THE EFFECT OF [illegible] ON NITRIFICATION AND ACCUMULATION OF [illegible] IN THE SOIL, AND YIELD [illegible] COMPOSITION OF [illegible] IVE APPLICATI[illegible]

by

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INTRODUCTION

Recent production of relatively large quantities of commercial ammonium nitrate in the state of Kansas has stimulated considerable interest in the most efficient use of this material as a nitrogen fertilizer for increased wheat production. It is an established fact that frequently the turning under of large quantities of straw residue has an adverse effect on succeeding wheat crops, particularly if delayed plowing is practiced. This adverse effect on wheat yields results, in part, from a lack of available nitrogen in the soil at the time of seeding the wheat crop due to the competition for nitrates by the organisms engaged in decomposition processes.

The practice of burning wheat straw has been partially justified sometimes as a means of eliminating this competition. However, it has been recognized that such practices do destroy a supply of organic matter for humus production, a component becoming quite deficient in many Kansas soils. Thus, any system of soil management that can most efficiently accomplish maximum wheat yields and result also in conservation of organic matter, both that contained in soil humus and in crop residues, has much practical significance in wheat production.

For the above reasons, it was deemed advisable to attempt a controlled investigation of this problem with the purpose of yielding additional information relative to the effects of applications of organic matter and nitrogen fertilizers to the soil on the yield and composition of wheat and the resultant influences on various soil properties and phenomena. A greenhouse experiment which involved the use of both normal applications and excessive quantities of straw residue was decided upon to investigate the effects of various amounts of ammonium nitrate when applied to the soil. In the following pages is described an experiment in which some of these problems were investigated.

REVIEW OF LITERATURE

Early investigations in the development of dry farming showed the advantage of early plowing and subsequent production of a good seed bed. These investigations indicate that the increased yields were due to the moisture conserved. Buckman (9) was one of the first to show that moisture was only one of the factors contributing to higher yields. He found that wheat yields on the dry lands of Montana were correlated with the amount of nitrates in the soil. Somewhat later, Call (11) likewise concluded that the supply of available nitrogen was an important factor in the production of grain in dry-land areas.

Bracken (6, 7), of Utah, collected data at the Nephi Dry Land Station from 1928 to 1933, inclusive, relative to the effect of soil treatment on the yield of winter wheat. It was concluded that decreased moisture supplies and reduced amounts of available nitrate nitrogen significantly reduced yields of winter wheat. Manural treatments, because of the content of considerable available nitrogen in this material, gave yields 16 percent higher than plots receiving no manure. Significant increases in protein content also resulted from application of barnyard manure.

The results of early investigation of Sievers and Holtz (40), on the nitrogen and organic matter relationships in the silt loam soils of eastern Washington, indicated that in the course of 39 years of cropping with small grains, principally wheat alternated every second or third year with summer fallow, these soils lost approximately 22 percent of their nitrogen and about 34 percent of their humus. The loss of humus resulted in a pronounced deterioration of the physical condition of the soil and severe erosion on the steeper slopes during periods of heavy rainfall.

Holtz and Vandecaveye (22), working with Palouse silt loam in Washington, concluded that the practice of returning straw to the soil, although having a beneficial physical effect on the soil and causing a decline in the rate of loss of soil humus under the prevailing cropping practices, cannot be expected to result in the production of substantial quantities of new humus, unless the straw is supplemented with some form of available nitrogen in sufficient quantities to make the supply approximately equivalent to alfalfa hay.

Various studies (3, 4, 6, 16, 23, 39, 41) indicate that prolonged periods of dry-land farming of semi-arid soils resulted generally in a loss of soil organic matter. Other investigators (45), working on the effects of organic residues and nitrogen fertilizers on Ritzville very fine sandy loam at Lind, Washington, found that applications of straw alone in amounts equivalent to or larger than those supplied by normal wheat crops are helpful in maintaining soil organic matter and nitrogen content under a system of wheat farming in semi-arid lands.

Sivers (42) made analyses of soil samples taken at the Massachusetts Agricultural Experiment Station experimental plots which had been treated with different kinds of nitrogen fertilizers. Determinations of total nitrogen, organic carbon, and volatile matter content were made. These results indicated that the nitrogen-carbon ratio of soils was a fairly constant phenomenon and that pronounced variations in soil treatment, even though effective in producing wide differences in yield, had no consistent influence on either soil organic matter or nitrogen content. It was concluded that any treatment which resulted in increased organic matter in the soil had also a very nearly proportional increase in nitrogen content and thus there can be no apparent increase in the amount of one without an accompanying increase of the other.

Various investigators (1, 15, 37, 47, 53) have shown that crops immediately following additions of strawy residues to the soil frequently suffer from a lack of available nitrogen. Some investigators (14, 1 , 25, 39) maintain that inadequate supplies of available nitrogen in the soil are reflected in a reduced protein content of the grain produced on such soils. Others (6, 18, 47) contend that climatic influences rather than available nitrogen are the principal controlling factors.

Pinck, Allison and Gaddy (31), working on the nitrogen requirement for the utilization of carbonaceous residues at Beltsville, found that additions of straw produced the usual marked decreases in yield of crop grown after its addition. The nitrogen content of the harvested crop was decreased by the straw in approximately the same proportion as was the yield. Additions of urea wholly counteracted the effect, showing that under greenhouse conditions the injury produced by the straw was due entirely to decreased availability of nitrogen. A delay of six weeks in planting after addition of straw resulted in an even lower nitrogen content of wheat.

To counteract the effect of straw on nitrogen availability, approximately 16.5 to 18.0 pounds of nitrogen as urea had to be added per ton of straw applied when the wheat was planted immediately following such treatment. Nearly two pounds more were required per acre under conditions of delayed planting. Thus sufficient nitrogen had to be added to make the nitrogen-carbon ratio approximately 1 to 35 to avoid injury by the excess straw. This is a nitrogen content of ordinary dry organic matter equivalent to 1.2 percent. There was no evidence of injury by straw other than its effect on nitrogen availability.

Pendleton (29), working with nitrate fertilizers on oats in Iowa, concluded that early applications of sodium nitrate to oats may appreciably increase the yield. Early applications were found superior to late ones. The late as well as early applications of sodium nitrate caused an increase in nitrogen content of grain, but the late applications gave the highest nitrogen content. The use of superphosphate without nitrate had little effect on the yield of oats.

Large increases in the yield of wheat can generally be obtained from the addition of nitrogen fertilizers to the soils in the Palouse area of eastern Washington as was shown by Doneen (14). Where only limited quantities of available nitrogen were in the soil, the addition of nitrogen fertilizer stimulated plant growth and caused an increased yield and increased nitrogen content of the grain. On soils containing sufficient quantities of available nitrogen for large yields of grain, the addition of sodium nitrate as a fertilizer caused a retardation of growth during the vegetative period of the plant and did not materially increase the yield or the nitrogen content of the grain.

The yield response of wheat to large amounts of available nitrate nitrogen in the soil, or to nitrogen fertilizer applied during the early vegetative period of the plant has been demonstrated by the studies of numerous other investigators. Notably among these are the experiments carried on by Burke (10), Davidson and LeClerc (13), Neidig and Snyder (25), Rivers and Holtz (40) and Vandecaveye and Baker (49). Vandecaveye and Baker (49) have shown that for every 100 pounds of sodium nitrate fertilizer employed, the yield was increased by three or four bushels.

Gainey and Sewell (17) of Kansas indicate that the small, well-defined areas, usually 2 to 4 feet in diameter, of taller and darker green plants in grain fields in central and eastern states may logically be attributed to urine deposits from winter pasturing.

Data of these investigators show that plants from such spots made 2.6 times the total growth, contained 1.8 times as much nitrogen per unit weight, and had actually assimilated 4.68 times as much nitrogen per plant as those from the field at large. The soil of the spots contained 2.5 times as much nitrate nitrogen and was capable of increasing this surplus 3.3 times in six weeks. These data indicate that the increased growth and yield of grain on the type of spots under study can be attributed primarily to a more abundant supply of nitrogen; and that the soil is able to supply more available nitrogen to the growing plant because a limited quantity of nitrogen capable of being more easily transformed into the nitrate form has found its way into the soil.

Thatcher (47), working on the importance of humus to dry farming, states that a lack of organic matter reduced fertility because of a scanty supply of nitrogen. The water holding capacity is reduced due to the lack of humus and friability is reduced rendering soil more difficult to till. Thatcher (47) concluded that the humus supply of the soil may be increased by regularly plowing under the stubble.

Albrecht (1), working with wheat straw mulches, noted changes in nitrate nitrogen in the soil beneath the straw. Results of his study suggest that mulching with straw depressed nitrification in the soil, and one may readily expect only those crops to do well which are able to obtain adequate nitrogen from such a low concentration.

Murphy (24) found that nitrogen fertilizers added to wheat in the fall just following seeding influenced its composition. The protein content increased as the amount of nitrogen in the fertilizer was increased. Seventy-five pounds of sodium nitrate did increase the protein content over untreated soils. One-hundred and fifty pounds of sodium nitrate gave the greatest returns per unit of nitrogen supplied. Above 150 pounds of sodium nitrate, the increase in protein was slight.

Pendleton (29), working on two different soils in Iowa, in an effort to clear up conflicting results formerly obtained by the use of sodium nitrate on wheat as a top dressing, obtained results which indicate that the yields may be increased by top dressing certain soil with sodium nitrate. A top dressing of 100 to 200 pounds per acre of sodium nitrate early in the spring seems to be most profitable. Increased yields produced by the fertilizer was of more significance than the increase in protein content of the grain.

The results of various investigators indicate that response to additions of nitrogen fertilizer is somewhat influenced by varietal characteristics, seasonal variations and other environmental factors. Parker and Truog (27) have shown by analysis of 34 species of plants that the variations in composition are mainly characteristics of the species. Many other investigators (21, 43, 20, 51, 26) have made similar observations where different species were grown under essentially the same conditions. These variations are frequently attributed to specific differences in selective absorption and feeding power (48).

METHODS OF EXPERIMENTATION

The experimental work reported in this study was accomplished in the greenhouse and in the soils laboratories of the Department of Agronomy. Forty-eight glazed earthenware jars of one gallon capacity each were used as containers for the various cultures. The soil used in this experiment was obtained from the Agronomy farm, Kansas Agricultural Experiment Station. This Geary silty clay loam previously had been cropped to wheat and had been plowed sometime before the sample was collected for use in the greenhouse.

Twenty-four of the cultures received an application of straw equivalent to 25 tons per acre while the other 24 received an application equivalent to 10 tons per acre. This straw was finely chopped with scissors and the sample for each culture was weighed individually before incorporation with the soil.

The two straw series were each divided into six fertility treatments as follows: no treatment, 300 pounds per acre of ammonium nitrate, 600 pounds per acre of ammonium nitrate, 900 pounds per acre of ammonium nitrate, 1200 pounds per acre of ammonium nitrate, and 1500 pounds per acre of ammonium nitrate. Both the straw and the fertilizer material were incorporated with the entire mass of soil by mixing in a rotating churn 14 days prior to planting. The cultures were given sufficient distilled water to bring the moisture content to the moisture equivalent and were maintained at this level throughout the course of investigation by frequent weighings.

Twenty-five grains of Reward wheat were planted in a circular band two inches from the outside edge of the cultures on November 30, 1946. The stand of wheat on all cultures was reduced to 12 plants each two weeks after planting. The jars were placed on a bench in the greenhouse at random and were moved about regularly so as to reduce to a minimum the differential effects of light and temperature. Six weeks after planting, an artificial lighting system was installed so as to provide an extra five hours of light daily during the remainder of the experiment.

The wheat was harvested on February 26, 1947. The heads of wheat were separated from the stems for convenience in threshing the samples. The stems were clipped just above the surface of the soil in each culture. All of the plant material was allowed to become thoroughly dry before threshing of the grain and chemical analyses were conducted. The threshing was accomplished by means of hand thresher and the chaff from each culture was placed with the stems of the plant material so that total yields of straw could be obtained.

Nitrate nitrogen determinations were made on the soil in the various cultures at three different times during the course of investigation. These determinations were made on the cultures just prior to planting, 30 days after planting and at the time of harvest. Soil samples were collected by means of a sampling tube for the first two determinations and were taken from the whole mass of soil at the conclusion of the experiment. Extraction of nitrate nitrogen was made on a 50-gram sample of soil in every determination. A separate 25-gram sample was dried in the oven for moisture determination. The method used for measuring the nitrate nitrogen content of the soil was the phenol disulfonic acid technique described by Prince (35). Results of these determinations are expressed in parts per million of the elemental nitrogen existing in the form of nitrates and based upon the amount of oven dry soil.

Total nitrogen determinations were made on each sample of grain and straw that was harvested from the various cultures. Total nitrogen determinations were also made on a sample of soil obtained from each of the cultures at the completion of the experiment. These analyses were accomplished by use of the Gunning-Hibbard method as outlined by the Association of Official Agricultural Chemists (5) except that the ammonia distillate was collected in a four percent solution of boric acid. The titration of the ammonia was accomplished by using standard sulfuric acid solution with a combination of brom cresol green and methyl red indicators being used. Total nitrogen content of the soil is expressed on a percentage basis as well as content of nitrogen in milligrams being reported for the total plant tissue for each of the various treatments.

Organic carbon determination on each sample of soil from the various cultures was accomplished by means of Allison's modification of the Schollenberger method (2). The results of these analyses are expressed on the percentage basis.

Statistical evaluations of the various data were made in accordance with the methods outlined by Patterson (28).

NITRIFICATION STUDIES

Nitrate nitrogen determinations indicated certain significant differences between the various treatments at each of the three dates such measurements were made. The results of these determinations are presented in Tables 1, 2, and 3, respectively, in chronological sequence. Graphic presentation of these variations are made in Figs. 1 and 2.

The various applications of nitrogen fertilizer all had a significant influence at planting time on the content of nitrate nitrogen in the soil of the 2.5 tons straw series when compared with the no treatment cultures. Inasmuch as the increased nitrate content appears to be very nearly a linear function of rate of ammonium nitrate addition made at the beginning of the experiment this trend, as seen in Fig. 1, probably does not reflect a marked influence on nitrification processes in the soil.

The various additions of ammonium nitrate fertilizer to the 10 tons straw series apparently had essentially the same effect on nitrate nitrogen content by the time of planting as did the same applications on the 2.5 tons straw series. There were several notable exceptions to the general trend, however. The application of this fertilizer at the rate of 1200 pounds per acre gave values significantly lower than those obtained with the addition of only 900 pounds per acre of ammonium nitrate. The mean nitrate nitrogen content of the various cultures in this series were all consistently lower in value than those of the 2.5 tons straw series. This difference between the two series was of lesser magnitude where ammonium nitrate fertilizer was applied at the rate of 1500 pounds per acre than at any other rate.

The data for nitrate nitrogen content of the soil 30 days after planting of the wheat indicated much the same trend on the 2.5 tons straw series as did the original investigations. The content of nitrate nitrogen in the various cultures remained progressively larger for the addition of each increment of nitrogen fertilizer. However, the nitrate content was not significantly greater than the no treatment culture for any rate of ammonium nitrate application until at least 900 pounds per acre had been added. The various cultures receiving more than 300 pounds per acre of ammonium nitrate fertilizer all had considerably greater amounts of nitrate nitrogen this date than was found at planting time. Both the no treatment cultures and those receiving only 300 pounds per acre of ammonium nitrate had lower levels of nitrate nitrogen than just 30 days previously. The nitrate content of the soil which received 1500 pounds per acre of ammonium nitrate per acre was slightly, though not significantly, lower than that of the cultures receiving 1200 pounds per acre of the same fertilizer.

The results of nitrate nitrogen determinations for this date on the 10 tons straw series revealed certain differences when compared with the content of the various cultures of the 2.5 tons straw series for the same date. The only two cultures which had significantly higher mean levels of nitrate nitrogen than the no treatment were those which received 300 pounds per acre and 1500 pounds per acre of ammonium nitrate. The cultures receiving 600 pounds per acre and 900 pounds per acre of ammonium nitrate fertilizer had essentially the same level of nitrate nitrogen this date that existed at planting time. All other treatments resulted in a markedly greater accumulation of nitrate nitrogen this date than at the time of planting. A comparison of the levels of nitrate nitrogen content between the two straw series indicated a significantly higher level at the 300 pounds per acre of ammonium nitrate application for the 10 tons straw series. The 10 tons straw series was also slightly higher at the 1500 pounds per acre rate of fertilizer addition although this difference was too slight to be significant.

The nitrification studies made on the soil at the completion of the experiment revealed additional differences not previously so apparent. The trend on the 2.5 tons straw series followed much the same pattern that had been noted on previous dates. The various cultures receiving the additions of ammonium nitrate at the beginning of the experiment all had progressively larger amounts of nitrate nitrogen at this time than the no treatment cultures but the magnitude of this difference in favor of the addition of nitrogen fertilizer became even much greater for the extremely large additions of this material than had been previously detected. The differences of nitrate nitrogen content between this date and both of the previous dates for the various cultures in the series were much larger at the higher rates of applications of nitrogen fertilizer. Such differences became particularly marked after the addition of at least 900 pounds per acre of ammonium nitrate.

The same studies at the close of the experiment for the 10 tons straw series indicated still additional differences. The level of nitrate nitrogen this date for both the no treatment cultures and the cultures receiving only 300 pounds per acre of ammonium nitrate was well below that for the previous date on which such studies were made. However, the content of nitrate nitrogen was still above that for the same cultures at the start of the experiment. The cultures receiving 600, 900 and 1200 pounds per acre of ammonium nitrate all had much higher levels of nitrate nitrogen at this time than at any previous date. The mean level of nitrate nitrogen in the cultures receiving 1500 pounds per acre of ammonium nitrate was also considerably greater than for any previous studies although not nearly so much greater, relatively speaking, as were the three rates of applications previously mentioned. It was also noted that the application of only 900 pounds per acre of ammonium nitrate resulted in the highest level of nitrate nitrogen for this series on this date. This was in distinct contrast with the 2.5 tons straw series where the highest level was not attained at this date until the maximum addition of nitrogen fertilizer at the beginning of the experiment was made.

Certain other considerations of the data discussed above were noteworthy. There was a consistent tendency for the various increments of ammonium nitrate fertilizer added at the beginning of the experiment to have a very favorable effect on nitrification on the 2.5 tons straw series. This favorable effect, as previously noted, became even more apparent with each succeeding determination of nitrate nitrogen content of the various cultures. The magnitude of this favorable influence was particularly obvious at the higher rates of ammonium nitrate fertilizer application at the time of the second and third determinations of nitrate nitrogen. However, such consistent variations were not apparent for the 10 tons straw series. That there was no consistent influence on nitrate nitrogen accumulation in the soil was suggested by both the determinations made 30 days after planting and at the conclusion of the experiment. Thus, the marked effect of excessive applications of straw to the soil on nitrification processes was clearly illustrated. This marked disturbance in nitrification processes due to the excessive application of straw was also indicated by the consistent tendency of various cultures of this series to attain levels of nitrate nitrogen considerably lower than those of the 2.5 tons straw series.

Table 1. Nitrate nitrogen data for November 30, 1946.

Equivalent application of ammonium nitrate	Mean* nitrate nitrogen content Straw series	
	2.5 tons	10 tons
lbs./acre	ppm	
No treatment	20.05**	12.25**
300	30.65	19.65
600	32.58	22.88
900	42.75	34.90
1200	47.70	24.96
1500	48.10	41.85

* Mean of four replicates.
** Difference required for significance 1% 9.20 5% 14.33

Table 2. Nitrate nitrogen data for December 30, 1946

Equivalent application of ammonium nitrate	Mean* nitrate nitrogen content Straw series	
	2.5 tons	10 tons
lbs./acre	ppm	
No treatment	17.33**	29.28**
300	22.51	57.08
600	38.49	23.65
900	5[illegible].10	34.64
1200	83.10	41.60
1500	77.60	78.73

* Mean of four replicates.
** Difference required for significance 1% 17.54 5% 23.05

Table 3. Nitrate nitrogen data for February 26, 1947.

Equivalent application of ammonium nitrate	Soil* nitrate nitrogen content: Straw series, 2.5 tons	Soil* nitrate nitrogen content: Straw series, 10 tons
lbs./acre	ppm	
No treatment	50.43**	20.32**
300	53.42	39.89
600	58.00	79.55
900	107.00	98.22
1200	106.66	82.92
1500	138.66	90.98

* Mean of four replicates.

** Difference required for significance: 1% 78.67; 5% 103.39

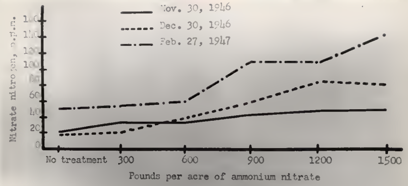

Fig. 1. Nitrification in 2.5 tons straw series.

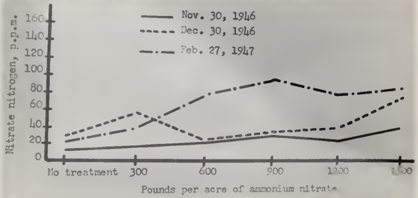

Fig. 2. Nitrification in 10 tons straw series.

YIELD DATA AND HARVEST RESULTS

Grain Yields

The paramount purpose in the production of most crops is to obtain maximum profits for the time and labor invested. The success of any small grain enterprise such as the production of wheat is determined, at least to a considerable extent, by the return in bushels per acre of harvested grain. Therefore, a considerate evaluation of the effect of nitrogen fertilizer on the production of grain is of much significance. The mean weight of grain for each culture for both series is presented in Table 4 and graphically in Figs. 3 and 4.

It is particularly interesting to note that applications of nitrogen fertilizer at the rate of less than 1200 pounds per acre of ammonium nitrate did not stimulate the yield of grain on the 2.5 tons straw series. Significant increases in grain yield for this series did not result until 1500 pounds per acre of ammonium nitrate had been applied. The trend afforded in Fig. 3 suggests, however, that there was an increasing tendency for higher yields of grain on this series with the addition of over 900 pounds per acre of ammonium nitrate.

A consideration of the 10 tons straw series suggests a different trend than was noticed for the 2.5 tons straw series.

Applications of 300 pounds per acre of ammonium nitrate and each rate above 600 pounds per acre resulted in increased yields as compared with no treatment. Inasmuch as a significant reduction was not obtained by the use of 600 pounds per acre of ammonium nitrate, the beneficial effect of additions of nitrogen fertilizer to a soil receiving 10 tons per acre of straw was clearly indicated.

A comparison of the grain yields for the two series reveals that the 2.5 tons straw series gave consistently higher yields for all fertilizer treatments than did the series receiving the very heavy application of straw. The difference between the two series was greatest where no treatment was employed and with an application of 900 pounds per acre of ammonium nitrate the difference was very small. However, above this rate of application, there was considerable difference in favor of the lesser amount of straw which was added to the soil.

Table 7 revealed that certain rates of nitrogen fertilizer addition were relative more efficient than others in increasing grain yields over no treatment. The maximum addition of fertilizer to the 2.5 tons straw series gave the greatest increase in grain yield per unit of added nitrogen over no treatment. On the 10 tons series this was not true as the addition of 1200 pounds per acre of ammonium nitrate proved the most efficient. There was comparatively little difference among the various other cultures except that the addition of

600 pounds per acre of ammonium nitrate did not increase the yield. There were considerably higher increases per unit of added nitrogen obtained with the heavy application of straw than were obtained from the cultures receiving a small application of straw.

Straw Yields

The yields of straw from the 2.5 tons straw series indicated differences which were not apparent from an examination of the grain yields. Every addition of nitrogen fertilizer resulted in increased straw yields when compared with no treatment. Thus the tendency for small additions of nitrogen fertilizer to depress grain yields on this series was not apparent in the straw yield data.

The straw yields for the 10 tons series followed much the same trend as did those for the 2.5 tons series insofar as each addition of nitrogen fertilizer resulted in an increased yield of straw over no treatment. However, the highest yield of straw on this series was obtained by the use of 900 pounds per acre of ammonium nitrate while on the 2.5 tons straw series 1200 pounds per acre were required. The straw yield obtained from the use of 900 pounds per acre of ammonium nitrate on the 10 tons straw series resulted in the highest mean yield of straw for either series. The heavier applications of nitrogen fertilizer resulted in higher yields of straw on the 2.5 tons straw series than on the 10 tons straw series.

The use of 900 pounds per acre of ammonium nitrate on the 2.5 tons straw series resulted in a noticeable decrease in yield of straw as comapred with the 600 pounds per acre application. However, in distinct contrast the same application of nitrogen fertilizer on the 10 tons straw series was particularly effective in stimulating the yield of straw. A comparison of these facts with corresponding grain yields for the same treatments indicated that at this rate of application the added nitrogen on the 10 tons series resulted in relatively much more stimulation of the straw than of the grain. Above this rate of application and on the same series this tendency seemed to diminish. Both grain and straw yields for the higher rates of application of nitrogen fertilizer on the 2.5 tons straw series increased in much the same manner, as evidenced by Fig. 3.

Yield of Total Plant Tissue

The mean yield of total plant tissue from each of the various cultures for both series is reported in Table 6 and presented graphically in Figs. 4 and 5 for the 2.5 and 10 tons straw series, respectively. These data merely reflect the cumulative yields reported previously under the discussion of grain and straw yields. The total plant yields for the 2.5 tons series were, with one exception, noticeably above those for the 10 tons series. It was particularly interesting that the 900 pound per acre application of ammonium nitrate on the 10 tons straw series resulted in the highest total yield of plant tissue while on the other series, this same treatment produced next to the lowest yield for the 2.5 tons application of straw. A slight decrease in total plant tissue was noticed on the 10 tons straw series for fertilizer applications above 900 pounds per acre while on the other series the most pronounced increase in total yield was noted above this rate of application.

Table 4. Yield of wheat, February 27, 1947.

Equivalent application of ammonium nitrate lbs/acre	Mean* yield of grain for Straw series 2.5 tons	10 tons
	grams	
No treatment	2.237**	1.640**
300	1.937	1.793
600	1.996	1.632
900	2.177	2.110
1200	2.588	2.340
1500	2.706	2.330

* Mean of four replicates.
** Difference required for significance: 5% .59; 1% .78

Table 5. Yield of straw, February 27, 1947.

Equivalent application of ammonium nitrate lbs./acre	Mean* yield of grain for Straw series 2.5 tons	10 tons
	grams	
No treatment	4.165**	4.171**
300	4.225	4.300
600	4.875	4.545
900	4.675	5.499
1200	5.362	4.923
1500	5.205	4.928

* Mean of four replicates.
** Difference required for significance: 5% .91; 1% 1.20

Table 6. Yield of total plant tissue, February 28, 1947.

Equivalent application of ammonium nitrate lbs./acre	Mean* yield of total plant tissue Straw series 2.5 tons	Mean* yield of total plant tissue Straw series 10 tons
	grams	
No treatment	6.402**	5.811**
300	6.162	6.093
600	6.[illegible]71	6.177
900	6.342	7.309
1200	7.950	7.263
1500	7.911	7.258

* Mean of four replicates.
** Difference required for significance: 5% 1.46; 1% 1.92

Table 7. Relative efficiency of added nitrogen fertilizer in increasing grain yields.

Equivalent application of ammonium nitrate lbs./acre	Increase in grain yield over no treatment Straw series 2.5 tons	Increase in grain yield over no treatment Straw series 10 tons	Increase in grain yield per gram added nitrogen Straw series 2.5 tons	Increase in grain yield per gram added nitrogen Straw series 10 tons
	grams			
300	-.300*	.153	-1.500	0.765
600	-.241	-.002	-0.602	0.002
900	-.060	.470	-0.100	0.783
1200	.351	.700	0.439	0.875
1500	.469	.690	0.469	0.690

* - values indicate decreases.

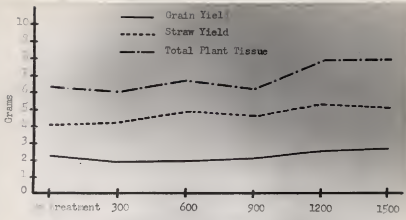

Fig. 3 Yield of wheat from 2.5 tons straw series

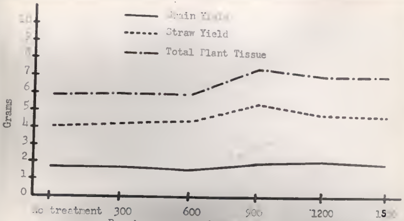

Fig. 4 Yield of wheat from 10 tons straw series

The Nitrogen Composition of the Grain

Table 8 contains a summary of the mean percentage composition of nitrogen in the grain from the various cultures of both series. The nitrogen composition, in general, was very high. The grain harvested from the various cultures was badly shriveled and apparently quite immature and a higher percentage nitrogen was found than could normally be anticipated.

The data for the 2.5 tons straw series indicate that the heaviest application of nitrogen fertilizer gave the highest percentage nitrogen composition of the grain. Several of the lower rates were also noticeably higher in percentage nitrogen than the no treatment cultures but results were not consistent.

The data in Table 9 for the 10 tons straw series were even less consistent than those for the 2.5 tons straw series. The grain from the cultures receiving the equivalent of 900 pounds per acre of ammonium nitrate was the only sample which had a higher percentage nitrogen than no treatment. There was a distinct tendency for the cultures of the 10 tons straw series to have a higher percent of nitrogen than those of the 2.5 tons straw series. This tendency was in distinct contrast to either yields of grain or nitrification processes noted previously.

The Nitrogen Composition of the Straw

The data reported in Table 9 pertaining to the percentage nitrogen composition of the straw reflected somewhat less inconsistency than noted for the composition of the grain. No culture receiving an application of nitrogen fertilizer produced a lower percent of nitrogen in the straw than no treatment. The highest application of fertilizer produced the culture with the highest percent of nitrogen in the straw.

These data for the 10 tons straw series indicated much the same tendency as was noted for the series receiving a smaller application of straw. All applications of ammonium nitrate, except that of 300 pounds per acre, produced slightly higher percentages of nitrogen in the straw than no treatment. The heaviest application of fertilizer also produced straw with the highest percent of nitrogen for this series. All except two of the cultures on this series were lower in percent nitrogen than of the 2.5 tons series.

Inasmuch as there was less inconsistency noted for the nitrogen composition of the straw, it may be assumed logically that applications of nitrogen fertilizer as made under the conditions of this experiment affect more readily the composition of the straw than that of the grain. The adverse effects of a heavy application of straw noted on yields of grain and on nitrification processes were also reflected to a con-

Table 8. Nitrogen composition of grain.

Equivalent application of ammonium nitrate	Mean* nitrogen composition grain for straw series	
	2.5 tons	10 tons
lbs./acre	percent	
No treatment	4.102	4.419
300	4.140	4.255
600	4.285	4.168
900	4.293	4.639
1200	4.053	4.146
1500	4.399	4.367

* Mean of four replicates.

Table 9. Nitrogen composition of straw.

Equivalent application of ammonium nitrate	Mean* nitrogen composition straw for Straw series	
	2.5 tons	10 tons
lbs./acre	percent	
No treatment	1.751	1.772
300	1.865	1.666
600	2.018	1.925
900	1.872	1.852
1200	1.325	1.841
1500	2.190	1.936

* Mean for four replicates.

siderable extent in the nitrogen composition of the straw even though not apparent when composition of the grain was considered.

The Nitrogen Content of the Grain

A consideration of the percent of nitrogen in plant tissue does not reflect all the necessary information needed in evaluating the affects of additions of nitrogen fertilizer. Since yields of plant tissue varied considerably more than actual percentage nitrogen composition of the plant tissue, it becomes necessary to consider the actual total recovery of nitrogen by the various cultures of both series. These data are reported in Table 10 and are presented graphically in Fig. 5.

No increase in total nitrogen content of grain for any culture on the 2.5 tons straw series was noticed until as much as 900 pounds per acre of ammonium nitrate fertilizer was applied. The recovery of nitrogen in the grain rose very noticeable above this rate of application.

There was even somewhat more tendency for the nitrogen applications to stimulate the total nitrogen content of grain from the 10 tons straw series inasmuch as all rates of application resulted in an average recovery for the culture higher than no treatment except the application of 600 pounds per acre. Inasmuch as noticeable variations in percentage composition of nitrogen did not occur for the grain, it was readily apparent that the total recovery of nitrogen in the grain was largely a function of the yield and not of the percentage composition.

The Nitrogen Content of the Straw

All cultures of the 2.5 tons straw series which received additions of nitrogen fertilizer had a greater quantity of nitrogen in the straw than the no treatment culture. There was a tendency for the increased recovery of nitrogen in the straw to be very nearly a linear function of the added increments of fertilizer with the exception of the treatment in which 600 pounds per acre of ammonium nitrate were applied. In all cultures, except this one, there was more nitrogen recovered in the grain than in the straw. There was a considerably greater recovery of nitrogen in the straw than in the grain for the treatment in which 600 pounds per acre of ammonium nitrate were applied.

The applications of added increments of nitrogen fertilizer on the 10 tons straw series did not reflect the same tendencies noted above. The greatest recovery of nitrogen in the straw occurred with addition of 900 pounds per acre of ammonium nitrate. Somewhat of a decrease in the recovery of nitrogen was noted on this series for heavier applications. Relatively more nitrogen was recovered in the grain than in the straw at both very low additions and very heavy applications of ammonium nitrate in the 10 tons straw series. Applications of 600 and 900 pounds per acre of ammonium nitrate resulted in more nitrogen being recovered in the straw than in the grain.

The Nitrogen Content of the Whole Plant

The data presented in Table 12 afford a better comparison of the total amount of nitrogen recovered in the various cultures than does a consideration of either grain or straw recovery alone. It may be seen from Fig. 8 that all applications of nitrogen fertilizer, except 100 pounds per acre of ammonium nitrate, resulted in a larger recovery of nitrogen in the plant tissue. However, the increased recovery of nitrogen was most strikingly apparent with additions of more than 900 pounds per acre of ammonium nitrate.

The same data indicate that somewhat of a different situation existed for the 10 tons straw series. The greatest recovery occurred with an application of 1500 pounds per acre with essentially the same amount being recovered with an addition of but 900 pounds per acre of ammonium nitrate.

It may be seen from Table 13 that the efficiency of nitrogen recovery was greatest with the heaviest application of nitrogen for the 2.5 tons straw series. There was essentially no difference between applications of 600 pounds per acre and

Table 10. Total nitrogen content of grain.

Equivalent application of ammonium nitrate	Mean* total nitrogen content grain for Straw series	
	2.5 tons	10 tons
lbs./acre	mgms	
No treatment	91.78	72.79
300	80.06	77.51
600	86.13	67.79
900	93.52	96.92
1200	105.31	95.93
1500	120.11	101.24

* Mean for four replicates.

Table 11. Total nitrogen content of straw.

Equivalent application of ammonium nitrate	Mean* total nitrogen content straw for Straw series	
	2.5 tons	10 tons
lbs./acre	mgms	
No treatment	72.95	73.66
300	78.39	72.21
600	98.49	87.24
900	87.09	101.11
1200	97.49	91.36
1500	114.42	95.17

* Mean of four replicates.

Table 12. Total nitrogen content of entire plant tissue.

Equivalent application of ammonium nitrage	Mean* total nitrogen content of entire plant for Straw series	
	2.5 tons	10 tons
lbs./acre	mgms	
No treatment	164.73	146.45
300	158.45	149.72
600	164.62	155.03
900	180.61	198.03
1200	202.80	187.29
1500	234.53	198.41

* Mean of four replicates.

Table 13. Relative efficiency of added nitrogen fertilizer as reflected in the recovery of nitrogen by wheat plants.

Equivalent application of ammonium nitrate	Recovery of additional nitrogen over no treatment		Increase in nitrogen content of plant per gram of added nitrogen	
	Straw series			
	2.5 tons	10 tons	2.5 tons	10 tons
lbs./acre	mgms			
300	- 6.28	3.27	-31.40	16.35
600	19.39	9.58	49.27	23.95
900	15.88	51.58	26.47	85.97
1200	38.07	40.84	47.59	51.05
1500	69.80	51.96	69.80	51.96

* - values indicate decreases.

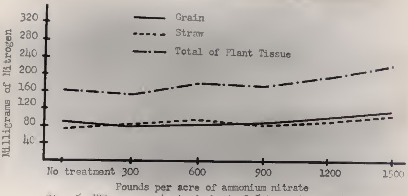

Fig. 5 Nitrogen content of wheat, 2.5 tons straw series

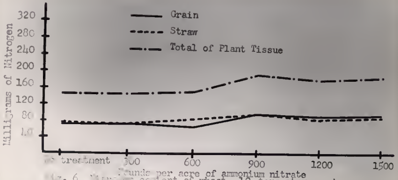

Fig. 6 Nitrogen content of wheat, 10 tons straw series

1200 pounds per acre of ammonium nitrate but 900 pounds per acre was of low efficiency and an application of only 300 pounds per acre caused a decrease in nitrogen recovery. There was an increase in efficiency of nitrogen recovery with each addition of nitrogen fertilizer on the 10 tons straw series up to an application of 900 pounds per acre of ammonium nitrate with an apparent decline for rates of fertilizer above this amount.

Nitrogen and Carbon Status of the Soil

The original nitrogen content of the soil used in this experiment was 0.1665 percent. An analysis of a sample of the same soil with the addition of straw equivalent to 2.5 tons per acre indicated a nitrogen content of 0.1672 percent. All applications of nitrogen fertilizer greater than 300 pounds per acre for this series resulted in a higher nitrogen content of the soil at the conclusion of the experiment than was apparent at the beginning. The application of 900 pounds per acre of ammonium nitrate resulted in more nitrogen remaining in the soil than either the rate of application immediately above or below. This was in agreement with data in Table 13 which indicated a relatively low recovery of nitrogen by the plants of this particular culture.

The mean nitrogen content of each of the various treatments which included nitrogen fertilizer for the 10 tons straw series was consistently above the original level of 0.1728 percent for the soil which was analyzed after an equivalent application of 10 tons of straw per acre. Thus, there was distinct indication that the heavy application of straw combined with the addition of nitrogen fertilizer was favorable for an elevation of the nitrogen content of the soil under the conditions of this investigation. There was also distinct indication that the culture which resulted in the most efficient recovery of nitrogen in the plant tissue did so at the expense of nitrogen conserved in the soil inasmuch as the application of 900 pounds per acre resulted in the lowest percentage of nitrogen in the soil for any culture of this series which had the benefit of added nitrogen. These data are reported in Table 14.

The data in Table 15 incidate little variation of significance with regard to percentage carbon in the soil at the conclusion of the experiment. There apparently was a slight tendency for those cultures receiving more than 900 pounds per acre of ammonium nitrate to have a lower percentage of carbon in the soil at the end of the experiment on the 2.5 tons straw series than cultures which received smaller applications. The application of 900 pounds per acre of ammonium nitrate on the 10 tons straw series gave the maximum efficiency of nitrogen recovery by the wheat plants and a comparatively low content of nitrogen in the soil. This culture had the highest percent of carbon in the soil at the conclusion of this investigation.

A comparison between the original carbon content of the soil and that at the completion of the experiment provided interesting facts. The cultures of the 2.5 tons straw series were all definitely below the original soil after the addition of straw in carbon content at this time. However, these cultures all had considerably more carbon in the soil than was in the original soil before the addition of any straw. The cultures of the 10 tons straw series were appreciably higher in most instances in carbon content at the end of the experiment than were the cultures of the 2.5 tons straw series but the reduction in carbon content when compared with that of the soil immediately after the addition of straw at the rate of 10 tons per acre was very much greater.

The mean carbon-nitrogen ratios for the various cultures are reported in Table 16. All of the treatments of the 2.5 tons straw series produced a narrower ratio than was found in the original soil after the addition of straw. All of the cultures of this series which received an application of more than 300 pounds per acre of ammonium nitrate had narrower ratios than the original soil even before the addition of straw had been made.

These data for the 10 tons straw series indicated that the various treatments which included nitrogen fertilizer all had mean carbon-nitrogen ratios which were narrower than that of the original soil before the addition of the straw except that in which 900 pounds per acre of ammonium nitrate were added. This treatment, however, produced a narrower ratio than did no treatment. The various treatments of the 10 tons straw series had a tendency to have narrower carbon-nitrogen ratios than did those of the 2.5 tons straw series except where no treatment or 900 pounds per acre of ammonium nitrate were used.

Table 14. The nitrogen and carbon composition of straw and soil, November 30, 1946.

Material	Composition: Carbon	Composition: Nitrogen	C-N ratio
	percent		
Straw	23.400	0.7900	29.62
Original soil	1.[illegible]91	0.1665	11.36
Soil + 2.5 tons/acre straw	1.949	0.1672	11.65
Soil + 10 tons/acre straw	2.125	0.1728	12.24

Table 15. The total nitrogen composition of the soil, February 27, 1947.

Equivalent application of ammonium nitrate	Mean* nitrogen composition of soil, Straw series: 2.5 tons	10 tons
lbs./acre	percent	
No treatment	0.1669**	0.1636
300	0.1670	0.1753
600	0.1727	0.1755
900	0.1744	0.1742
1200	0.1722	0.1[illegible]24
1500	0.1798	0.1[illegible]91

* Mean of four replicates.

** Difference required for significance: 5% 0.0090; 1% 0.0118

Table 16. The organic carbon composition of the soil, February 27, 1947.

Equivalent application of ammonium nitrate	Mean* organic carbon composition of soil	
	Straw series	
	2.5 tons	10 tons
lbs./acre	percent	
No treatment	1.926	1.946
300	1.924	1.936
600	1.939	1.915
900	1.940	2.003
1200	1.911	1.971
1500	1.906	1.951

* Mean of four replicates.

Table 17. The ratio of carbon to nitrogen in soil, February 27, 1947.

Equivalent application of ammonium nitrate	Mean* carbon-nitrogen ratio	
	Straw series	
	2.5 tons	10 tons
lbs./acre		
No treatment	11.54**	11.89**
300	11.52	11.04
600	11.23	10.92
900	11.12	11.50
1200	11.09	10.81
1500	10.60	10.32

* Mean of four replicates.
** Difference required for significance 5% 0.89 1% 1.17

SUMMARY AND CONCLUSIONS

A greenhouse experiment was conducted on Geary silty clay loam soil to ascertain the influence of relatively heavy applications of nitrogen fertilizer on the yield and composition of wheat and on certain chemical phenomena related to the soil. This investigation was conducted in conjunction with both normal and excessive applications of carbonaceous organic matter on the soil prior to the planting of Pawnee wheat.

The data discussed in this treatise revealed certain interesting and significant facts with regard to nitrification processes in the soil during the course of investigation. The level of nitrate nitrogen accumulation in the 2.5 tons straw series followed very closely the applications of nitrogen fertilizer made prior to seeding. The amount of nitrate nitrogen showed a distinct tendency to increase for each treatment throughout the course of study. A very high level of nitrate nitrogen was present in the cultures receiving very large amounts of ammonium nitrate fertilizer. Nitrification processes apparently were much disturbed by the addition of an equivalent of 10 tons of straw per acre. There was some tendency for the level of nitrate accumulations to increase during the course of investigation but fluctuations were quite pronounced.

The addition of ammonium nitrate fertilizer was quite effective in stimulating grain yields when very large quantities were used in conjunction with the excessive application of straw. This tendency was much less apparent on the series receiving only the normal applications of straw. Straw yields were stimulated in a somewhat similar manner to that noted for grain yields. Apparently the tendency for increased straw yields was even more apparent on the 2.5 tons straw series than on the 10 tons straw series at the very high levels of nitrogen fertilizer applications. The maximum yield of straw, however, for all treatments was obtained by an application of 900 pounds per acre of ammonium nitrate on the 10 tons straw series.

The percentage nitrogen composition of the grain was not appreciably influenced by the addition of ammonium nitrate on either straw series. There was, however, a marked tendency for additional nitrogen in the form of ammonium nitrate fertilizer to result in a higher percentage of nitrogen in the straw. This influence was most marked on the various cultures of the series receiving 10 tons of straw per acre.

The total quantity of nitrogen recovered by the wheat plants was influenced by the addition of ammonium nitrate fertilizer. The maximum amount was recovered on the 2.5 tons straw series where the largest amount of ammonium nitrate had been used and the relative efficiency of recovery was greatfor this treatment on this particular series. Maximum efficiency occurred with the addition of only 900 pounds per acre on the 10 tons straw series.

There was a distinct tendency for a portion of the added nitrogen which was not used by the plants to remain in the soil. This was especially true on the series receiving an application of straw equivalent to 10 tons per acre. The organic carbon content of the soil was appreciably lower on each series at the conclusion of the experiment than immediately after the addition of the straw. The various cultures of the 10 tons straw series all lost a very large amount of carbon during the experiment. Carbon-nitrogen ratios were very much narrower as a result of these tendencies. These ratios for the 10 tons straw series were not materially different from those of the 2.5 tons straw series at the close of the experiment.

A practical evaluation of these data and discussions is suggested. Even if it is granted that a greenhouse experiment has numerous restrictions when applied to the field, it may be concluded that excessive applications of carbonaceous organic matter do have a detrimental effect on the nitrification processes in the soil. This adverse influence is also reflected in the yield of wheat following such treatment.

The application of large quantities of nitrogen fertilizer has a very favorable effect in stimulating wheat yields after the incorporation of very large amounts of carbonaceous material. This favorable effect is not apparent on a soil initially well supplied with nitrogen and to which an excess of carbonaceous material has not been applied.

Added nitrogen in the form of commercial ammonium nitrate also has a favorable effect in restoring to the soil a normal carbon-nitrogen ratio. Added nitrogen which was not recovered by wheat plants growing on the soil remained in the soil at the end of the experiment and it may be concluded logically that this would become available for future plant utilization. Thus it may be concluded that additional benefits from the use of large quantities of ammonium nitrate could be anticipated, particularly in conjunction with a very heavy application of carbonaceous material, beyond the production of one crop of wheat.

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