COMPOSITION OF GREEN MANURES AT DIFFERENT STAGES OF GROWTH

A THESIS

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL
OF CORNELL UNIVERSITY FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

BY

THOMAS LYSONS MARTIN

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CONTENTS

	PAGE
Review of literature.....	139
Experimental work.....	141
Plan of the investigation.....	141
Results.....	145
Effect of stage of growth of green manure on rate of humus formation.....	145
Effect of stage of growth of green manure on rate of nitrification in soil.....	147
Effect of stage of growth of green manure on increased availability of nutrients as measured by effect on subsequent plant growth.....	151
Consideration of experimental error.....	154
Summary.....	155
Conclusion.....	156
Literature cited.....	157
Appendix.....	159

DECOMPOSITION OF GREEN MANURES AT DIFFERENT STAGES OF GROWTH

THOMAS LYSONS MARTIN

The value of organic matter in soil improvement has long been recognized. It benefits the tilth of the soil, affects the availability of the nutrients, stimulates bacterial activity, and gives to the soil a greater crop-producing power. Farm manures and green manures are the principal sources of this organic material. Green manures, as one of the sources of organic matter, are increasing in importance as the need for soil humus is becoming more widely recognized.

The humus stage of decomposition is in all likelihood the period at which many of the desirable effects of manures are produced. The ease with which a manure reaches this stage is probably a measure of its effectiveness. It is well known that plants vary, according to their degree of maturity, in the readiness with which they are broken down into humus. However, the exact stage of growth at which the crops used as green manures decompose most rapidly and exert their greatest influence on the soils so treated is yet to be determined.

The investigation here described was undertaken with the purpose of throwing some light on this question.

REVIEW OF LITERATURE

A survey of the literature of the subject indicates that the work thus far has been only of a general nature. The effect of the manures on the soil has been studied, and incidentally, in these studies, it has been found that the young material, as compared with the old, decomposes more rapidly. Not much attention has been given to attempting to find the period when the plant used as a green manure decomposes most rapidly and has the greatest influence on the various soil activities.

Muntz (1890)¹, in his investigations, found that the value of green manuring is proportional to the rapidity with which the nitrogen is converted into nitrates.

Snyder (1895) placed a mixture of soil and green clover in boxes and allowed it to ferment for one year. In a majority of cases he found an increase in the availability of the phosphorus and the potassium of the soils so treated.

¹Dates in parenthesis refer to *Literature Cited*, page 157.

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Conn (1901) says:

The building of nitrates will not take place in the soil so long as there is any considerable amount of organic material or any considerable amount of free ammonia present. If there is much organic material rapidly decomposing so as to produce ammonia, this will completely check the formation of nitrates, for these nitrifying bacteria will not grow in the presence of either organic material or ammonia. It is not until after decomposition has been completed and practically all the organic compounds used up that the nitrifying germs can begin to act.

Marshall (1912) states that under suitable conditions the accumulation of humus in the soil stimulates nitrification to a very striking extent.

Velbel (1914) found that soil nitrification increases directly with the rate of decay of the humus-forming material.

Hutchinson and Milligan (1914) used nitrate accumulation in the soil as a measure of organic decay and found that the percentage of nitrification decreased markedly with the age of the green material added.

Hill (1915) found that the nitrogen of green manures appears to pass rapidly into the nitrate form as the decay processes advance.

Using chemical analyses and subsequent crop growth as a measure, Hopkins and Aumer (1915) found that decomposing green manures increase the availability of the nutrients in the soil. Potassium seemed particularly influenced.

Wright (1915) plowed under green manure, which decayed rapidly, the decay being accompanied by vigorous nitrification. When resistant material was added, it reduced the rate of nitrification.

Brown and Allison (1916) claim that the application of large quantities of humus-forming material to soils increases ammonification and nitrification to a very considerable extent. They found that straw, due to its greater resistance, does not increase nitrification as much as do green manures.

White (1916), utilizing crimson clover as a green manure, found that the younger the crop when plowed under, the more rapidly did it decay. A corresponding stimulation was also observed in the growth of a subsequent tomato crop.

Maynard (1917) studied the rate of decomposition of a sweet-clover green manure, and, using the accumulation of nitrates in the soil as a measure, found that the rate of decay decreases as the maturity of the plant tissue is approached.

Carr (1917) suggested that, since humus formation is a step in the process of decomposition, the rate of decay may be measured by the rate at which humus is produced.

Merkle (1918) used the rate of humus formation and the evolution of carbon dioxide as a measure of the degree of decay, and found that the greater the succulency of the material studied and the greater its nitrogen content, the more rapidly does it decay.

These citations suffice to show that green manures are of value; that the younger the material when incorporated with the soil, the more rapidly does it decompose; and that as it decomposes, its favorable influence on the soil is proportional to the rate of decay. This information is all of a general character. There is nothing to indicate the exact stage in the growth of the plant at which these favorable influences occur. The knowledge that has been obtained has been based on a single method of measurement of the rate of decay. Unfortunately, no one method has been devised which in every respect satisfactorily indicates the rate of organic decomposition in soils. It therefore becomes necessary, in investigations of this nature, to use a variety of methods, each one of which will tend to check up the others. The results from such a procedure should consequently be more conclusive than results otherwise obtained.

It is the aim of the present investigation to follow such a plan, and to determine, if possible, at what stage of growth the crops used as green manures decompose most rapidly and what effect this stage has on the soil so treated.

EXPERIMENTAL WORK

PLAN OF THE INVESTIGATION

The method of conducting the investigation here discussed is briefly outlined as follows:

Dunkirk clayey silt loam, a glacial-lake soil comprising the larger part of the soil on the Cornell University experimental farm, was used in the work. This soil was passed thru a 2-millimeter sieve, and samples of 3600 grams each were then weighed into one-gallon jars, the inside dimensions of which were $7\frac{1}{2}$ by 7 inches.

Rye, oats, and buckwheat were used as green manure, each crop being obtained at three different stages of growth. The material, while still fresh, was cut into pieces of about one inch in length, and thoroly mixed with the soil. The mixture was then brought to and maintained at a moisture content of 25 per cent, and was kept at a constant temperature in the greenhouse. Untreated soils served as checks. All incorporations were made in triplicate.

The investigation consisted of a series of three experiments and covered a period of three years. The experimental series were as follows:

Series 1916. Equal green weights of rye, oats, and buckwheat, respectively, at three stages of maturity, were incorporated with separate samples of soil and incubated for twelve months.

Series 1917. Equal dry weights of the same crops were added to separate soil samples and incubated for four months.

Series 1918. Nine areas of soil were sown to rye, oats, and buckwheat, respectively, three areas being given to each crop. Green material, representing the first, second, and third stages of maturity for each crop, was then successively obtained from the respective areas, for incorporation with the soil to be experimented on. With increase in maturity, there was, of course, a corresponding increase in the green and the dry weights added to the soil, thus approximating field conditions.

The areas selected for the rye crop were each 4.4 square feet, the total material produced at each stage being divided equally among the three triplicate pots. The areas for oats and buckwheat were 4.5 and 3.4 square feet, respectively. These crops were treated exactly as was the rye.

In representing the successive stages of maturity in the tables and diagrams on the following pages, the letters *A*, *B*, and *C* are used. For the three series, and for the three different crops used, the stages of growth indicated by these letters are as follows:

SERIES 1916

Crop		Height	Condition
Rye.....	{ A	16 inches...	Boot stage
	{ B	38 inches...	Well headed
	{ C	60 inches...	Almost ripe
Oats.....	{ A	10 inches...	Preceding boot stage
	{ B	24 inches...	Boot stage
	{ C	36 inches...	Almost ripe
Buckwheat.....	{ A	12 inches...	Blossoming
	{ B	30 inches...	Well blossomed
	{ C	36 inches...	Seeds forming

SERIES 1917

Crop		Height	Condition
Rye.....	{ A	60 inches...	Fully headed
	{ B	65 inches...	Heads yellow
	{ C	72 inches...	Ripe
Oats.....	{ A	48 inches...	Fully headed
	{ B	60 inches...	Heads yellow
	{ C	62 inches...	Ripe
Buckwheat.....	{ A	40 inches...	Well blossomed
	{ B	48 inches...	Seeds forming
	{ C	48 inches...	Ripe

SERIES 1918

Crop		Height	Condition
Rye.....	{ A	24 inches...	Preceding boot stage
	{ B	48 inches...	Blossoming
	{ C	48 inches...	Almost ripe
Oats.....	{ A	11 inches...	Boot stage
	{ B	30 inches...	Well headed
	{ C	36 inches...	Almost ripe
Buckwheat.....	{ A	10 inches...	Blossoming
	{ B	20 inches...	Well blossomed
	{ C	26 inches...	Almost ripe

After various periods of incubation, soil samples were taken from each of the pots and analyses were made to determine the rate of decay.

With investigations of this nature, the methods used for determining the amount of decomposition are of prime importance. As previously stated, no single method has been devised which in every respect satisfactorily indicates the rate of organic decay in soils. The methods already suggested, and tested to some extent, are as follows: (1) determination of the rate of humus formation; (2) determination of the rate of evolution of carbon dioxide; (3) study of the accumulation of nitrates; and (4) study of the increased availability of plant nutrients as measured by the effect on subsequent plant growth.

Each of these methods is open to objection. In making humus determinations, the humus extract is difficult to filter and the process is in consequence associated with such a large experimental error that the results are not dependable. Gortner (1917) used this method and found no evidence that an increase in soil humus was brought about by specific humification. He found maximum ammonia-soluble material present in the soil immediately after green manures were turned under and before humifying bacteria could have begun work. Carr (1917) obtained similar results while attempting to discover whether the humus content of the soil was a measure of its fertility. Christie (1916), studying the decomposition of organic matter in the soil, stated that the percentage of humus was not necessarily an index of the value of the organic matter in the soil.

The rate of evolution of carbon dioxide as an indicator of the rate of decay is dependent on a number of soil conditions. The looseness which the organic material produces in the soil influences the ease with which the carbon dioxide is extracted. The amount of carbon dioxide utilized by the bacteria as a source of carbon is also a factor. Moreover, certain groups of organisms in the soil produce only intermediate products, such

as butyric and acetic acids, and this condition must also be considered in using this method.

When the accumulation of nitrates is used as a measure of organic decay, the possibility of a large probable error should not be overlooked; for much of the nitrogen that might otherwise be changed to nitrates is used by the organisms present in the soil, while the method used for obtaining a soil extract for nitrate determination may introduce a further source of error.

The increased crop growth on soils receiving treatments of decaying organic materials may be due to factors other than the increased availability of plant nutrients. The tilth is improved by the placing of the soil in the pots; and this, in turn, has a stimulating effect on the biological and chemical reactions in the soil.

The foregoing criticisms of the means available for measuring the rate of organic decay indicate that the use of one method alone may not give very dependable results. As previously stated, it is obviously better, in an investigation of this kind, to use several methods, each one tending to check up the others. The results obtained from such a procedure should be more conclusive by far.

In the present investigation, the following methods were used to measure the rate of decay:

- (1) Determination of the rate of humus formation;
- (2) Study of the accumulation of nitrates;
- (3) Study of the increased availability of plant nutrients as measured by the effect on subsequent plant growth.

The method of measuring the rate of decay by a determination of the rate of evolution of carbon dioxide was omitted because it was thought that three methods, each one of which would tend to check up the others, would give amply significant results.

The amount of humus in the soil sample obtained from each pot was determined according to the method recommended by the United States Bureau of Chemistry (1912), with the exception that 50 grams of soil was used instead of 5 grams. The humus extract was filtered thru a 10-centimeter Buchner funnel, the treated soil serving as a filter.

Nitrates were determined according to the method given by Schreiner and Failyer (1906).

Total nitrogen was determined according to the Kjeldahl-Gunning method (U. S. Bureau of Chemistry, 1912).

After the soils had been sampled for analysis, wheat was planted in each pot and grown to maturity. The moisture content, while the crop was growing, was kept at 25 per cent, the optimum condition for this particular soil.

RESULTS

Effect of stage of growth of green manure on rate of humus formation

It would appear in general, from the curves shown in figures 28 and 29 that the greater the succulency of the manure when incorporated with the soil, the larger is the amount of humus formed.

The first marked exception to this generalization, however, appears in figure 27, showing the results of allowing the material to decompose for twelve months. Here, in every instance, the most succulent crop resulted in the least amount of humus. This is in exact opposition to the results shown in figures 28 and 29, when the manure was allowed to decompose

FIG. 26. STAGES OF INCREASE AND DECREASE IN HUMUS PRODUCTION

The A-B part of the figure represents the period of humus formation, during which humus is formed and no end products are developed. B-C indicates the stage in which there is a humic-decomposition process at work and end products are formed as rapidly as the humus is produced from the crude organic material. C-D represents the stage in which the humic-decomposition process is in the ascendancy and more end products are produced than there is humus formed.

for four and five months, respectively. The data given in table 1², from which the curves in figure 27 were obtained, show that more dry matter was added to each soil as the maturity of the manure increased; but the rate of increase of this dry matter added was, in general, less than the rate of increase of the humus formed.

It would seem that in the breaking down of the crude organic material of the soil into its end products, there occur a period of humus formation and a period of humus decomposition, involving three distinct steps which are illustrated in figure 26.

With this understanding of the process, the results shown in figure 27 may be explained. In all probability the earliest stages of maturity, the

²All tables are found in the appendix pages 159-169.

A stage, of the rye, oats, and buckwheat, in the 1916 series, had reached that phase of organic decay indicated by *C-D* in figure 26. The older materials, the *B* and *C* stages of the same crops, were still in the stage during which the production of humus and the development of the end products balance each other.

Where the period of incubation was shorter, as shown in figures 28 and 29, the most succulent material used as manure was probably well along

FIG. 27. SERIES 1916. EFFECT OF MATURITY OF GREEN MANURE ON AMOUNT OF HUMUS FORMED AT THE END OF TWELVE MONTHS

The weights of green material were constant
(Data given in table 1)

in the period represented by the *B-C* part of figure 26, while the materials added at their maturer stages were still in the period of humus formation.

In figure 28, the curve for buckwheat is a second exception to the original generalization — that the greater the succulency of the manure when incorporated with the soil, the larger is the amount of humus formed. This may be accounted for by the probability that the youngest and most succulent material incorporated had decomposed very rapidly and was in the period of humic decomposition at the time of the analysis.

It appears, from this study of the rate of humus formation, that the decomposition of the green-manure crop, when incorporated with the soil, is most rapid when the crop is at the half-mature stage, the early blossoming period. This applies to all the crops studied.

FIG. 28. SERIES 1917. EFFECT OF MATURITY OF GREEN MANURE ON PERCENTAGE OF DRY MATTER HUMIFIED AT THE END OF FOUR MONTHS

The weights of dry matter were constant
(Data given in table 4)

Effect of stage of growth of green manure on rate of nitrification in soil

As already stated, the accumulation of nitrates was also used as a measure of organic decay. The results of this method, as expressed in figures 30, 31, and 32, show that the process of nitrification goes on most vigorously with the most succulent material.

In figure 31, evidence of nitrification is lacking for rye and oats in the two later stages of maturity. It is unjustifiable to conclude, however,

that no nitrification has occurred, for evidence is given in table 2 and in the curves for humus (figures 27, 28, and 29) that some decomposition has taken place. It is probable that these two exceptions are due to the fact that nitrification has not become sufficiently pronounced to respond to the tests. Moreover, the nitrogen rendered available has perhaps been converted into some other form by the organisms of decomposition. This idea is supported by Gaaney (1914), who shows that in using the

FIG. 29. SERIES 1918, EFFECT OF MATURITY OF GREEN MANURE ON PERCENTAGE OF DRY MATTER HUMIFIED AT THE END OF FIVE MONTHS

The green material at each stage came from equal soil areas, but were, of course, different in amounts (Data given in table 7)

accumulation of nitrates as a measure of the nitrifying power, one is confronted with the difficulty that the nitrates are sometimes used as a source of nitrogen by the saprophytic organisms of the soil.

In the curve for buckwheat in figure 30, the youngest material shows the least amount of nitrification as compared with the later stages of growth. In figure 31, the most succulent period, compared with the medium or B-stage, of maturity, indicates the same result. A physical examination of the soil itself, at the time of sampling for analysis, revealed that the

FIG. 30. SERIES 1916. EFFECT OF MATURITY OF GREEN MANURE ON AMOUNT OF NITRATES FORMED AT THE END OF TWELVE MONTHS

The weights of green material added to the soil were constant
(Data given in table 2)

FIG. 31. SERIES 1917. EFFECT OF MATURITY OF GREEN MANURE ON NITRIFICATION PROCESS AT THE END OF FOUR MONTHS

The weights of dry matter added were constant
(Data given in table 5)

older material used for incorporation had not been fully broken down during the period of incubation. The soil containing the most succulent manure gave no physical evidence that organic matter was present, complete decomposition having apparently occurred.

The question arises as to what has happened to the nitrates in this stage of complete decay. As mentioned previously, Gainey (1914) has shown that the nitrates are used as a source of nitrogen by the saprophytic organisms in the soil. Doryland (1916) presents data showing the reduction

FIG. 32. SERIES 1918. EFFECT OF MATURITY OF GREEN MANURE ON NITRIFICATION PROCESS AT THE END OF FIVE MONTHS

The green manure at each stage came from equal soil areas
(Data given in table 8)

of nitrates in the soil to other forms of nitrogen, whereby no loss of nitrogen has occurred, as revealed by the analysis of the total nitrogen content of the soil. It is probable that the nitrates are utilized by the organisms present. In fact, the writer has found that the total number of organisms was much greater in the soil receiving the succulent buckwheat than in that to which material of a later stage of maturity had been added.

Conn (1901) claims that in the process of decay, nitrification does not occur until toward the end of the decomposition period. There is evi-

dently too great an accumulation of carbon dioxide at first to allow the nitrifying organisms to work. Nevertheless it is not probable that the nitrifying process is entirely eliminated. Altho it is possible for some nitrates to be produced continuously, they are probably utilized as fast as they are formed. Later, when the decomposition process slows up, the oxygen replaces the carbon dioxide and a favorable environment prevails for the nitrifying activities. It would appear, from this, that conditions particularly favoring the accumulation of nitrates are present at the later stages of decomposition. This supports the conclusion that plant tissue at the period of greatest succulency — the half-mature stage of green material — decomposes so readily when incorporated with the soil, that its nitrogen very quickly becomes available to the organisms that control nitrate formation.

Effect of stage of growth of green manure on increased availability of nutrients as measured by effect on subsequent plant growth

When crops were grown on soils previously treated with green manures of varying degrees of maturity, there was a marked stimulating effect. This was greatest with the most succulent additions, and was probably due to an increased availability of soil nutrients. The data on these results are shown diagrammatically in figures 33, 34, and 35.

The amount of dry matter added in the 1916 and 1918 series varied with the maturity of the manure used, the pots treated with the maturer material receiving the larger amounts of dry matter. In the 1917 series the dry matter was kept constant. This was done in order to learn whether the effects produced by increased maturity were due to increasing the amount of the dry matter, rather than to its lack of succulency. The effect seems to be the same in all cases. The crops produced for each unit of added dry matter decreased with the increased maturity of the additions. The younger the material when incorporated with the soil, the greater was the increase in crop growth.

Why does green manure of maximum succulency at the time of its incorporation with the soil produce the most beneficial effect on the growth of subsequent crops? It may be because of a more favorable effect on the physical condition of the soil. The manure in the succulent state undoubtedly decomposes very readily, and nutrients combined with the organic compounds of the tissues are very soon released, thus becoming available to the crop. The decomposition products may also react on the soil constituents and render them more readily available to the growing plants. Decomposition of organic matter in the soil appears to render available the essential nutrients in the soil. Jensen (1917) found increased

solubility of iron, calcium, magnesium, and phosphorus after alfalfa had been incorporated with the soil and allowed to decompose for six months. He found also that sweet clover, after decomposing for three months in the soil, increased the solubility of the phosphorus present from 30 to 100 per cent; and he states further that the amounts of available calcium, magnesium, iron, and phosphorus in citrus soils are measurably increased by the addition of decaying organic material. Hopkins and Aumer (1915) claim that the nitrite organisms associated with the decaying processes

FIG. 33. SERIES 1916. EFFECT ON GROWTH OF A SUBSEQUENT WHEAT CROP PRODUCED BY THE INCORPORATION IN THE SOIL OF GREEN MANURE AT VARIOUS STAGES OF MATURITY AND THE SUBJECTION OF THE MIXTURE TO A TWELVE-MONTHS INCUBATION PERIOD

The weights of green material added were constant
(Data given in table 3)

render available the insoluble phosphorus in the soil. Hopkins and Whiting (1916) applied green manures to soil residues from which the soluble potassium had been extracted. Sufficient insoluble potassium was liberated thereby to enable clover to grow luxuriantly when treated with lime and phosphorus. Snyder (1897) treated soils with green manures, and after allowing fermentation to proceed for one year he found

a considerable increase in the amount of available phosphorus and potassium in the soil humus. He attributes these results to the large amounts of carbon dioxide given off by the decaying organic matter, since this gas acts as a solvent on the minerals of the soil. Truog (1912) shows in his work that the availability of the insoluble compounds of phosphorus is due to the carbon-dioxide accumulations brought about by the decay of green manures.

FIG. 34. SERIES 1917. EFFECT ON GROWTH OF A SUBSEQUENT WHEAT CROP PRODUCED BY THE INCORPORATION IN THE SOIL OF GREEN MANURE AT VARIOUS STAGES OF MATURITY AND THE SUBJECTION OF THE MIXTURE TO A FOUR-MONTHS INCUBATION PERIOD

The weights of dry matter added were constant
(Data given in table 6)

It would appear, therefore, that decaying organic matter renders available the otherwise insoluble plant nutrients in the soil. The decomposition products, such as carbon dioxide and butyric, acetic, lactic, and other organic acids, are in all probability the causative factors for much of this increase. The more rapid or more complete the decay process, the more quickly do the decomposition products accumulate, accompanied by an increased amount of available nutrients. As an

increase in the availability of the plant nutrients in soil may be measured by the growth of crops, it is reasonable to conclude, from the foregoing data, that the increased crop yields from the soils receiving the more succulent manure were due to an increase in the availability of the nutrients in the soil.

CONSIDERATION OF EXPERIMENTAL ERROR

In order to determine the degree of significance of the data just presented, and also to obtain a check on the accuracy with which the various analyses

FIG. 35. SERIES 1918. EFFECT ON GROWTH OF A SUBSEQUENT WHEAT CROP PRODUCED BY THE INCORPORATION IN THE SOIL OF GREEN MANURE AT VARIOUS STAGES OF MATURITY AND THE SUBJECTION OF THE MIXTURE TO A FIVE-MONTHS INCUBATION PERIOD

The green manure at each stage came from equal soil areas
(Data given in table 9)

were performed, it was considered necessary to calculate the experimental error for the data obtained. This was done by finding the arithmetical mean values of the dry matter humified, of the nitrogen nitrified in the green manure, and of the total crop grown on the soils variously treated. The first two sets of means were expressed in percentages, the third in grams of dry matter produced. The probable error of these mean values

was then determined according to Peter's formula, as given by Mellor (1909). The formula is as follows:

$$R = \pm 0.8453 \frac{\Sigma (+v)}{n \sqrt{n-1}}$$

R represents the probable error; $\Sigma (+v)$ indicates the sum of the deviations of every observation from the mean, the sign of each deviation being disregarded; n denotes the number of observations actually made.

Before conclusions could be drawn as to the rate of decomposition of the green-manure crops, the following question was of necessity considered: Are the differences in the percentages of dry matter humified, in the grams of crop grown, and in the percentages of nitrogen nitrified in the green manure, in the variously treated pots, large enough to be significant? This question could be answered only by determining these differences and then calculating the probable error of each. The probable error was obtained by the use of the following formula:

$$E = \sqrt{E_1^2 + E_2^2}$$

In this formula E_1 and E_2 represent the probable errors of the values to be compared. Wood and Stratton (1910) state that such differences, to be significant, must be greater than 3.8 times the probable error. This would mean that the chances are thirty to one that such differences are due to treatment.

It is evident that the differences existing between the results obtained from pots treated with the most succulent manure and those from pots treated with manure at more advanced stages, are evidently greater than 3.8 times the probable error. Hence they are significant. In general, the differences existing between the two maturer stages, B and C , are not large. This is true not only for the humus data, but also for the nitrate and crop figures as well. It indicates that as the crops used for green manures approach maturity, the results show proportionately less benefit derived.

SUMMARY

The value of organic matter in soil is dependent on the ease with which it decays. The more rapidly it decomposes, the more quickly can it be used by the various agencies within the soil.

The greater the succulency of the crops used as green manures, the more quickly do they decay.

When crops are about half grown, they are at the point of maximum succulency. This is also the stage at which enough bulk has developed to create a fairly large increase in organic matter when the crop is incorporated with the soil.

Soils receiving incorporations of green manures at the half-mature stage, A, produced the largest crop yields when subsequently cropped.

Increasing amounts of dry matter added to a soil, in conjunction with increased maturity, have the same general effect on the humus formation, the accumulation of nitrates, and the crop growth, as does the addition of equal weights at each stage of increased maturity.

The more rapid the decomposition of green manures, the greater is the increase in the availability of plant nutrients in the soil, as shown by greater crop yields.

The younger the organic matter used, the larger is the percentage of total nitrogen present therein. —

Nitrates accumulate at the greatest rate when green manures of maximum succulency are incorporated with the soil.

Some of the nitrates formed in the soil by the influence of green manure are probably utilized by growing organisms.

Nitrates do not accumulate in the soil until the green manures have become considerably decomposed.

The more readily the organic material is decomposed, the more rapidly does humus accumulate and the sooner does it break down to simple products.

The longer the period during which green manures are allowed to humify in the soil, the less is the amount of humus found in the soil on analysis.

There are apparently three periods in the humification of organic matter. In the first period humus alone is formed, thus allowing an accumulation in the soil. During the second stage humic decomposition sets in and the humus is reduced as rapidly as it is formed; accordingly no further accumulation is accomplished. In the third period, humus formation ceases and the only process at work is that of humus decomposition, resulting in a rapid decrease in the amount of humus in the soil.

Under the same conditions, rye and oats decay at approximately the same rate. Buckwheat, however, particularly in the maturer stages, decays much more readily than do rye and oats of corresponding maturity.

CONCLUSION

In these investigations, using as measurements the rapidity of humus formation, the accumulation of nitrates, and the increased availability of the plant nutrients, the subsequent crop growth proved that the greatest rapidity of decomposition and the greatest benefit to the soil were achieved by the use of green manures at the half-grown stage. This is true for all three of the green manures used in this series of experiments.

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APPENDIX

TABLE 1. SERIES 1916.* EFFECT OF MATURITY OF GREEN MANURE ON AMOUNT OF HUMUS FORMED AT THE END OF TWELVE MONTHS

Crop	Number of pot	Green manure (grams)	Dry matter added (grams)	Proportionate amounts of dry matter added (per cent)	Humus formed in 12 months	
					Total (grams)	Average (grams)
Rye	1	181.5	30.9	100	14.56	15.55 $\pm$ 0.39
	2				16.25	
	3				15.84	
Rye.....	1	181.5	40.0	129	22.55	20.86 $\pm$ 0.67
	2				19.44	
	3				20.60	
Rye.....	1	181.5	53.0	171.5	25.10	22.77 $\pm$ 0.93
	2				21.80	
	3				21.40	
Oats.....	1	181.5	38.6	100	18.77	17.59 $\pm$ 1.28
	2				19.64	
	3				14.36	
Oats.....	1	181.5	38.5	99.7	15.09	16.62 $\pm$ 0.87
	2				16.45	
	3				18.32	
Oats.....	1	181.5	39.1	101.6	22.50	20.62 $\pm$ 0.74
	2				20.03	
	3				19.33	
Buckwheat.....	1	181.5	21.3	100	17.47	15.49 $\pm$ 0.80
	2				13.46	
	3				15.53	
Buckwheat.....	1	181.5	36.2	170	34.17	31.71 $\pm$ 1.33
	2				32.60	
	3				28.35	
Buckwheat.....	1	181.5	45.3	213	34.56	31.23 $\pm$ 1.32
	2				31.03	
	3				28.09	

* No checks were used with the 1916 series; hence the results will have to be interpreted in the light of this fact.

TABLE 2. SERIES 1916.* EFFECT OF MATURITY OF GREEN MANURE ON AMOUNT OF NITRATES FORMED AT THE END OF TWELVE MONTHS

Crop	Number of pot	Green manure (grams)	Dry matter added (grams)	Proportionate amounts of dry matter added (per cent)	Nitrates formed in 12 months	
					Total (parts per million)	Average (parts per million)
Rye.....A	1	181.5	30.9	100	248	253 $\pm$ 2.58
	2				260	
	3				252	
Rye.....B	1	181.5	40.0	129	97.5	104 $\pm$ 2.58
	2				108	
	3				108	
Rye.....C	1	181.5	53.0	171.5	42	42 $\pm$ 0.00
	2				42	
	3				42	
Oats.....A	1	181.5	38.6	100	270	280 $\pm$ 3.98
	2				290	
	3				280	
Oats.....B	1	181.5	38.5	99.7	120	109 $\pm$ 4.58
	2				108	
	3				98	
Oats.....C	1	181.5	39.1	101.6	22	20 $\pm$ 0.59
	2				20	
	3				19	
Buckwheat.....A	1	181.5	21.3	100	136	133 $\pm$ 1.39
	2				133	
	3				129	
Buckwheat.....B	1	181.5	36.2	170	295	291 $\pm$ 4.92
	2				279	
	3				300	
Buckwheat.....C	1	181.5	45.3	213	243	237 $\pm$ 2.78
	2				238	
	3				230	

* No checks were used in the 1916 series.

TABLE 3. SERIES 1916.* EFFECT OF MATURITY OF GREEN MANURE INCUBATED IN SOIL FOR TWELVE MONTHS ON GROWTH OF A SUBSEQUENT WHEAT CROP

Crop	Number of pot	Green manure (grams)	Dry matter added (grams)	Proportionate amounts of dry matter added (per cent)	Crop to each unit of dry matter added (grams)	Straw crop (grams)	Grain crop (grams)	Total crop (grams)	Average crop (grams)
Rye.....A	1	181.5	30.9	100	1.14	23.40	11.10	34.50	35.38 $\pm$ 1.87
	2					21.40	10.15	31.55	
	3					28.90	11.20	40.10	
Rye.....B	1	181.5	40.0	129	0.543	12.30	4.80	17.10	21.73 $\pm$ 1.84
	2					18.50	4.50	23.00	
	3					17.70	7.40	25.10	
Rye.....C	1	181.5	53.0	171.5	0.16	5.05	2.15	7.20	8.33 $\pm$ 1.19
	2					5.60	0.80	6.40	
	3					7.80	3.60	11.40	
Oats.....A	1	181.5	38.6	100	0.847	22.97	6.53	29.50	32.70 $\pm$ 1.27
	2					23.40	11.10	34.50	
	3					23.80	10.30	34.10	
Oats.....B	1	181.5	38.5	99.7	0.29	8.30	4.20	12.50	11.07 $\pm$ 1.02
	2					7.00	1.50	8.50	
	3					8.70	3.50	12.20	
Oats.....C	1	181.5	39.1	101.6	0.20	7.19	0.91	8.10	7.83 $\pm$ 0.25
	2					4.80	2.40	7.20	
	3					5.60	2.60	8.20	

* No checks were used in the 1916 series.

TABLE 4. SERIES 1917. EFFECT OF MATURITY OF GREEN MANURE ON PERCENTAGE OF DRY MATTER HUMIFIED AT THE END OF FOUR MONTHS

Crop	Number of pot	Green manure (grams)	Dry matter added (grams)	Proportionate amounts of green manure (per cent)	Humus recovered from each pot (grams)	Humus due to treatment* (grams)	Dry matter humified	
							Total (per cent)	Average (per cent)
Rye.....A	1	181.5	56.3	100	44.70	40.46	72	72 ± 0.60
	2				46.20	41.96	74	
	3				43.00	38.76	71	
Rye.....B	1	180.0	56.3	99.1	41.50	37.26	66	63 ± 1.39
	2				38.00	33.76	60	
	3				40.10	35.86	64	
Rye.....C	1	150.0	56.3	83	36.50	32.26	57	56 ± 1.59
	2				37.42	33.18	59	
	3				33.10	28.86	52	
Oats.....A	1	181.5	52.7	100	49.42	45.18	85	84 ± 1.79
	2				51.58	47.34	88	
	3				46.96	42.72	80	
Oats.....B	1	181.5	52.7	100	33.92	29.68	56	57 ± 0.99
	2				33.50	29.26	55	
	3				35.44	31.20	59	
Oats.....C	1	155.0	52.7	85.3	33.54	29.30	55	55 ± 0.59
	2				33.14	28.90	54	
	3				34.26	30.02	56	
Buckwheat...A	1	181.5	36.5	100	13.77	9.53	26	26 ± 1.79
	2				11.77	7.53	21	
	3				15.32	11.08	30	
Buckwheat...B	1	181.5	36.5	100	26.39	22.15	60	76 ± 6.17
	2				35.71	31.47	86	
	3				33.91	29.67	81	
Buckwheat...C	1	144.0	36.5	79.3	27.64	23.40	64	73 ± 5.67
	2				29.14	24.90	68	
	3				36.34	32.10	87	

* Untreated checks showed an average humus content of 4.24 grams to each pot.

TABLE 5. SERIES 1917. EFFECT OF MATURITY OF GREEN MANURE ON NITRIFICATION PROCESS AT THE END OF FOUR MONTHS

Crop	Number of pot	Green manure (grams)	Dry matter added (grams)	Proportionate amounts of green manure (per cent)	Nitrates in soil (parts per million)	Nitrates due to treatment* (parts per million)	Nitrogen added for each 100 grams of soil (milligrams)	Nitrogen in manure nitrified	
								Total (per cent)	Average (per cent)
Rye.....A	1	181.5	56.3	100	172	87		4.5	4.9 ± 0.13
	2				181	96	43.3	4.9	
	3				187	102	.....	5.2	
Rye.....B	1	180.0	56.3	99.1	62				
	2				69	.....	23.5	.....	
	3				60	.....	.....	.....	
Rye.....C	1	150.0	56.3	83	40				
	2				37	.....	18.3	.....	
	3				37	.....	.....	.....	
Oats.....A	1	181.5	52.7	100	262	177		17.0	17.0 ± 0.14
	2				258	173	22.7	16.7	
	3				267	182	.....	17.3	
Oats.....B	1	181.5	52.7	100	62				
	2				65	.....	17.0	.....	
	3				69	.....	.....	.....	
Oats.....C	1	155.0	52.7	85.3	51				
	2				47	.....	12.2	.....	
	3				44	.....	.....	.....	
Buckwheat..A	1	181.5	36.5	100	248	163		12.7	12.1 ± 0.23
	2				238	153	27.9	12.1	
	3				234	149	.....	11.5	
Buckwheat..B	1	181.5	36.5	100	297	212		19.0	19.7 ± 0.51
	2				305	220	24.0	21.0	
	3				298	213	.....	19.1	
Buckwheat..C	1	144.0	36.5	79.3	123	38		9.8	10.0 ± 0.08
	2				129	44	9.0	10.2	
	3				126	41	.....	10.0	

* Untreated checks showed an average nitrate content of 85 parts per million.

TABLE 6. SERIES 1917. EFFECT OF MATURITY OF GREEN MANURE INCUBATED IN SOIL FOR FOUR MONTHS ON GROWTH OF A SUBSEQUENT WHEAT CROP

Crop	Num- ber of pot	Green manure (grams)	Dry matter added (grams)	Propor- tionate amounts of green manure (per cent)	Crop to each unit of dry matter (grams)	Straw crop (grams)	Grain crop (grams)	Total crop (grams)	Total crop treat- ment* (grams)	Average crop due to treatment (grams)
Rye.....A	1	181.5	56.3	100	0.24	9.20	4.4	13.60	11.30	13.62 ± 1.19
	2					10.01	4.5	14.51	12.21	
	3					14.05	5.6	19.65	17.35	
Rye.....B	1	180.0	56.3	99.1	0.13	4.10	4.1	8.20	5.90	7.25 ± 0.82
	2					4.90	3.9	8.80	6.50	
	3					7.55	4.1	11.65	9.35	
Rye.....C	1	150.0	56.3	83	0.09	1.90	3.2	5.10	2.80	4.85 ± 0.81
	2					4.25	4.1	8.35	6.05	
	3					3.60	4.4	8.00	5.70	
Oats.....A	1	181.5	52.7	100	0.48	20.00	7.6	27.60	25.30	25.57 ± 0.81
	2					19.00	7.1	26.10	23.80	
	3					21.20	8.7	29.90	27.60	
Oats.....B	1	181.5	52.7	100	0.25	8.60	4.1	12.70	10.40	12.92 ± 2.72
	2					16.85	5.2	22.05	19.75	
	3					7.60	3.3	10.90	8.60	
Oats.....C	1	155.0	52.7	85.3	0.14	8.10	2.1	10.20	7.90	6.95 ± 0.71
	2					6.70	3.4	10.10	7.80	
	3					4.35	3.1	7.45	5.15	
Buckwheat.....A	1	181.5	36.5	100	0.70	18.60	3.9	22.50	20.20	25.23 ± 2.00
	2					27.10	4.5	31.60	29.30	
	3					24.40	4.1	28.50	26.20	
Buckwheat.....B	1	181.5	36.5	100	0.34	9.00	2.7	11.70	9.40	12.07 ± 1.72
	2					15.10	3.6	18.70	16.40	
	3					9.70	3.0	12.70	10.40	
Buckwheat.....C	1	144.0	36.5	79.3	0.24	8.50	2.1	10.60	8.30	8.60 ± 0.47
	2					9.00	3.1	12.10	9.80	
	3					7.60	2.4	10.00	7.70	

* Untreated checks showed an average total crop growth of 2.3 grams.

TABLE 7. SERIES 1918. EFFECT OF MATURITY OF GREEN MANURE ON PERCENTAGE OF DRY MATTER HUMIFIED AT THE END OF FIVE MONTHS

The green material at each stage came from equal soil areas

Crop	Number of pot	Green manure (grams)	Dry matter added (grams)	Proportionate amounts of dry matter added (per cent)	Humus recovered from each pot (grams)	Humus due to treatment* (grams)	Dry matter humified	
							Total (per cent)	Average (per cent)
Rye.....A	1	181.5	36.3	100	11.16	4.43	12.2	15.3 ± 2.39
	2				14.58	7.85	21.6	
	3				11.14	4.41	12.1	
Rye.....B	1	323.0	78.0	215	12.44	5.71	7.3	8.3 ± 0.47
	2				13.07	6.34	8.1	
	3				14.12	7.39	9.5	
Rye.....C	1	366.0	150.0	413	16.72	9.99	6.6	8.1 ± 0.51
	2				19.90	13.17	8.8	
	3				20.02	13.29	8.8	
Oats.....A	1	181.4	34.4	100	13.93	7.20	21.0	20.0 ± 0.40
	2				13.81	7.08	20.0	
	3				13.12	6.39	19.0	
Oats.....B	1	273.0	63.0	183	15.60	8.96	14.1	15.9 ± 0.53
	2				17.39	10.66	16.9	
	3				17.36	10.63	16.8	
Oats.....C	1	350.0	122.0	355	23.97	17.24	14.1	14.0 ± 0.04
	2				23.38	16.65	13.9	
	3				24.03	17.30	14.1	
Buckwheat...A	1	181.5	27.2	100	17.00	10.27	38.0	32.4 ± 2.25
	2				14.93	8.20	30.0	
	3				14.63	7.90	29.1	
Buckwheat...B	1	345.0	69.0	254	19.82	13.09	18.9	19.7 ± 1.31
	2				19.52	12.79	18.5	
	3				21.62	14.89	21.6	
Buckwheat...C	1	400.0	100.0	368	21.03	14.30	14.3	15.8 ± 0.73
	2				24.33	17.60	17.6	
	3				22.16	15.43	15.4	

* Untreated checks showed an average humus content of 6.73 grams to each pot.

TABLE 8. SERIES 1918. EFFECT OF MATURITY OF GREEN MANURE ON NITRIFICATION
PROCESS AT THE END OF FIVE MONTHS
The green material at each stage came from equal soil areas

Crop	Num- ber of pot	Green manure (grams)	Dry matter added (grams)	Proportionate amounts of dry matter added (per cent)	Ni- trates in soil (parts per million)	Ni- trates due to treat- ment* (parts per million)	Ni- trogen added for each 100 grams of soil (milli- grams)	Nitrogen in manure nitrified	
								Total (per cent)	Average (per cent)
Rye.....A	1	181.5	36.3	100	100	142		12.56	12.44 ± 0.10
	2				190	142	24.0	12.56	
	3				175	127	.....	12.20	
Rye.....B	1	323.0	78.0	215	165	117		7.40	7.30 ± 0.02
	2				160	112	33.5	7.30	
	3				160	112	.....	7.30	
Rye.....C	1	366.0	150.0	413	44	0		0.00	0.04 ± 0.007
	2				52	4	66.0	0.06	
	3				54	6	.....	0.06	
Oats.....A	1	181.4	34.4	100	280	232		15.80	15.63 ± 0.08
	2				267	219	26.0	15.40	
	3				272	224	.....	15.70	
Oats.....B	1	273.0	63.0	183	195	147		9.45	9.30 ± 0.08
	2				165	117	28.8	9.10	
	3				180	132	.....	9.35	
Oats.....C	1	350.0	122.0	355	150	102		6.23	6.21 ± 0.06
	2				158	110	37.0	6.35	
	3				142	94	.....	6.05	
Buckwheat..A	1	181.5	27.2	100	400	352		35.30	35.37 ± 0.17
	2				385	337	22.4	34.00	
	3				415	367	.....	36.80	
Buckwheat..B	1	345.0	69.0	254	533	485		20.00	20.80 ± 0.64
	2				533	485	52.0	20.00	
	3				571	523	.....	22.40	
Buckwheat..C	1	400.0	100.0	368	460	412		18.00	18.20 ± 0.55
	2				440	392	56.5	17.00	
	3				492	444	.....	19.60	

* Untreated checks showed an average nitrate content of 48 parts per million.

DECOMPOSITION OF GREEN MANURES

167

The green material at each stage came from equal soil areas

Crop	Num- ber of pot	Green manure (grams)	Dry matter added (grams)	Propor- tionate amounts of dry matter added (per cent)	Crop to each unit of dry matter (grams)	Straw crop (grams)	Grain crop (grams)	Total crop (grams)	Total crop due to treat- ment* (grams)	Average crop due to treatment (grams)
Rye.....A	1	181.5	36.3	100	0.64	24.0	2.5	26.5	22.2	23.4 ± 1.33
	2					28.6	2.4	31.0	26.7	
	3					23.6	1.9	25.5	21.2	
Rye.....B	1	323.0	78.0	215	0.17	17.1	0.9	18.0	13.7	13.2 ± 0.79
	2					14.3	1.2	15.5	11.2	
	3					17.1	1.9	19.0	14.7	
Rye.....C	1	366.0	150.0	413	0.07	11.2	1.8	13.0	8.7	9.4 ± 1.33
	2					9.0	2.0	11.0	6.7	
	3					15.1	1.9	17.0	12.7	
Oats.....A	1	181.4	34.4	100	0.56	20.5	2.5	23.0	18.7	19.0 ± 0.45
	2					20.5	2.0	22.5	18.2	
	3					22.6	1.9	24.5	20.2	
Oats.....B	1	273.0	63.0	183	0.13	11.4	1.6	13.0	8.7	8.5 ± 0.73
	2					9.5	1.5	11.0	6.7	
	3					12.7	1.8	14.5	10.2	
Oats.....C	1	350.0	122.0	355	0.04	9.0	1.2	10.2	5.9	4.8 ± 1.09
	2					9.1	1.7	10.8	6.5	
	3					5.4	1.0	6.4	2.1	
Buckwheat.....A	1	181.5	27.2	100	0.74	20.3	2.3	22.6	18.3	20.2 ± 0.99
	2					21.4	2.4	23.8	19.5	
	3					24.0	3.0	27.0	22.7	
Buckwheat.....B	1	345.0	69.0	254	0.19	17.6	1.8	19.4	15.1	13.1 ± 0.83
	2					13.9	1.9	15.8	11.5	
	3					15.9	1.1	17.0	12.7	
Buckwheat.....C	1	400.0	100.0	368	0.13	18.2	1.3	19.5	15.2	12.9 ± 0.91
	2					15.9	1.2	17.1	12.8	
	3					13.2	1.8	15.0	10.7	

* Untreated checks showed an average total crop growth of 4.3 grams.

TABLE 10. COMPARISON OF THE AMOUNTS OF DRY MATTER HUMIFIED FROM CROPS INCORPORATED WITH SOIL AT DIFFERENT STAGES OF GROWTH*

(The first letter appearing on the left side of the column represents the greater percentage of humification. For the differences to be significant, they must be 3.8 times the probable error.)

Crop	Series 1917 (Data given in table 4)		Series 1918 (Data given in table 7)	
	Stages of growth compared	Difference (per cent)	Stages of growth compared	Difference (per cent)
Rye.....	A and B A and C B and C	9 ± 1.51 16 ± 1.67 7 ± 1.95	A and B A and C B and C	7.0 ± 2.43 7.2 ± 2.44 0.1 ± 0.69
Oats.....	A and B A and C B and C	27 ± 2.04 29 ± 1.87 2 ± 1.14	A and B A and C B and C	5.0 ± 0.90 6.0 ± 0.40 1.0 ± 0.80
Buckwheat.....	B and A B and C C and A	50 ± 6.45 3 ± 8.41 47 ± 5.93	A and B B and C A and C	12.7 ± 2.13 3.9 ± 1.49 16.6 ± 1.84

* No checks were used in the 1916 series; hence for that series no calculations could be made.

TABLE 11. COMPARISON OF THE AMOUNTS OF NITROGEN NITRIFIED IN CROPS INCORPORATED WITH SOIL AT DIFFERENT STAGES OF GROWTH*

(The first letter appearing on the left side of the column represents the greater percentage of nitrification. For the differences to be significant, they must be 3.8 times the probable error.)

Crop	Series 1917 (Data given in table 5)		Series 1918 (Data given in table 8)	
	Stages of growth compared	Difference (per cent)	Stages of growth compared	Difference (per cent)
Rye.....	..... ..... .....	..... ..... .....	A and B A and C B and C	5.11 ± 0.10 12.40 ± 0.10 7.29 ± 0.02
Oats.....	..... ..... .....	..... ..... .....	A and B A and C B and C	6.33 ± 0.11 9.42 ± 0.10 3.09 ± 0.10
Buckwheat.....	B and A B and C A and C	$7.6 \pm .55$ $9.7 \pm .51$ $2.1 \pm .24$	A and B A and C B and C	14.57 ± 0.65 17.17 ± 0.57 2.60 ± 0.84

* No checks were used in the 1916 series; hence for that series no calculations could be made.

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