	- 11	2 12
11. Sorghum	9 12		2 15	1 11	2 22	2 14
12. Tobacco	40 5		40 6	3 4	35 10	1 10

TABLE II - Parts per million of ammonia and nitrate nitrogen
(Cont.2) produced in sand with and without lime also the
parallel moistures for those determinations.

Nitrogen as p.p.m. of NH_3 & NO_3
Moisture on percentage of dry wt.

	Sand			Sand & Lime	
	Av. p.p.m. N	% of control	A H_2O	Av. p.p.m. N	% of control
1. Sudan grass	4	16	8	4	74
2. German millet	6	25	7	4	77
3. Oat straw	2	7	9	3	58
4. Rye straw	3	14	11	1	29
5. Timothy	3	13	10	1	31
6. Corn stover	1	6	10	1	22
7. Red clover	7	29	6	2	52
8. Alfalfa	23	100	6	4	100
9. Buckwheat hulls	1	6	8	1	27
10. Cottonseed hulls	2	7	10	1	22
11. Sorghum	3	14	12	1	24
12. Tobacco	38	166	6	2	37

TABLE III - Grams of dry weight of barley produced in soil with and without lime from .41 grams of nitrogen from the plant source listed.

Soil

Check	Av. # Plants	Av. dry Wt. in g.	% of Control
	26.0	15.62	100%
1. Sudan grass	27.5	2.56	16.46
2. German millet	30.	4.49	30.19
3. Oat straw	22.5	1.51	9.74
4. Rye straw	20.5	1.44	9.28
5. Timothy	25.0	2.13	13.69
6. Corn stover	23.5	1.36	8.77
7. Red clover	32.0	3.38	21.11
8. Alfalfa	26.5	9.01	58.08
9. Buckwheat hulls	27.0	1.48	9.53
10. Cottonseed hulls	25.0	1.93	12.41
11. Sorghum	23.5	1.30	8.34
12. Tobacco	25.5	12.37	79.90
13. Fungi	18.0	0.62	9.00
14. Sawweed	17.0	5.99	87.00
15. Club moss	16.5	1.73	24.8
16. Horsetails	17.5	3.03	44.1
17. Fern	18.0	1.37	19.9
18. Buttercup	16.5	3.05	44.3
19. Buckwheat	17.5	1.52	22.0
20. Knotweed	18.5	5.64	82.0
21. Smartweed	14.5	2.86	41.50
22. Pepper	18.0	5.02	73.0
23. Potato tops	17.0	6.13	88.9
24. Tomato	18.5	6.45	93.6
25. Artichoke	17.0	0.76	11.0
26. Bidens	16.5	4.85	70.4
27. Ragweed	17.5	5.31	77.0
28. Xanthium	18.5	5.77	83.7
29. Pursley	16.0	8.77	57.0
30. Amaranth	16.5	9.38	61.55
31. Cabbage	19.0	9.28	60.90
32. Onion	18.5	7.61	49.93
33. Orchard grass	17.0	6.10	40.03
34. Lambs quarter	16.0	5.26	34.51
35. Kentucky blue grass	16.5	7.11	46.65
36. Turnip top	18.0	6.68	43.83
37. Canadian blue grass	18.5	8.58	54.99
38. Sweet clover	15.5	6.23	40.88
39. Carex lupulinus	17.0	3.70	24.28
40. Juncus effusus	18.0	1.15	7.55
41. Moss (hairs cap)	17.0	5.36	35.17
42. Carex stricta	21.0	2.10	13.78
43. Witch grass	15.5	1.27	8.33
44. Gladioli	20.0	1.37	8.99
45. Red top	18.0	1.18	7.74

TABLE III - Grams of dry weight of barley produced in soil with
(Cont.2) and without lime from .41 grams of nitrogen from
the plant source listed.

	Soil Lime Treatment		Sand Only	Sand Lime Treatment	
	# of plants	Dry Wt. % in g. of con- trol		Dry wt.	% of control
Check	30	13.03	100	1.96	100
1. Sudan grass	29	4.82	37.00	1.26	64.3
2. German millet	30	10.21	78.20	1.53	78.4
3. Oat straw	27	2.47	18.90	1.02	52.5
4. Rye straw	23	1.43	10.95	1.11	56.7
5. Timothy	22	1.36	10.42	1.31	66.8
6. Corn stover	20	1.82	13.94	1.44	66.8
7. Red clover	27	4.32	33.10	1.14	74.0
8. Alfalfa	29	11.39	83.70	1.50	58.1
9. Buckwheat hulls	27	1.96	15.00	1.12	76.5
10. Cottonseed hulls	21	1.55	11.87	0.89	57.1
11. Sorghum	21	1.17	9.00	5.63	45.7
12. Tobacco	28	14.60	107.62	1.11	287.2
13. Fungi	19	0.75	20.10		
14. Seaweed	19	4.61	123.6		
15. Club moss	20	1.06	28.4		
16. Horsetails	21	1.22	32.7		
17. Fern	15	0.69	18.5		
18. Buttercup	20	2.12	56.8		
19. Buckwheat	19	0.72	19.3		
20. Knotweed	14	3.15	84.5		
21. Smartweed	19	2.17	58.2		
22. Pepper	14	2.70	72.4		
23. Potato tops	14	5.80	155.5		
24. Tomato	18	2.20	59.00		
25. Artichoke	8	0.40	10.70		
26. Bidens	19	2.51	67.30		
27. Ragweed	10	2.92	78.3		
28. Xanthium	23	3.57	95.7		

Died soon after germinating

Fig. No. I
Leguminosae Soil+Lime

Fig. II
SOLANACEAE SOIL-NO LIME

Fig. III
Solanaceae Soil + Lime

Fig. IV
Gramineae Soil-NoLime

Fig. V
Compositae Soil-No Lime

Fig. VI
Polygonaceae Soil-NoLime

Fig. VII
Soil - No Lime

Approved by

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Wm. S. L. L.

Stan L. Clark

Graduate comtee.

Date May 31 1935

Spaulding, Major Franklin (Thesis, Ph.D) 631.1 Sp2

Factors Influencing the Rate of Decomposition of
Different Types of Plant Tissue in Soil and the Effect
of the Products on Plant Growth May 1935

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