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The vast area of sandy soils in Thailand which are low in fertility and can hardly hold water, prompted this investigation. A greenhouse study was conducted from December 1978 to April 1980 to find out the effect of straw on nitrogen availability that could affect dry matter yield and nitrogen uptake of spring wheat and ryegrass. A randomized block design with four replications was used. Each replication was composed of 27 treatments which include a factorial arrangement of three levels of straw, nitrogen fertilizer and water. Three crops of spring wheat followed by three cuttings of ryegrass were used as indicator plants. Dry matter yield and nitrogen uptake from both spring wheat and ryegrass were measured. Soils at different periods of cropping were analyzed for total nitrogen, incubated nitrogen and organic matter content. Results obtained were analyzed statistically to determine the factors significantly affecting dry matter yield, nitrogen uptake, total soil nitrogen, incubated nitrogen and soil organic matter.

It was observed in this study that in the first two cuttings of spring wheat, straw depressed dry matter yield when no nitrogen fertilizer was applied but when fertilizer was applied, straw aided in increasing dry matter yield. In the third cutting, however, increasing levels of straw gave higher dry matter yield both with and without

nitrogen application. For the first cutting of ryegrass, straw depressed dry matter yield at all levels of nitrogen fertilizer, but in the second and third cuttings, there were inconsistencies in dry matter yield due to added straw. Higher rates of fertilizer always gave higher dry matter yield in ryegrass but only in the second crop of spring wheat. Higher water content of soil always resulted in higher dry matter yield in spring wheat, but not always so in ryegrass. Nitrogen uptake by plants followed dry matter yield closely in most cases. Total soil nitrogen and incubated soil nitrogen decreased slowly following successive croppings. The addition of straw and fertilizer reduced the rate of decrease of total soil nitrogen while increasing straw levels helped to increase the amount of incubated nitrogen. Straw also had a tendency to increase soil organic matter content.

Results from this study suggest that straw together with fertilizer could have beneficial effects on dry matter yield, conserve total soil nitrogen and increase soil organic matter.

Effect of Organic Residue and Nitrogen Levels on Growth of Spring Wheat and Ryegrass

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INTRODUCTION

Organic matter is a part of every soil. Although the quantity of organic matter compared to the total weight of most mineral soil is relatively small, it can dramatically influence the soil's physical and chemical properties. More than half of the cation exchange capacity of soil may be associated with organic matter. Addition of organic materials to soil means adding nutrients for the plant, improving structure, influencing soil water, air and temperature relationships, helping control run off and erosion and making tillage easier. Intensive cultivation can reduce the amount of organic matter rapidly. This reduction is due mainly to a lower return of plant residues, a greater oxidation rate, and loss of surface soil by erosion.

Scientists agree that use of crop residue is desirable in modern agriculture, but the question of how much residue should be returned to the soil depends on the inherent soil properties, kinds of residue and methods of management, fertilizer application, soil moisture and the crop itself.

About 400 million metric tons of crop residues are produced each year by the nine leading crops in the U.S. These residues contain about 4.0, 0.5 and 4.0 million metric tons of nitrogen, phosphorus and potassium, respectively. Therefore, any system that will remove these residues must consider the return of the nutrients associated with the residue if crop production levels are to be maintained. Incorporation of straw may increase soil-borne diseases, interfere with stand establishment and reduce yields.

It is well known that immobilization of available N occurs when crop residues of low N content are incorporated into soil. This is due to the N demand of microorganisms during the decomposition process. Cereal and grass straws may contain N in a range from 0.2 to

0.6% and are considered to be lower than the quantity needed by micro-organisms. So there is immediate concern that N deficiency will take place at least during early periods.

The main objective of this study is to determine the differences in yield and nitrogen uptake of spring wheat and ryegrass grown on soil with different levels of straw incorporated and with different levels of applied inorganic N fertilizer at three soil water levels.

LITERATURE REVIEW

General

When crop residues such as straw are added to soil, there occurs an exceedingly rapid increase in microorganism activities with the resultant depletion of available N. If no N is supplied, the rate of decomposition slows down and plants may suffer from N starvation (Pinck et al., 1946). Secondly, when straw is incorporated into soil, microorganisms may produce decomposition products such as organic acids, which affect plant growth (Rao and Mikkelsen, 1976).

The rate of decomposition will depend on what compounds are present. Sugar and water-soluble protein are examples of readily available energy sources for soil organisms. Lignins are a very slowly available source of food, although they eventually supply much total energy (Brady, 1974).

Soil organic matter is made up of fresh and incompletely decomposed plant and animal residues and humus (Kononova, 1961). Humus consists of two major types of compounds, unhumified substances and the humified remains of plant and animal tissues. The former are represented by the various classes of organic compounds; including carbohydrates, fats, waxes, protein, tannins and lignins. The humified material consists of humic acid, fulvic acid, humins and hymatomelanic acid. Humic acid is defined as the material which is extracted from soil by alkaline solutions and which is precipitated upon acidification; fulvic acid is the material remaining in solution (Stevenson, 1972).

Nitrogen Cycle

Heterogenous soil organisms will attack the organic nitrogen compounds and as the result of enzymatic digestion, the more complex proteins and allied compounds are simplified and hydrolyzed. The end product is ammonia. Ammonium compounds are used by microorganisms, fixed by clay minerals and utilized by higher plants. Some ammonium-N will be oxidized by bacteria to become nitrite and then nitrate. Nitrate may be utilized by microorganisms and higher plants and can be readily leached from the soil. Denitrification allows its gaseous by-products to be lost from the soil system (Brady, 1974).

Losses and Conservation of Soil Nitrogen and Organic Matter

Under the semi-arid dryland agriculture conditions of Pacific Northwest, maintaining an adequate supply of nitrogen and organic matter for crops is of major importance (Oveson, 1966). Soil N is closely associated with organic matter. Brady (1974) stated that the ratio between soil N and soil organic matter is rather constant. A value for the ratio of 20:1 is commonly used.

Jones and Yates (1924) found that a soil in Sherman County (12" annually rainfall) had lost 12.8% of the total N and 16.1% of the organic matter in the surface foot of soil after 40 years of cropping.

Sievers and Holtz (1926) determined that the rate of decomposition of organic matter is in proportion to the nitrogen content of soil.

Russel (1929) concluded from his study that on the dry lands of Nebraska, losses of organic matter varied from 6.5% to 28%. Gainey et al. (1929) indicated that the greater the original N content of the soils, the greater the N losses. The losses over a 19-year period ranged from 40 to 676 pounds of N from soils with N range of 0.08% to 0.20%. They concluded that, under conditions found in a dry land farming area of Kansas, when N content of soil falls to approximately 0.1%, the factors responsible for additions of N to soil will counterbalance those tending to cause a removal, thereby establishing a nitrogen equilibrium near this level.

Oveson (1966) demonstrated by a series of experiments that when wheat straw was burned, either in the fall following the crop or in the spring before plowing, the soil N levels showed a continuous downward trend. When straw was returned without added N, no additional benefit was gained over burning the straw, either in retaining soil N or increasing wheat yields. When some form of N fertilizer was added to wheat straw before plowing, the results were improved N retention and increased wheat yields.

Stephens (1939) observed that N content of the surface foot of soil in a wheat-fallow system in the Northwest declined 12% in 10 years or decreased from 0.088% to 0.077%. Smith et al. (1946) did a comprehensive study on soil N and C at Pullman, Washington for 24 years and showed a depletion of soil N for a wheat-fallow system. The application of 6 tons of manure per acre (50 lbs. of N per acre) resulted in small loss of soil N under fallow and a large increase under annual cropping.

Results of a 34-year study conducted on Walla Walla silt loam at Pendleton, Oregon by Oveson (1966), as well as those obtained at St. Anthony, Idaho (1966) parallel those obtained in the Pullman study. Under the wheat-fallow system, a general loss of N occurred with time except where extremely high rates of residue were returned to soil. The biennial application of 10 tons of manure per acre at Pendleton increased the soil N by 7.5% over a period of 34 years.

Rate of Decomposition, Immobilization

Allison and Klein (1961) studied the rates of decomposition of woods and barks at two N levels. They found that when the rate of decomposition was slow, the soil was able to furnish adequate available N for maximum rates of decomposition for all wood products, and supplemental N was not needed. There are two reasons why the wood products were usually oxidized more rapidly in the absence of fertilizer N than in its presence. There was a salt effect at high N rate (200 lbs./A and above), which is in excess of microorganisms' need and the acidity produced during the nitrification of N, that lowered the pH below the level of optimum decomposition rates.

Allison and Klein (1962) pointed out that immobilization of N, in soil that was mixed with wheat straw, was very rapid during the first seven days, then decreased at a constant rate until the maximum value of approximately 1.7% N was reached at the end of 19 to 21 days. Nitrogen immobilization during this initial three weeks paralleled closely the rate of decomposition of the straw, as shown by CO_2 evolution. Following the maximum tie-up of N a slow release began almost immediately.

Pal and Broadbent (1975) incubated fine-textured soils, amended with doubly tagged (^{13}C and ^{15}N) rice straw under different moisture regimes at 22 C for four months. They found that net release of straw-N at 60% water holding capacity was higher than at 30% WHC. Soil inorganic N changes followed trends similar to net release of straw-N.

Quantity of N required and C/N Ratio

Allison and Cover (1960) showed the quantity of N required by soil microorganisms in the decomposition of straw. These values vary between 1.1 and 2.0% of dry weight of readily decomposable plant materials. Immobilization and mineralization proceed simultaneously; that is, N which is first immobilized may be in part released later.

Nitrogen requirement in the utilization of carbonaceous materials is shown to be dependent upon the composition of the material, the environmental conditions which affect the nature of the flora and rate of decay, and the time of incubation (Allison, 1961).

Pinck et al. (1946) reported that under winter greenhouse condition, if the C/N ratio of undecomposed straw was made about 35, no injury to plants was observed. Under spring and summer greenhouse conditions, the corresponding figure was 27 to 31.

Hutchinson and Richards (1921) demonstrated that for every 1,000 lbs. of dry straw containing 0.5% N, between 7 and 7.5 lbs. of

N are required to rot it. The rotted straw contained about 2% N.

Jensen (1929) observed that the critical C/N ratio of fresh plant materials decomposing in alkaline soil was 20 to 25, but in an acid soil it was 13 to 18.

Bartholomew (1965) stated that residues with a ratio of C/N greater than 33:1 are considered to give net immobilization of N, implying that more than the usual N fertilizer application may be required to meet the N requirements of crop and to maintain yield. The C/N ratio in corn stover residue is seldom less than 33:1. Net mineralization of N, on the other hand, may not occur until the ratio narrows to 20:1.

Most authors agreed that a value between 2 to 2.5% N are needed in order for a ready release of ammonia to occur from decay of dry straw.

The Effect of Straw on Yield, Nutrient and Soil

Ketcheson and Beauchamp (1978) studied the effect of corn stover, manure, and nitrogen on crop yield and found that where fertilizer N was not applied, stover depressed yields. Where N was applied, stover resulted in slightly higher yields than where stover was removed. Stover returned to soil did not increase fertilizer N requirement at normal rates of application. Fertilizer N narrowed the C/N ratio of stover residue, but this additional N was not reflected in total N content of grain or soil. Yields from residual N were higher on plots where stover had not been applied than where applied. Soil organic matter declined during the experiment, but stover residues and manure gave smaller declines than without residues. Corn stover and manure appear to have increased soil organic matter slightly over stover-removed treatments, but N fertilizer did not add to the effect. Likewise, total N tended to be highest without manure or stover.

Sandford et al. (1968) studied on the rate of N fertilizer with corn stover residue and concluded that stover incorporated in fall and N applied in spring maintained corn grain yields equal to that with residue removed. Stover incorporated in spring or N applied in fall reduced yields. They further showed that fall-incorporated residue also increased soil organic C and total N.

Ferguson (1967) showed consistently that in a field experiment in Manitoba, Canada, that repeated applications of cereal straw made a significant contribution to the yield of cereal grains. He attributed the benefit to more readily mineralizable N, and this was supported by higher N mineralization on incubation for 20 hours at 25 C in the laboratory.

Ferguson (1957) noted that oats yield from three tests, each of which compared three rates of N, were higher in stubble plus 4,500 lbs. of straw per acre than in stubble plus 1,500 or stubble plus 3,000 lbs. of straw per acre.

Rao and Mikkelsen (1976) believed that rice straw disposal by soil incorporation may have adverse effects on subsequent rice seedlings. When soil and rice straw were not incubated prior to planting rice seedlings, applied N was immobilized, causing inhibition of plant growth and low N content of plants. When rice straw was incubated in soil for 15 to 30 days before planting, N immobilization was reduced and growth was promoted.

Sicar and Bhowrick (1940) demonstrated that green manure crops decompose faster than rice straw in flooded soil and both may produce organic acids.

Chandrasekaran and Yoshida (1973) incorporated fresh leaves of Sesbania sp. and observed, under anaerobic conditions, the production of organic acid reaches its peak at five days after application.

Rai (1965) studied the effect of incorporating sorghum straw on yields of the subsequent sesame crop. When N was not applied, incorporation of straw 30 days before planting depressed yields. When straw was removed, yields were increased. With the application of 48 kg of N/ha or more, yields were the same with any of the methods of straw disposal.

Krantz et al. (1968) had similar results with sugar beet and safflower. Adding N fertilizer together with the straw residues reduced the uptake of fertilizer N by succeeding crops. The reduced uptake was a consequence of microbial N immobilization.

Williams et al. (1968) found that the critical N content of the rice straw was 0.54%. Straw with N above this value increased rice yields while straw-N below this value reduced yields.

Ferguson and Gorby (1964) incorporated straw in early fall and applied N in the following spring before planting oats and wheat. No N deficiency or yield reduction resulted from the straw addition.

Chaminade (1963) summarized his work on the depressing effect of straw, that straw lost its effects in two months and that yields were higher in the presence of straw decomposed for longer incubation periods than in controls.

Pinck (1946) found that additions of straw produced the usual marked decreases in yield of crop grown after its addition. Additions of urea wholly counteracted the effect, showing that under greenhouse conditions the injury produced by straw was due entirely to decreased N availability.

Reddy and Patrick, Jr. (1978) found that in the plots where no N was applied the plants were apparently dependent on the N mineralized from the organic fraction of the added rice straw. The grain and straw yields were higher in all the plots receiving larger amounts of rice straw. This trend was reversed when both straw and fertilizer N were applied and indicates that more of the applied fertilizer N was immobilized in the plots receiving high rates of straw as compared to check plots.

Morachan et al. (1972) believed that yield decline in cornstalk treatments was due to a lowering of pH and an aluminum-induced calcium deficiency in the plant.

Larson et al. (1972) stated that organic C, N, S, and P contents of soils increased in proportion to the amount of plant residues added. The amount of cornstalk residue needed to prevent loss of organic C was estimated to be 6 tons per hectare per year.

Ferguson and Gorby (1964) concluded on their studies that incorporation of straw into soil did not generally induce a N deficiency in the succeeding cereal crop. Low temperatures and lack of moisture in the fall and spring reduced the rate of straw decomposition.

Storrier (1963) observed that rains of greater than one inch following a dry period in the spring did stimulate mineralization of organic N and increase yield.

Stanford and Epstein (1974) reported that the highest mineralization rates occurred at moisture tensions between 1/3 and 1/10 bar when 80 to 90% of the pore space was filled with water. Soil water contents above optimum reduced nitrate accumulation due to denitrification.

Black (1973) found that as residue levels increased, soil organic matter, N, C, and C/N ratio increased significantly in the 0 to 15 cm. soil depth after four crop-fallow cycles; no changes occurred below 15 cm.

MATERIALS AND METHODS

Newburg soil, Fluventic Haploxerolls subgroup, zero to six inches deep which had never been cultivated was collected from the Hathaway farm, five miles Southeast of Corvallis. Some properties of this soil are given in Table 1.

Table 1. Properties of Newburg Soil Used in the Experiment

Total Nitrogen	0.156%
Organic matter	3.066%
Water holding capacity at field capacity	31.35 %
Texture	fine sandy loam
Base saturation	75.00 %
pH (1:5)	5.9

The soil was air-dried and passed through a 1/4 x 1/4 inch sieve. Bentgrass straw (0.5% N) obtained in the Corvallis area was chopped into pieces approximately one inch long and mixed with 2,500 grams (oven-dried basis) of test soil in separate pots (8 inches in diameter and 8 inches deep) at the rate of 0, 1 and 2% by weight of soil. Phosphate fertilizer was applied to all treatments at 50 lbs. P_2O_5/A or 0.11 grams per pot as treble superphosphate. Soil was limed to pH 6.5 with calcium carbonate. Both phosphate and lime were thoroughly mixed into soil. Three rates of nitrogen (0, 100 and 200 lbs. of N/A) or 0, 0.22 and 0.44 grams of N per pot, respectively, as ammonium nitrate (33% N) was applied to each level of straw and soil water. These elements were mixed thoroughly and kept for one week in the greenhouse at respective soil water levels (50, 65 and 80% of field capacity). The temperature in the greenhouse was maintained between 65 and 80°F. Artificial light was also used to supplement the natural light intensity. Day length was maintained at the minimum of 14 hours during the winter.

Three crops of spring wheat (Triticum aestivum L. var. 'Siete Cerros') were seeded consecutively using the same pots. Seeds were germinated on a moist cloth for three days prior to planting. The first planting was made on December 15, 1978 and three weeks later (January 9) a second crop was established. The first set was harvested at flowering stage when plants were 45 days old, and the second at maturing stage when plants were 100 days old. After the January 9th planted wheat was harvested, a third crop of wheat was begun in the same pots. This last set was harvested 100 days later. During the experiment, soil water was maintained at the three indicated levels by weighing each pot and adding water to reach the desired moisture level every other day.

After the final crop of wheat was harvested, bentgrass straw, nitrogen and phosphate fertilizer were again applied to the respective treatments at the rates previously given. The mixtures were incubated in greenhouse at 65 to 80°F for one week at the three different moisture levels. Then Manhattan perennial ryegrass seeds were sown to each pot at the rate of 8 lbs./1,000 square feet. Three consecutive cuttings of ryegrass were done at 65-day intervals at half-inch above ground.

Dry matter, height, and number of tillers were measured on all wheat plants. Only dry matter was determined for ryegrass. Total nitrogen of both wheat and ryegrass for each harvest or cutting was determined by micro-kjeldahl method of Nelson and Sommers (1973) and Bremner and Edwards (1965).

Following the harvest of the second and third spring wheat crops and the third cutting of ryegrass, soil samples were collected for chemical analysis of total nitrogen by Bremner (1965), incubated nitrogen by Waring and Bremner (1964) and soil organic matter by Walkley and Black (1934).

The experimental design was a randomized block arrangement with four replications for the total of 108 pots. Treatments used in the experiment are listed in Appendix Table 1.

RESULTS AND DISCUSSION

Dry Matter Yield of the First, Second and Third Cuttings of Spring Wheat

The effect of different rates of N and levels of straw and soil water on dry matter yield of the first spring wheat crop is presented in Table 2. The interaction between straw and N was highly significant (Table 3). Straw acted to suppress dry matter production where N was not applied. Yields at zero N were reduced by 0.22 g as straw increased from 0 to 2%. The addition of N overcame the negative effect of straw, with yield increasing by 0.09 and 0.12 at 100 and 200 lbs of N/A, respectively. Dry matter production also was depressed by the 200 lbs of N/A, with an average of 0.76 g at 100 lbs of N/A, compared to 0.71 g at 200 lbs of N/A. The depressive effect of the high rate of N could have come from two reasons. First, the application of 200 lbs of N/A which was in excess of the need of microorganisms could have created a salt effect. Secondly, the acidity produced during nitrification of this N would affect the yield. These two effects may have been either direct inhibitions or they may have modified the microflora and may have reduced the nutrient uptake rates (Allison and Klein, 1961).

The means of dry matter production as affected by three levels of soil water are shown in Table 2. Water has a strong influence on dry matter. In general, as soil water increased, dry matter production increased. There were no significant interactions between N, straw and water.

Mean square values for dry matter yield of the three harvests of spring wheat are presented in Table 3. The application of straw did not significantly affect the dry matter yield of the first cutting, but it did on the second and third cuttings. The first set of spring wheat was grown during the first 45 days; within this period plants could absorb enough N from soil so addition of straw did not affect dry matter yield. However, when plants were allowed to grow for a

Table 2. Dry matter yield of the first cutting of spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		g/pot					
0	0	0.48	0.55	0.78	0.60		
	100	0.65	0.76	0.84	0.75		
	200	0.66	0.67	0.69	0.67	0.67	
1	0	0.46	0.53	0.64	0.54		
	100	0.62	0.75	0.75	0.71		
	200	0.70	0.57	0.71	0.66	0.64	
2	0	0.36	0.39	0.38	0.38		
	100	0.79	0.81	0.93	0.84		
	200	0.59	0.84	0.93	0.79	0.67	
Mean Water		0.59	0.65	0.74			
N x W	N_0	0.43	0.49	0.60			0.51
	N_{100}	0.68	0.77	0.84			0.76
	N_{200}	0.65	0.70	0.77			0.71
S x W	S_0	0.59	0.66	0.77			
	S_1	0.59	0.62	0.70			
	S_2	0.58	0.68	0.74			

Table 3. Mean square values for dry matter yield of the first, second and third cuttings of spring wheat.

Source of Variation	df	First Cutting	Second Cutting	Third Cutting
Block	3	0.04	3.57*	0.96*
Straw	2	0.01	6.37**	19.69**
Nitrogen	2	0.67**	56.70**	1.42**
Straw x Nitrogen	4	0.13**	4.33**	0.35
Water	2	0.20**	169.04**	94.73**
Straw x Water	4	0.01	1.71	3.27**
Nitrogen x Water	4	0.00	2.14	0.61
Straw x Nitrogen x Water	8	0.04	0.63	0.41
Error	78	0.02	1.18	0.29
Total	107			

*Significant at .05 probability level.

**Significant at .01 probability level.

longer period as in the second and third cutting, the addition of straw had a highly significant effect on dry matter yield (Table 3).

The second crop was grown at 52 to 152 days following straw incorporation. During this period mineralization of N contained in the straw may have increased plant available N and enhanced yields. Table 23 shows that the concentration of incubated N, representing the product of mineralization, was significantly higher at 2% than at 0 or 1% straw, following the second wheat cutting. Although incubated N comprises only a small fraction of the total soil N, the fact that its level increased directly with increases in straw suggests that N immobilization, initially stimulated by the straw, had been surpassed in importance by N mineralization.

In the second cutting, the mean square values for block indicated significant differences (0.05 level). This was due mainly to light intensity that was hard to control in the greenhouse. There was evidence that blocks that were assigned to the table near the wall produced lower yields. However, the significant difference from block indicated that physical arrangement of the experiment successfully decreased the experimental error.

Dry matter yield of the second cutting of spring wheat is presented in Table 4. The interaction between straw and N was highly significant (0.01 level). The nature of the interaction was similar to the first cutting. When N was not applied, both levels of straw produced lower yields. When N was applied, dry matter increased as straw increased. When N was not applied, dry matter decreased as straw levels increased, due to depressive effect of N immobilization. When straw was incorporated into soil, microbial populations may have multiplied rapidly. Since straw was generally low in N, microorganisms must get N from soil. They would utilize and change soil N into organic N which would not be immediately available to plants. Plants that were grown during this period would suffer from N deficiency and have lowered yield. In the second case, when N was applied, dry

Table 4. Dry matter yield of the second cutting of spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
				g/pot			
0	0	5.04	6.40	9.31	6.91		
	100	5.52	6.87	10.39	7.59		
	200	5.92	8.15	10.84	8.30	7.60	
1	0	4.37	5.37	7.52	5.75		
	100	5.85	7.64	10.31	7.93		
	200	6.48	7.38	10.88	8.25	7.31	
2	0	4.56	6.49	7.27	6.11		
	100	6.54	9.32	11.14	9.00		
	200	6.69	9.14	12.10	9.31	8.14	
Mean Water		5.66	7.42	9.97			
N x W	N_0	4.66	6.09	8.03			6.26
	N_{100}	5.97	7.95	10.61			8.18
	N_{200}	6.36	8.22	11.27			8.62
S x W	S_0	5.49	7.14	10.18			
	S_1	5.57	6.80	9.57			
	S_2	5.93	8.32	10.17			

matter increased as straw increased. In this situation, N would overcome the depressive effect of straw and there would be enough N for microorganisms to utilize during the decomposition process. Straw would improve the soil physical condition such as water-holding capacity and better aeration. Plant roots probably had a better environment to develop and to take up more nutrients.

Straw had a highly significant effect on dry matter yield. Straw at 2% gave the highest dry matter compared to control. Nitrogen also had a highly significant effect (0.01 level) on dry matter yield. As the levels of N increased from 0 to 100 and 200 lbs of N/A, dry matter yield increased from 6.26 to 8.18 and 8.62 g/pot.

Water was shown to have the greatest effect on dry matter in this cutting (Tables 3 and 4).

As the soil water level increased from 50 to 65 and 80% of field capacity, dry matter yield increased from 5.66 to 7.42 and 9.97 g/pot respectively.

In the third cutting, straw x water was the only two-way interaction that was highly significant (0.01 level) as shown in Table 3. The means of this interaction are presented in Table 5. The response of dry matter was greater when both straw and water levels were high, indicating an increase in the water-holding capacity where straw was added. Higher levels of soil water were probably able to support larger populations of the microbes involved in straw decomposition. This would accelerate the breakdown of organic residue and reduce the period of N immobilization (Figure 1).

Straw as well as N and water levels produced highly significant differences (0.01 level). As the levels of straw increased, dry matter yields increased (Table 5). The third spring wheat crop was grown at 152 to 252 days after the straw had been incorporated into the soil. During that period, N immobilization had already decreased. Mineralization was greater, thus soil N which was previously converted into the organic cycle was released together with N from straw.

Table 5. Dry matter yield of the third cutting of spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity)			Mean		
		50	65	80	S x N	S	N
		----------	----------	g/pot	----------	----------	----------
0	0	1.43	2.47	3.63	2.51		
	100	1.42	2.75	3.93	2.70		
	200	1.19	2.25	2.80	2.08	2.43	
1	0	1.88	3.52	4.64	3.35		
	100	1.69	3.38	5.53	3.53		
	200	1.31	2.82	5.28	3.14	3.34	
2	0	2.16	3.53	5.38	3.69		
	100	1.98	3.81	6.44	4.07		
	200	1.64	3.85	6.25	3.91	3.89	
Mean Water		1.63	3.15	4.87			
N x W	N_0	1.82	3.17	4.55			3.18
	N_{100}	1.69	3.31	5.30			3.43
	N_{200}	1.38	2.97	4.78			3.04
S x W	S_0	1.35	2.49	3.45			
	S_1	1.63	3.24	5.15			
	S_2	1.93	3.73	6.02			

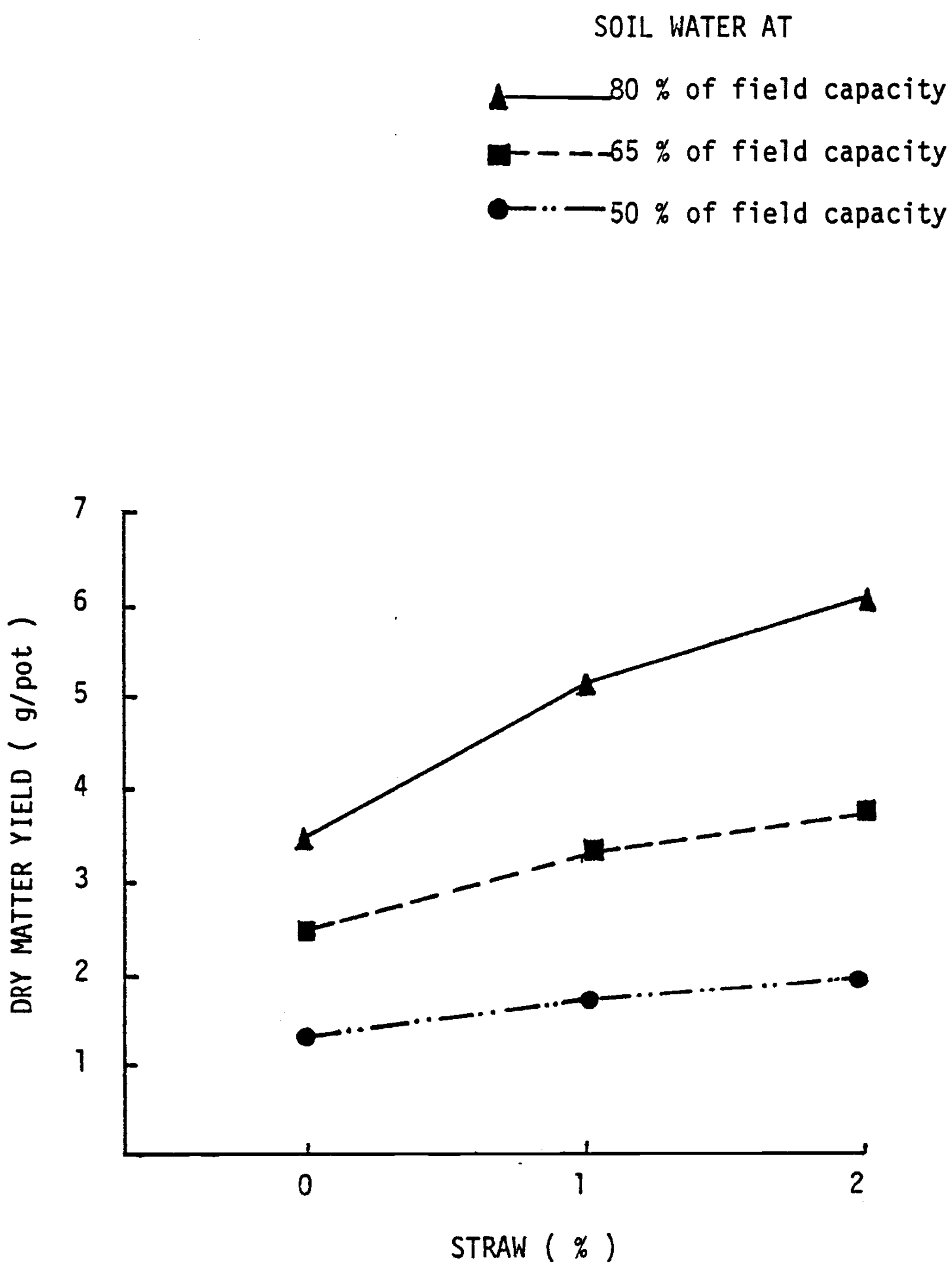

Figure 1. The effect of straw and soil water on dry matter yield of spring wheat. Third cutting.

Nitrogen also had a highly significant effect (0.01 level) on dry matter. It was observed in the third cutting that the application of N at 100 lbs/A gave the highest dry matter yield compared to 0 and 200 lbs of N/A.

In this cutting, water content of the soil was the most influential factor in contributing to dry matter yield. As soil water increased from 50 to 65 and 80% of field capacity the dry matter yield increased from 1.63 to 3.15 and 4.87 g/pot, respectively. An increase in soil water would act to increase plant water potential. Higher soil water potential would facilitate solute uptake and transport through the plant and produces better water use efficiency. These factors are ultimately translated into higher plant yields.

Dry Matter Yield of the First, Second and Third Cutting of Ryegrass

Mean square values for dry matter yield obtained from the three cuttings of ryegrass are presented in Table 6. In the first cutting, N, straw, water and straw by nitrogen interaction were all highly significant (0.01 level). Table 7 shows the straw by nitrogen interaction of the first cutting of ryegrass. Dry matter yield from zero straw with no N treatment did not differ from the 2% straw with 100 lbs of N/A. And for the zero straw with 100 lbs of N/A treatment, yield was slightly higher than at 2% straw with 200 lbs of N/A treatment. As the levels of straw increased, dry matter yield decreased at every level of N. This was apparent at 100 lbs of N/A (Figure 2). Again, this was due to N immobilization since straw was incorporated before the ryegrass planting.

There was also a significant interaction between N and water, but the magnitude was smaller than that of the straw by nitrogen (Table 6). Nitrogen had the greatest effect on dry matter yield as expressed by the highest mean square values. The application of nitrogen either at 100 or 200 lbs of N/A caused increased dry matter

Table 6. Mean square values for dry matter yield of the first, second and third cuttings of ryegrass.

Source of Variation	df	First Cutting	Second Cutting	Third Cutting
Block	3	0.46	0.26	1.33
Straw	2	77.02**	2.03**	4.38**
Nitrogen	2	417.56**	160.13**	119.93**
Straw x Nitrogen	4	12.49**	3.46**	19.87**
Water	2	3.61**	0.44	15.61**
Straw x Water	4	2.11*	0.06	7.66**
Nitrogen x Water	4	6.64**	0.17	4.46**
Straw x Nitrogen x Water	8	2.43**	0.55**	2.74**
Error	78	0.67	0.24	0.62
Total	107			

*Significant at .05 probability level.

**Significant at .01 probability level.

Table 7. Dry matter yield of the first cutting of ryegrass as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		----------	g/pot	----------	----------	----------	----------
0	0	5.02	5.17	3.23	4.47		
	100	7.36	8.71	10.00	8.69		
	200	7.48	9.55	10.99	9.34	7.50	
1	0	1.35	0.85	0.90	1.04		
	100	7.01	7.25	6.73	6.99		
	200	8.25	9.81	9.44	9.17	5.73	
2	0	1.67	0.59	1.01	1.09		
	100	4.72	5.04	4.15	4.63		
	200	7.36	8.44	8.42	8.07	4.60	
Mean Water		5.58	6.16	6.10			
N x W	N_0	2.68	2.21	1.71			2.20
	N_{100}	6.36	7.00	6.96			6.77
	N_{200}	7.70	9.27	9.62			8.86
S x W	S_0	6.62	7.81	8.07			
	S_1	5.54	5.97	5.69			
	S_2	4.58	4.69	4.53			

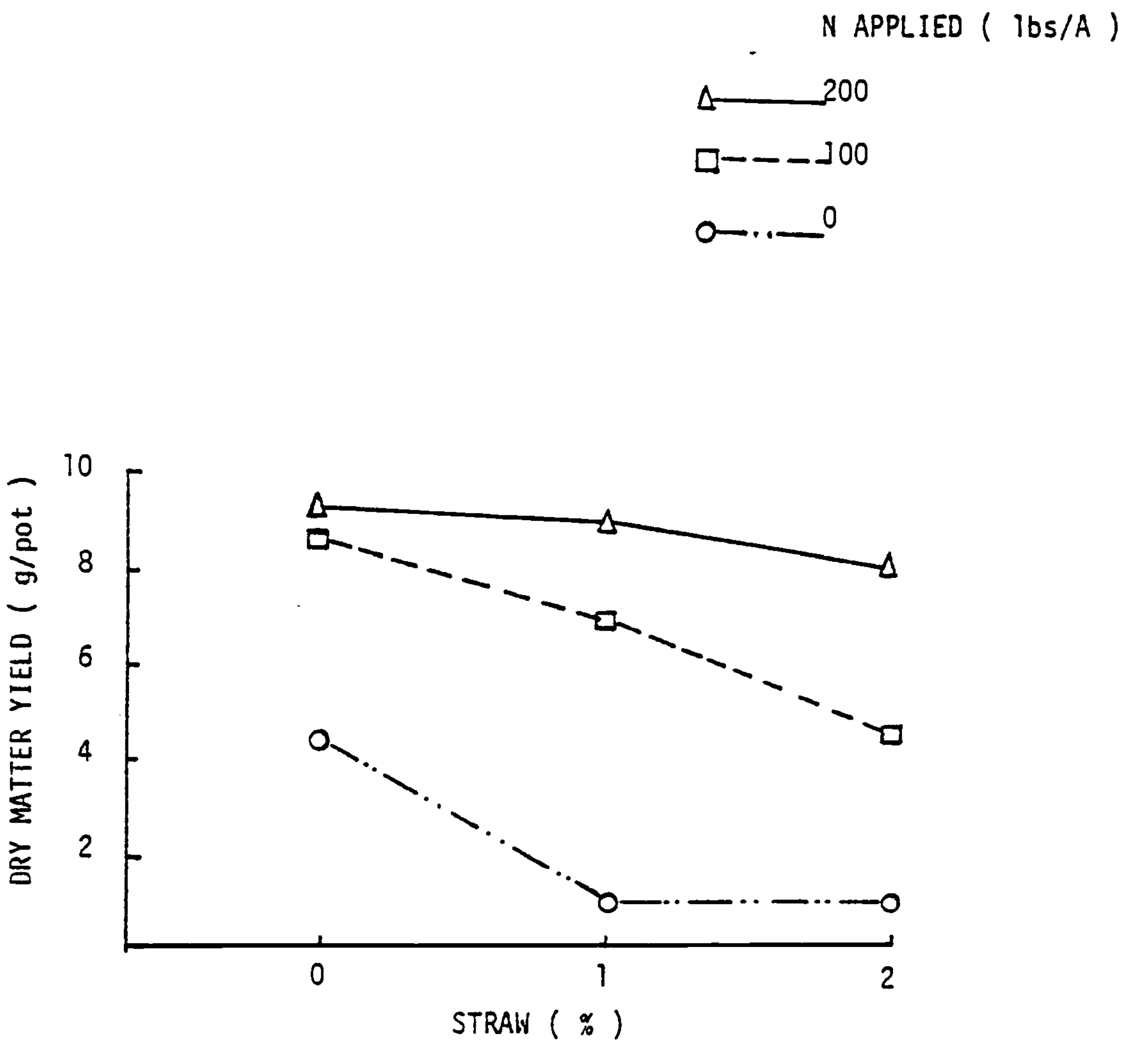

Figure 2. The effect of straw and fertilizer N on dry matter yield of ryegrass. First cutting.

yields at every level of straw and soil water.

Water at 65 and 80% of field capacity produced about the same dry matter, whereas at 50% of field capacity, yields were appreciably lower. The highly significant interaction between straw and nitrogen compared to straw, nitrogen and water interaction indicated that the soil and nitrogen response was only slightly influenced by changes in soil water. The difference in dry matter yield between the three levels of N became larger as soil water increased, indicating that more N was available to the plant as the soil water increased.

The effect of straw, N and water on dry matter yield of the second ryegrass cutting is shown in Table 8. The high mean square value for the straw by nitrogen interaction suggests that it contributed the most to the three-way interaction between straw, nitrogen and water (Table 6). Yields at different levels of straw increased uniformly and significantly as the N rate increased.

The different levels of soil water did not significantly affect dry matter yield (Table 8). It is possible that N and not water was the growth-limiting factor of the second ryegrass crop. Table 15 shows that the amount of N utilized by the first crop often exceeded the amount of fertilizer N applied. Therefore, plants in the second and third cuttings would be dependent upon mineralized N from the straw and natural N reserves of the soil. Any factor, such as a greater than optimal soil water content, which reduced mineralization of N would also have a negative effect on dry matter production

The effect of straw, N and water on dry matter yield of the third cutting of ryegrass is presented in Table 9. At zero N, straw at higher rates generally yielded higher dry matter. The application of N increased dry matter yield at every level of straw and water. The application of 200 lbs of N/A at 50% of field capacity decreased dry matter yield drastically when straw levels changed from 0 to 1%, indicated strong immobilization at the high N level.

Mean square value of the straw by N interaction was about eight

Table 8. Dry matter yield of the second cutting of ryegrass as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity)			Mean		
		50	65	80	S x N	S	N
		g/pot					
0	0	1.39	1.26	1.28	1.31		
	100	4.43	4.12	3.71	4.08		
	200	5.20	5.44	5.88	5.51	3.63	
1	0	1.36	1.10	1.37	1.28		
	100	3.79	3.35	3.45	3.53		
	200	6.41	6.34	6.39	6.38	3.73	
2	0	1.62	1.42	1.97	1.67		
	100	2.98	3.26	3.21	3.15		
	200	5.69	4.61	4.75	5.02	3.28	
Mean Water		3.65	3.43	3.55			
N x W	N_0	1.45	1.26	1.54			1.42
	N_{100}	3.73	3.57	3.45			3.59
	N_{200}	5.77	5.46	5.67			5.63
S x W	S_0	3.67	3.61	3.62			
	S_1	3.85	3.60	3.74			
	S_2	3.43	3.09	3.31			

Table 9. Dry matter yield of the third cutting of ryegrass as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		------------	------------	g/pot	------------	------------	------------
0	0	1.66	1.49	1.73	1.62		
	100	6.25	2.49	2.13	3.62		
	200	10.55	8.17	5.33	8.02	4.42	
1	0	2.69	2.66	2.80	2.71		
	100	3.42	3.64	3.57	3.54		
	200	5.68	4.91	4.40	5.00	3.75	
2	0	3.19	3.06	2.77	3.01		
	100	4.59	4.59	4.40	4.53		
	200	5.63	5.17	4.83	5.21	4.25	
Mean Water		4.85	4.02	3.55			
N x W	N_0	2.51	2.40	2.43			2.45
	N_{100}	4.75	3.57	3.36			3.90
	N_{200}	7.29	6.08	4.85			6.07
S x W	S_0	6.15	4.05	3.06			
	S_1	3.93	3.73	3.59			
	S_2	4.47	4.27	4.00			

times that of the three-way interaction between straw, nitrogen and water (Table 6). Thus the straw and nitrogen treatments did not have a differential influence on dry matter yields at various soil water levels.

N Uptake by the First, Second and Third Cutting of Spring Wheat

Mean square values for N uptake of the three cuttings of spring wheat are presented in Table 10. For the first cutting, the effect of straw, N and water were all highly significant (0.01 level). The means uptake of N are shown in Table 11. Increasing the amount of straw caused a decrease in N uptake from 15.00 to 11.99 and 10.54 mg/pot for 0, 1 and 2% straw, respectively. Increasing the rate of fertilizer N from 0 to 100 and 200 lbs/A resulted in increased N uptake from 8.89 to 14.11 and 14.52 mg/pot, respectively. Soil water had a significant influence on N uptake. As soil water content increased from 50 to 65 and 80% of field capacity, N uptake increased from 11.03 to 12.34 and 14.16 mg/pot, respectively. There were no significant two-way or three-way interactions in the first cutting.

Treatment mean uptake data for N in the second cutting of spring wheat are shown in Table 12. Increases in straw significantly decreased N uptake by the zero N treatment, but had no effect on the 100 and 200 lbs of N/A treatments. The application of N at 200 lbs/A without straw gave the highest uptake and the lowest was from 2% straw with no nitrogen. For N and water interaction, increasing soil water resulted in higher uptake at every rate of N. With the highest from 200 lbs of N/A and water at 80% of the field capacity and the lowest from zero N treatment and water at 50% of the field capacity. Reasons for these results were previously discussed. It was concluded that (a) straw immobilized N and caused reduction in plant uptake; (b) adding N fertilizer overcame this effect of immobilization; (c) an increase in soil water facilitated N uptake.

Table 10. Mean square values for N uptake of the first, second and third cuttings of spring wheat.

Source of Variation	df	First Cutting	Second Cutting	Third Cutting
Block	3	19.28	875.19*	300.85*
Straw	2	186.30**	2118.01**	9657.48**
Nitrogen	2	355.33**	37236.50**	565.03**
Straw x Nitrogen	4	19.28	1496.40**	122.42
Water	2	89.28**	43596.50**	31131.60**
Straw x Water	4	4.46	732.90	1355.04**
Nitrogen x Water	4	1.19	1002.61*	343.62**
Straw x Nitrogen x Water	8	10.99	231.65	164.00
Error	78	7.79	294.90	95.94
Total	107			

*Significant at .05 probability level.

**Significant at .01 probability level.

Table 11. N uptake of the first cutting of spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		mg/pot					
0	0	9.26	10.58	15.05	11.63		
	100	13.35	16.86	19.05	16.42		
	200	16.21	17.02	17.59	16.94	15.00	
1	0	8.10	9.44	11.55	9.69		
	100	11.56	13.52	13.61	12.89		
	200	13.85	11.55	14.79	13.40	11.99	
2	0	4.93	5.57	5.54	5.35		
	100	12.13	12.55	14.40	13.03		
	200	9.87	13.96	15.88	13.23	10.54	
Mean Water		11.03	12.34	14.16			
N x W	N_0	7.43	8.53	10.71			8.89
	N_{100}	12.35	14.31	15.69			14.11
	N_{200}	13.31	14.18	16.08			14.52
S x W	S_0	12.94	14.82	17.23			
	S_1	11.17	11.50	13.32			
	S_2	8.97	10.69	11.94			

Table 12. N uptake of the second cutting of spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		mg/pot					
0	0	65.12	92.29	140.97	99.46		
	100	85.39	110.14	166.26	120.59		
	200	99.84	145.26	195.57	146.89	122.31	
1	0	52.62	67.12	94.76	71.50		
	100	90.80	120.39	168.77	126.66		
	200	104.22	120.53	175.10	133.28	110.48	
2	0	46.69	66.66	75.83	63.06		
	100	82.85	124.97	149.57	119.13		
	200	102.60	136.21	186.09	141.64	107.94	
Mean Water		81.12	109.29	150.33			
N x W	N_0	54.81	75.36	103.85			78.01
	N_{100}	86.35	118.50	161.53			122.13
	N_{200}	102.22	134.00	185.59			140.60
S x W	S_0	83.45	115.89	167.60			
	S_1	82.55	102.68	146.21			
	S_2	77.38	109.28	137.16			

In the second and third cutting, soil water levels had the greatest effect on N uptake as expressed by the highest mean square values.

Increasing soil water content caused an increase in N uptake for all three spring wheat cuttings. A higher soil water content would have the effect of increasing the difference between the chemical potential of the soil water and that of the plant. This would establish a steeper gradient favoring water and nutrient absorption by the plant.

The mean N uptake for the third cutting of spring wheat is presented in Table 13. The straw and water interaction gave the highest mean square value among the two factors comparison (Table 10). At every level of straw, increases in soil water caused an increase in N uptake. The highest uptake was from 2% straw and soil water at 80% of field capacity, whereas the lowest was from no straw and soil water at 50% of field capacity. At higher soil water the magnitude of N uptake increased as the levels of straw increased (Figure 3). This might have resulted from higher water holding capacity of soil as straw levels increased and the possibly higher microbe population at higher soil water which could accelerate the breakdown of organic residue.

The added straw increased N uptake in the third cutting but not in the first or second cuttings. There are two possible reasons which may have caused this to happen. First, a decrease in N immobilization since the third spring wheat set was grown during the period of 152 and 252 days after straw was incorporated into soil when the magnitude of N immobilization would have been surpassed by mineralization. Secondly, straw increases the soil water-holding capacity, thus permitting more water and nutrients to be taken up by plant.

For the N and water interaction, at every level of N, increasing water caused increased N uptake. At water content of 50% of field capacity, application of N did not increase uptake partly because of the lower soil solution that the plant can utilize. Nitrogen

Table 13. N uptake of the third cutting of spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
				mg/pot			
0	0	21.59	38.89	58.66	39.71		
	100	23.29	47.39	66.71	45.80		
	200	20.40	39.53	49.01	36.31	40.61	
1	0	28.42	52.99	72.39	51.27		
	100	29.02	58.54	97.56	61.71		
	200	22.99	50.80	97.59	57.13	56.70	
2	0	41.12	65.19	99.49	68.60		
	100	36.02	71.09	120.04	75.71		
	200	31.50	74.13	121.70	75.78	73.36	
Mean Water		28.26	55.39	87.02			
N x W	N_0	30.38	52.35	76.85			53.19
	N_{100}	29.44	59.00	94.77			61.07
	N_{200}	24.96	54.82	89.43			56.41
S x W	S_0	21.76	41.94	58.13			
	S_1	26.81	54.11	89.18			
	S_2	36.21	70.14	113.74			

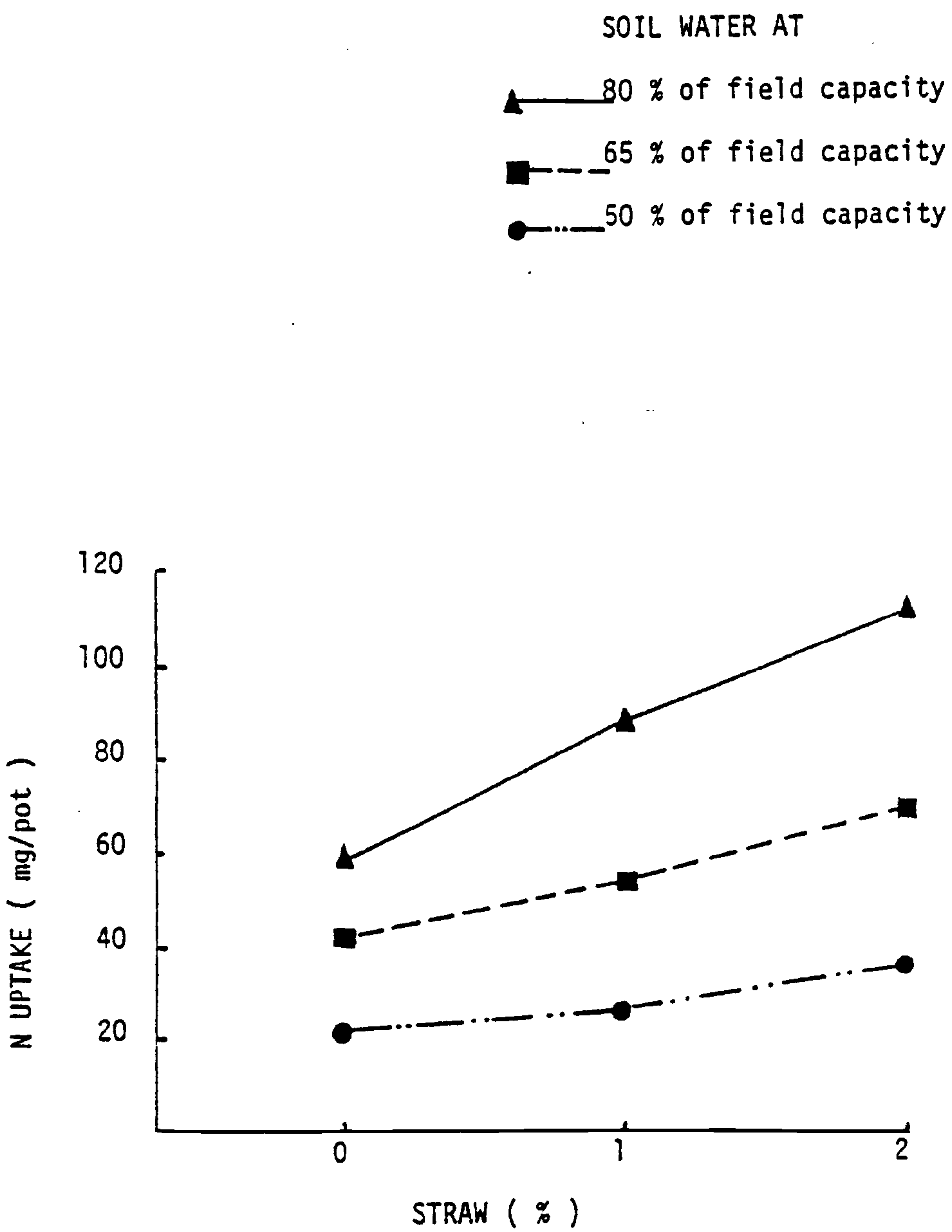

Figure 3. The effect of straw and soil water on nitrogen uptake of spring wheat. Third cutting.

fertilizer increased uptake when soil water content was at 65 and 80% of field capacity.

N Uptake by the First, Second and Third Cuttings of Ryegrass

Mean square values for N uptake of the three cuttings of ryegrass are shown in Table 14. The straw by nitrogen by water interaction was significant in all three cuttings. Mean N uptake for the first cutting is shown in Table 15. At zero N, high soil water generally resulted in lower uptake. At every level of straw, as N increased, uptake increased drastically. Higher straw resulted in lower uptake almost at every N level. The straw by nitrogen interaction was the main factor contributing to the three-way interaction (Table 14). The highest uptake was from no straw with 200 lbs of N/A and the lowest came from zero N both at 1 and 2% straw (Figure 4).

The mean N uptake of the second ryegrass cutting for the straw, N, water and their interaction means are presented in Table 16. The straw by nitrogen interaction had the mean square value of about six times greater than the straw, N and water three-way interaction (Table 14). This indicated that at different soil water levels, the differential response from straw and nitrogen was of little significance (Figure 5).

Table 16 shows the mean uptake for the straw and nitrogen interaction. Without N, increased straw rates gave slightly increased N uptake but when fertilizer N was applied either at 100 or 200 lbs of N/A, increased straw depressed uptake. This indicated that with N at every level of straw, uptake increased but straw at higher rates could still immobilize N. The visual relationship of straw, nitrogen interaction is shown in Figure 6.

The increase of soil water also resulted in lower N uptake in the second cutting. The depressive effect of soil water on N uptake

Table 14. Mean square values for N uptake of the first, second and third cuttings of ryegrass.

Source of Variation	df	First Cutting	Second Cutting	Third Cutting
Block	3	2987.36	476.48	372.80
Straw	2	181672.00**	27644.60**	7336.78**
Nitrogen	2	673418.00**	184246.00**	36740.90**
Straw x Nitrogen	4	20466.70**	13025.00**	15543.60**
Water	2	1217.42	7801.27**	8191.13**
Straw x Water	4	2708.18	339.36	5953.34**
Nitrogen x Water	4	2316.30	2623.72**	3869.12**
Straw x Nitrogen x Water	8	4528.53*	2190.62**	2970.76**
Error	78	1879.49	443.25	162.94
Total	107			

*Significant at .05 probability level.

**Significant at .01 probability level.

Table 15. N uptake of the first cutting of ryegrass as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		mg/pot					
0	0	116.20	80.07	39.48	78.58		
	100	278.85	311.29	327.49	305.87		
	200	325.57	380.36	432.02	379.32	254.59	
1	0	18.53	12.21	13.60	14.78		
	100	193.73	163.40	163.77	173.63		
	200	321.72	348.26	282.26	317.41	168.61	
2	0	24.63	11.38	18.08	18.03		
	100	108.11	92.59	67.88	89.53		
	200	239.91	252.93	207.33	233.39	113.65	
Mean Water		180.80	183.61	172.43			
N x W	N_0	53.12	34.56	23.72			37.13
	N_{100}	193.56	189.09	186.38			189.68
	N_{200}	295.73	327.18	307.20			310.04
S x W	S_0	240.20	257.24	266.33			
	S_1	177.99	174.62	153.21			
	S_2	124.22	118.97	97.76			

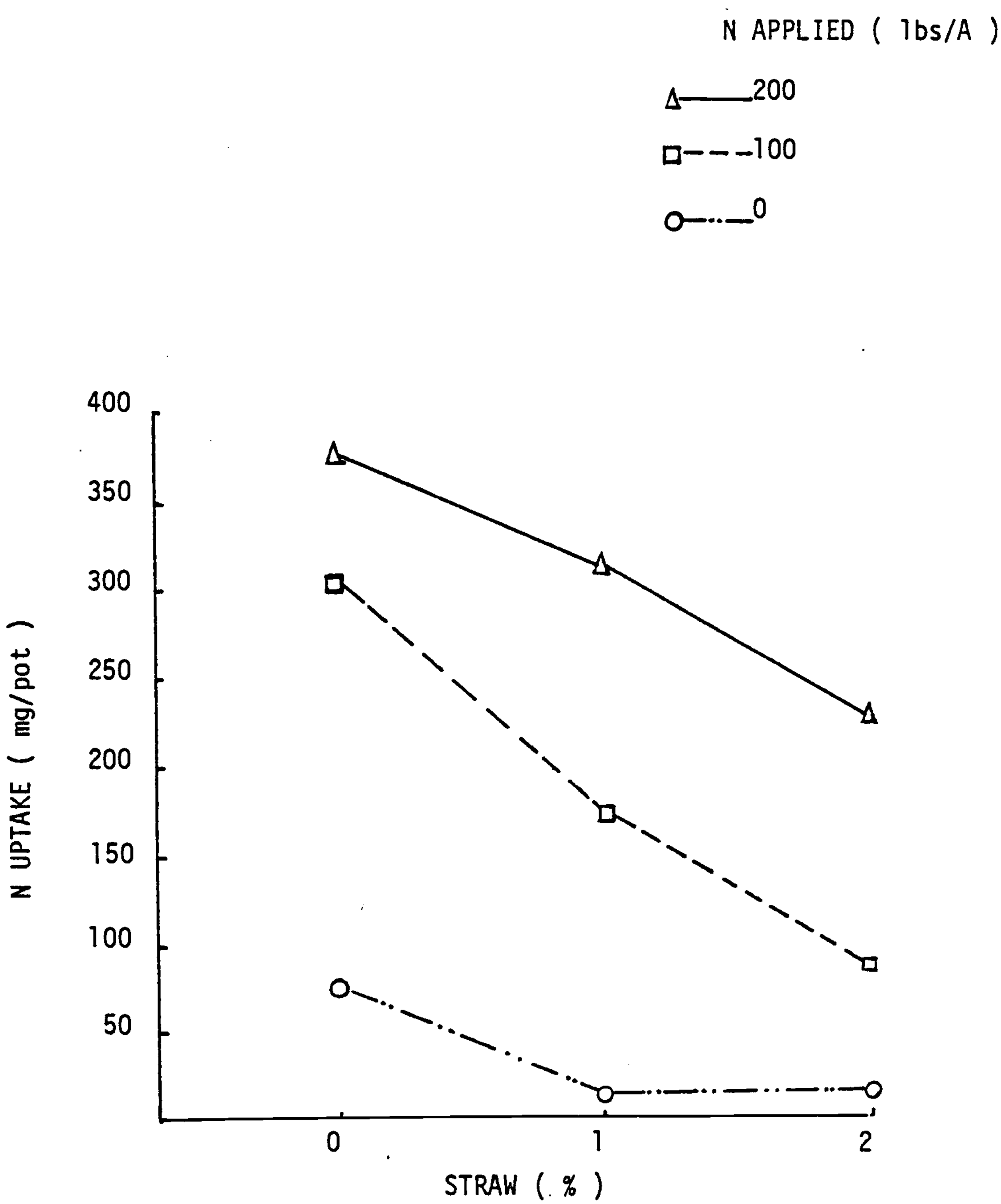

Figure 4. The effect of straw and fertilizer N on nitrogen uptake of ryegrass. First cutting.

Table 16. N uptake of the second cutting of ryegrass as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		----------	----------	mg/pot	----------	----------	----------
0	0	20.55	17.19	18.62	18.79		
	100	167.85	115.18	74.14	119.06		
	200	214.99	200.58	211.04	208.87	115.57	
1	0	22.47	19.39	25.67	22.51		
	100	71.15	50.17	53.19	58.17		
	200	229.62	172.01	143.74	181.79	87.49	
2	0	24.14	23.98	34.47	27.53		
	100	46.52	49.94	53.71	50.06		
	200	143.65	85.17	79.79	102.87	60.15	
Mean Water		104.55	81.51	77.15			
N x W	N_0	22.39	20.19	26.25			22.94
	N_{100}	95.17	71.76	60.35			75.76
	N_{200}	196.09	152.59	144.86			164.51
S x W	S_0	134.46	110.99	101.27			
	S_1	107.74	80.52	74.20			
	S_2	71.44	53.03	55.99			

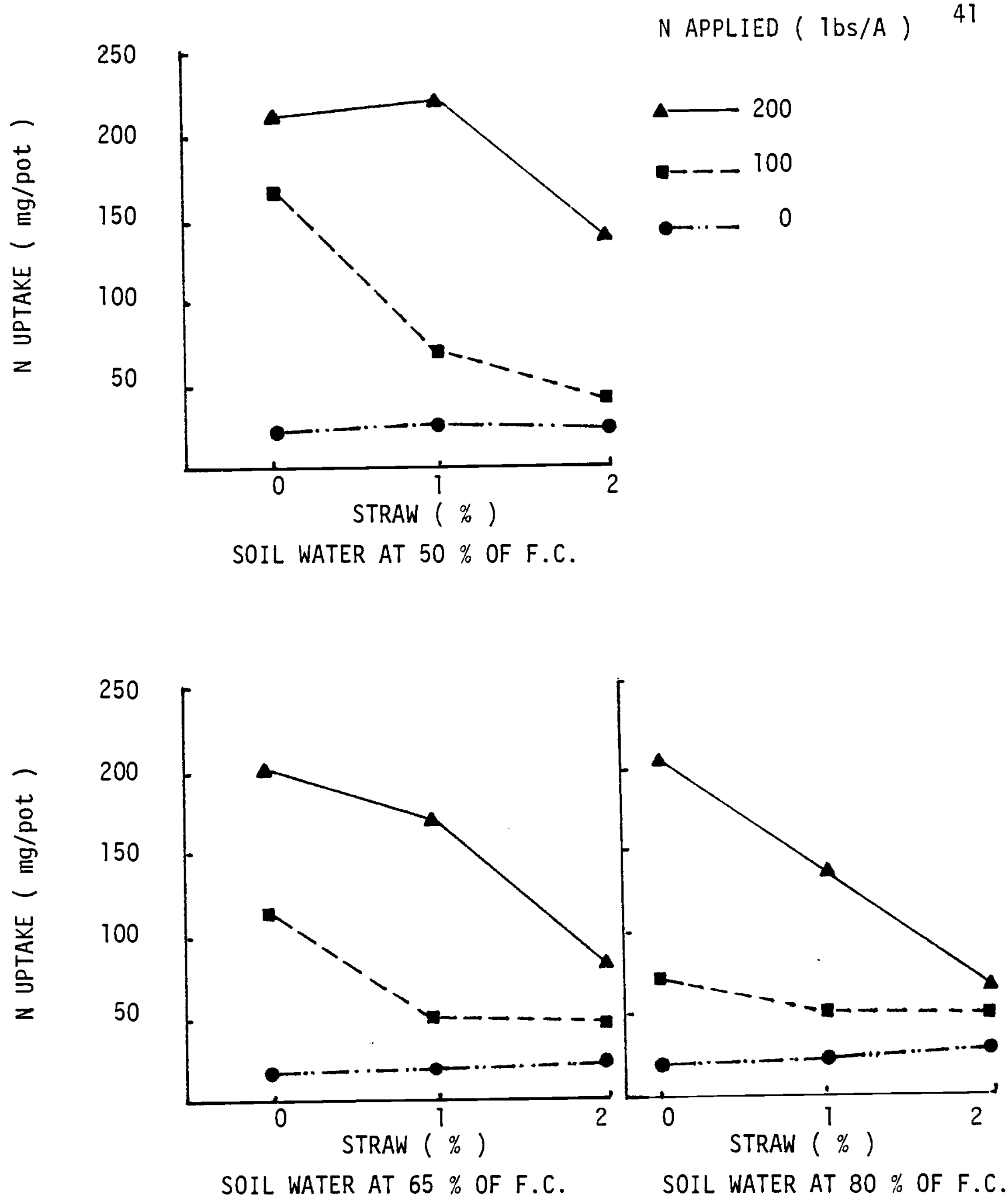

Figure 5. The effect of straw, fertilizer N and soil water on N uptake of ryegrass. Second cutting.

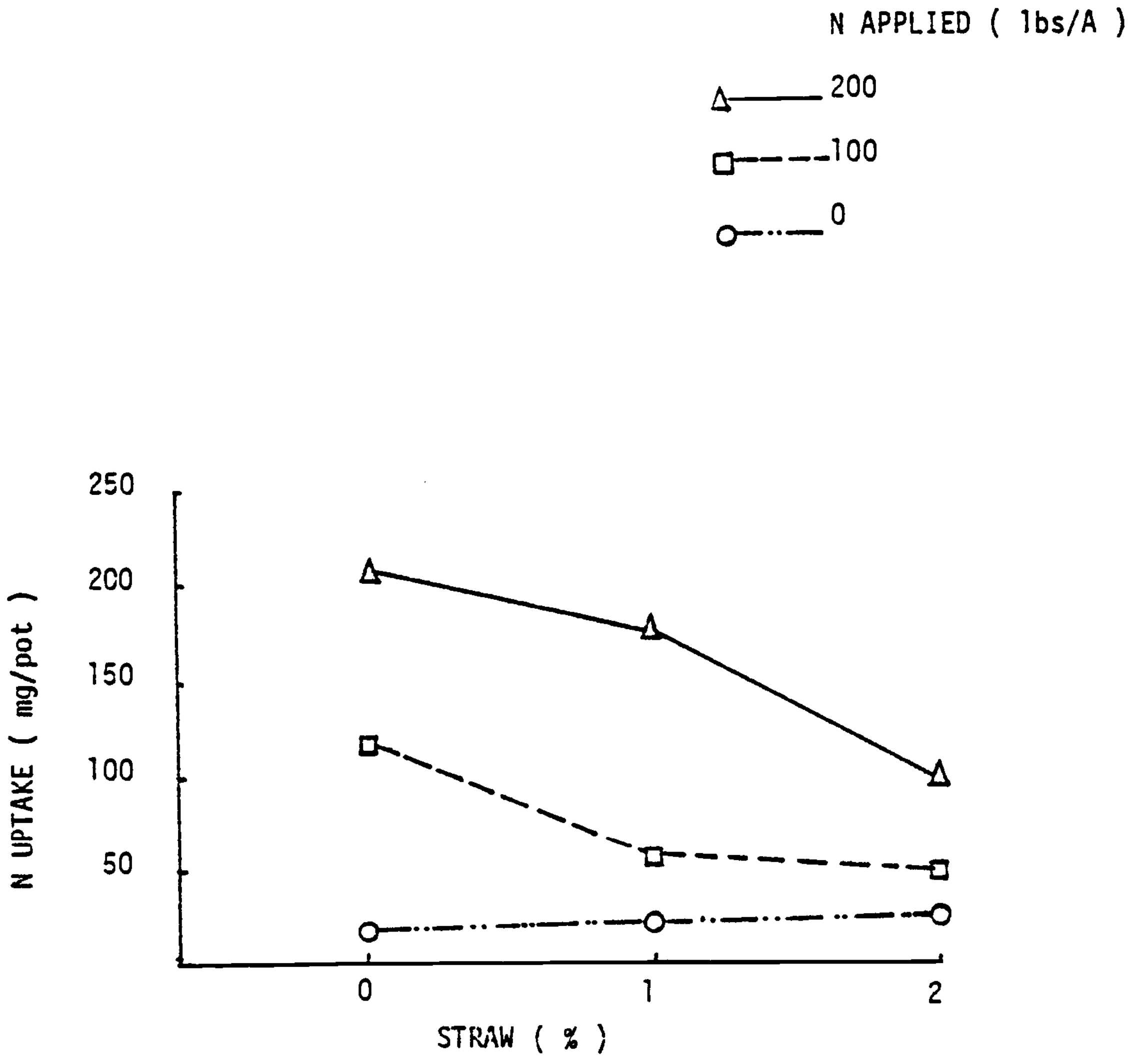

Figure 6. The effect of straw and fertilizer N on nitrogen uptake of ryegrass. Second cutting.

may be attributed to the large amount of N used by the previous rye-grass crop. In most pots more N was taken up by the first crop than was applied as fertilizer N. This implies that mineralized N was the main N source for the second and third ryegrass crops. High soil water levels may have reduced yields by inhibiting mineralization. Tables 15, 16 and 17 show that the depressive effect of water on N uptake became increasingly pronounced from the first to the third cutting, coinciding with an increased demand for mineralized N.

The mean N uptake of the third ryegrass cutting for the straw, nitrogen and water interactions are shown in Table 17. At zero and 100 lbs of N/A, an increase in straw always caused increased N uptake, but at 200 lbs of N/A both levels of straw depressed uptake. This was further evidence that there was no immobilization at 0 and 100 lbs of N/A but at 200 lbs of N/A, immobilization of N was still going on due to a higher microbe population in response to higher concentrations of available N. At each level of straw, higher uptake occurred as nitrogen rates increased. Table 14 also shows that straw by nitrogen interaction was the main factor contributing to the three-way interaction.

Total Soil N

Following the second and third spring wheat crop and at the end of the experiment soil samples were collected and analyzed for total soil N. With the exception of soil water following the third cutting of spring wheat; straw, nitrogen, soil water and straw by nitrogen interaction had significant effects on the amount of total soil N following the three periods of cropping (Table 18). The effect of straw by nitrogen interaction on total soil N following the second spring wheat, the third spring wheat and the third ryegrass are shown in Table 19, 20 and 21, respectively. In general, at every level of fertilizer N, total soil N increased with increased amount of straw

Table 17. N uptake of the third cutting of ryegrass as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		mg/pot					
0	0	26.16	22.58	26.26	25.00		
	100	79.29	30.33	28.02	45.88		
	200	259.76	150.90	70.92	160.52	77.13	
1	0	38.19	36.77	37.81	37.58		
	100	44.95	50.13	47.96	47.68		
	200	73.90	59.57	58.29	63.92	49.73	
2	0	44.47	42.35	40.80	42.54		
	100	62.78	63.06	57.56	61.13		
	200	68.26	66.11	63.09	65.82	56.50	
Mean Water		77.53	57.98	47.89			
N x W	N_0	36.28	33.90	34.96			35.04
	N_{100}	62.34	47.84	44.51			51.56
	N_{200}	133.97	92.19	64.10			96.75
S x W	S_0	121.74	67.93	41.73			
	S_1	52.35	48.82	48.02			
	S_2	58.50	57.17	53.82			

Table 18. Mean square values for total soil nitrogen following second spring wheat, third spring wheat and third ryegrass.

Source of Variation	df	Second Wheat	Third Wheat	Third Ryegrass
Block	3	2610.22*	274.49	115.37
Straw	2	272544.00**	177186.00**	531624.00**
Nitrogen	2	285533.00**	45712.20**	214719.00**
Straw x Nitrogen	4	14283.70**	6200.81**	50296.70**
Water	2	6379.53**	1477.78	6118.12**
Straw x Water	4	358.26	98.22	1051.52*
Nitrogen x Water	4	794.89	240.26	770.13*
Straw x Nitrogen x Water	8	611.54	530.50	562.62*
Error	78	821.56	492.50	261.82
Total	107			

*Significant at .05 probability level.

**Significant at .01 probability level.

Table 19. Total soil N following second spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
				ppm			
0	0	1468	1469	1460	1465		
	100	1668	1647	1627	1648		
	200	1661	1662	1651	1658	1590	
1	0	1640	1639	1624	1634		
	100	1767	1771	1726	1754		
	200	1772	1757	1733	1754	1714	
2	0	1672	1661	1650	1661		
	100	1755	1770	1741	1755		
	200	1892	1836	1846	1858	1758	
Mean Water		1699	1690	1673			
N x W	N_0	1593	1590	1578			1587
	N_{100}	1730	1729	1698			1719
	N_{200}	1775	1752	1743			1757
S x W	S_0	1599	1593	1579			
	S_1	1726	1722	1694			
	S_2	1773	1755	1146			

Table 20. Total soil N following third spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		-----	-----	ppm	-----	-----	-----
0	0	1378	1369	1345	1364		
	100	1452	1450	1448	1450		
	200	1459	1470	1458	1462	1425	
1	0	1474	1473	1479	1475		
	100	1557	1559	1533	1550		
	200	1563	1540	1542	1549	1525	
2	0	1552	1556	1539	1549		
	100	1562	1562	1554	1559		
	200	1589	1556	1575	1574	1561	
Mean Water		1510	1504	1497			
N x W	N_0	1468	1466	1454			1463
	N_{100}	1524	1524	1511			1520
	N_{200}	1537	1523	1525			1528
S x W	S_0	1430	1429	1417			
	S_1	1532	1524	1518			
	S_2	1568	1559	1556			

Table 21. Total soil N following third ryegrass as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		ppm					
0	0	1317	1323	1370	1336		
	100	1356	1373	1380	1369		
	200	1379	1386	1421	1395	1367	
1	0	1413	1428	1433	1425		
	100	1543	1551	1566	1553		
	200	1536	1561	1565	1554	1511	
2	0	1476	1479	1512	1489		
	100	1596	1551	1573	1573		
	200	1755	1766	1772	1764	1609	
Mean Water		1485	1491	1510			
N x W	N_0	1402	1410	1438			1417
	N_{100}	1498	1491	1506			1499
	N_{200}	1556	1571	1586			1571
S x W	S_0	1350	1361	1390			
	S_1	1497	1513	1521			
	S_2	1609	1599	1619			

incorporated into the soil (Figure 7). The application of fertilizer N also gave higher total soil N. As the levels of fertilizer N increased, total soil N increased at every level of straw. In comparing the amount of total soil N at the three periods following cropping, the quantity of total soil N decreased as crops were grown. Black (1973) found that the residue levels had a significant influence on total soil N. The addition of 3,360 kg/ha and above of residue increased total soil N, while the control and 1,680 kg/ha treatments decreased total soil N. In this experiment, it was found that total soil N decreased at 0 and 1% straw following the three periods of cropping. At 2% straw, there was a decrease from second to third spring wheat crops but a slight increase after ryegrass croppings. This evidence indicated that higher equilibrium levels of total soil N will be established by addition of relatively large amount of carbonaceous material.

While the quantity of crop residue returned to the soil is one of the most important factors governing the rate of soil N decline, the application of N fertilizer can also influence total soil N. This is because of the residual of fertilizer N not recovered by plants will remain in the soil and is counted as a part of total soil N. Broadbent and Nakashima (1965) used tagged ammonium sulfate and found that 46 to 64% of tagged N was recovered by plants in the no straw treatment while 20 to 55% was recovered in the 1% straw treatment. A considerable amount of fertilizer N then remained in soil.

Incubated Soil N Following the Second, Third Spring Wheat and the Third Ryegrass Cuttings

Incubated N is the amount of ammonium-N produced during the period of two weeks of anaerobic incubation less the amount of soil ammonium-N originally present in the soil. This method has many advantages over the measurement of mineralization by aerobic incubation, including the greater ease in establishing and maintaining the experimental

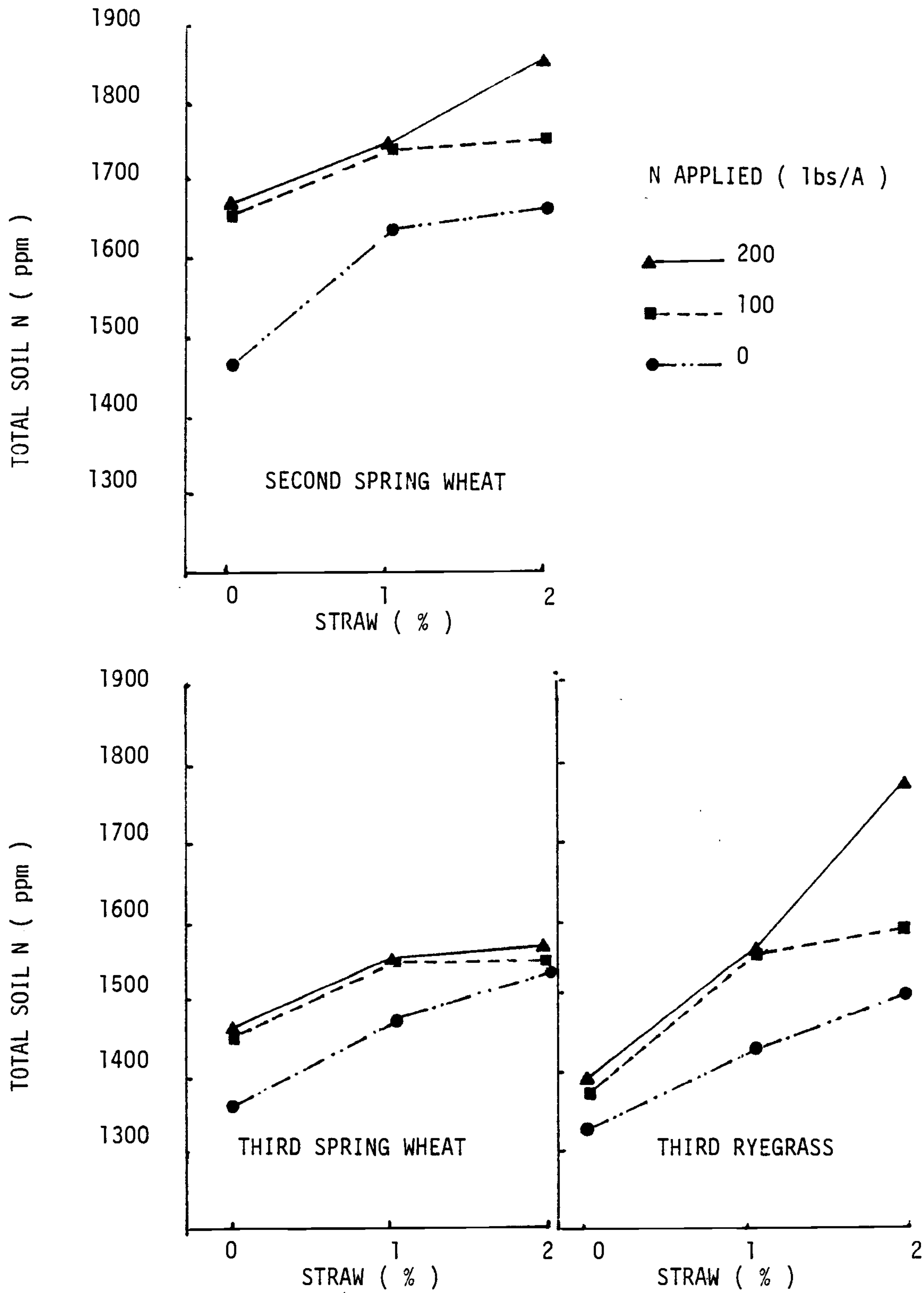

Figure 7. The effect of straw and fertilizer N on total soil N. following second and third spring wheat and third ryegrass.

conditions. However, Waring and Bremner (1964) found a strong correlation between the incubated N produced under anaerobic condition and nitrates plus nitrites and ammonium-N.

Straw, nitrogen, water, straw by nitrogen and straw by water always gave significant differences for the amount of incubated N following the second, third spring wheat and the third ryegrass cutting (Table 22). Following the second spring wheat as well as the third ryegrass harvests, the straw by nitrogen interaction had the highest mean square value among the two factor interactions. Tables 23, 24 and 25 show the values of incubated N as affected by straw, nitrogen, water and their interactions following the three periods of cropping. In general, incubated N increased as straw levels increased at every level of fertilizer N. The application of fertilizer N did not seem to increase the amount of incubated N at any level of straw, probably because of the strong plant demand for N under continuous cropping. The increase of incubated N as straw increased, followed the similar trend as total soil N. However, the quantity of incubated N was about 60 to 100 times lower indicating the small percentage of total soil N which is represented by mineralized N at any given time. The quantity of incubated N declined between the second and third cutting of spring wheat, probably signifying the use of this N source by the crop. The increase in incubated N after the third cutting of spring wheat was probably due to a combination of organic N from the straw together with the N from the decomposition of roots of the previous crops.

The incorporation of straw into soil prior to ryegrass planting might have an effect on the increasing quantity of incubated N. Ferguson (1967) found that the repeated applications of straw made significant contribution to yield of cereal grains by increased mineralizable N. Tillage would also have significant contribution, since soil in the pot was pulverized and straw was incorporated, aeration would aid in faster decomposition rate. Sievers and Holtz (1927) stated that extra tillage would enhance the release of nitrogen from

Table 22. Mean square values for incubated nitrogen after second spring wheat, third spring wheat and third ryegrass.

Source of Variation	df	Second Wheat	Third Wheat	Third Ryegrass
Block	3	1.45	1.51	6.66
Straw	2	4374.31**	1660.81**	4513.08**
Nitrogen	2	57.20**	66.52**	1250.07**
Straw x Nitrogen	4	132.73**	17.21**	117.50**
Water	2	188.77**	53.10**	43.25**
Straw x Water	4	60.90**	39.95**	9.56*
Nitrogen x Water	4	5.50	35.11**	29.01**
Straw x Nitrogen x Water	8	6.39	18.80**	40.03**
Error	78	4.32	2.05	3.76
Total	107			

*Significant at .05 probability level.

**Significant at .01 probability level.

Table 23. Incubated N following second spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
				ppm			
0	0	7.58	7.48	7.50	7.52		
	100	7.55	7.48	6.70	7.24		
	200	6.58	6.28	5.83	6.23	6.99	
1	0	21.48	20.48	20.15	20.70		
	100	23.95	18.85	16.50	19.77		
	200	18.03	16.28	15.58	16.63	19.03	
2	0	29.98	22.28	18.68	23.64		
	100	37.90	29.75	28.98	32.21		
	200	35.03	30.23	28.28	31.18	29.01	
Mean Water		20.89	17.68	16.46			
N x W	N_0	19.68	16.74	15.44			17.29
	N_{100}	23.13	18.69	17.39			19.74
	N_{200}	19.88	17.59	16.56			18.01
S x W	S_0	7.23	7.08	6.68			
	S_1	21.15	18.53	17.41			
	S_2	34.30	27.42	25.31			

Table 24. Incubated N following third spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		ppm					
0	0	6.05	5.50	5.40	5.65		
	100	5.68	5.20	5.00	5.29		
	200	5.88	5.45	5.23	5.52	5.49	
1	0	14.55	19.30	19.58	17.81		
	100	19.00	15.00	12.10	15.37		
	200	12.43	13.10	14.13	13.22	15.46	
2	0	24.45	18.55	16.80	19.93		
	100	24.73	18.68	13.40	18.93		
	200	16.60	17.05	15.88	16.51	18.46	
Mean Water		14.37	13.09	11.94			
N x W	N_0	15.02	14.45	13.93			14.46
	N_{100}	16.47	12.96	10.17			13.20
	N_{200}	11.63	11.87	11.74			11.75
S x W	S_0	5.87	5.38	5.21			
	S_1	15.33	15.80	15.27			
	S_2	21.93	18.09	15.39			

Table 25. Incubated N following third ryegrass as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		ppm					
0	0	7.88	10.48	10.20	9.52		
	100	15.50	16.35	15.78	15.88		
	200	11.10	11.70	14.05	12.29	12.56	
1	0	13.23	22.23	25.65	20.37		
	100	33.15	33.77	35.20	34.04		
	200	36.30	37.20	29.80	34.43	29.61	
2	0	26.30	25.28	26.78	26.12		
	100	37.55	40.60	41.95	40.03		
	200	35.30	33.55	35.58	34.81	33.65	
Mean Water		24.03	25.68	26.11			
N x W	N_0	15.80	19.33	20.88			18.67
	N_{100}	28.73	30.24	30.98			29.98
	N_{200}	27.57	27.48	26.48			27.18
S x W	S_0	11.49	12.89	13.34			
	S_1	27.56	31.07	30.22			
	S_2	33.05	33.14	34.77			

the soil organic reserves.

N Recovery by Plant and Soil

A balance sheet of N and N recovery by plant and soil is presented in Tables 26(a) and 26(b). The percentage recovery was calculated from the total amount of N taken up by plant plus residual N left over in soil after the experiment divided by the amount of N from soil, fertilizer and straw. The percentage recovery ranged from 88 to 97%. At zero N, percentage recovery decreased as straw levels increased, but with the application of 200 lbs N/A recovery seems to increase with the amount of straw added. This was due to the total uptake by plants which was greater at zero straw treatment, while the amount of N left over in soil was greater at high straw levels. However, the amount of N uptake was only 1/4 to 1/7 of the residual N in soil. Water had a strong influence on the recovery of N. Higher soil water always gave higher recovery. This was probably due to the higher activity of soil microorganisms.

Soil Organic Matter Following the Second, Third Spring Wheat and Third Ryegrass Cuttings

Straw, nitrogen and water had a great influence on the amount of soil organic matter (Table 27). Although this experiment may not have been conducted long enough and/or with sufficient precision to permit a satisfactory determination of the ultimate equilibrium level or a more precise measure of the rate of change in the content of soil organic matter, one can see the changing trend of soil organic matter.

Higher levels of straw as well as nitrogen resulted in higher amounts of soil organic matter (Tables 28, 29 and 30). The zero straw with no N applied always gave the lowest values. The effect of straw was greater in increasing soil organic matter compared to

Table 26(a). Nitrogen Balance Sheet and Percentage Recovery of N by Plant and Soil.

Treatment No.	Straw (%)	Nitrogen (lbs/A)	Water (% of F.C.)	N from Soil, Fertilizer & Straw	N Uptake by Plant	Residual in Soil	N Recovery by Plant & Soil (%)
				g/pot			
1	0	0	50	3.90	0.26	3.29	90.95
2	0	0	65	3.90	0.26	3.31	91.51
3	0	0	80	3.90	0.27	3.43	94.87
4	0	100	50	4.34	0.65	3.39	92.97
5	0	100	65	4.34	0.63	3.43	93.53
6	0	100	80	4.34	0.68	3.45	95.16
7	0	200	50	4.78	0.93	3.45	91.70
8	0	200	65	4.78	0.93	3.47	92.07
9	0	200	80	4.78	0.97	3.55	94.64
10	1	0	50	4.11	0.17	3.50	89.18
11	1	0	65	4.11	0.20	3.53	90.61
12	1	0	80	4.11	0.25	3.55	92.48
13	1	100	50	4.55	0.44	3.82	93.56
14	1	100	65	4.55	0.45	3.84	94.35
15	1	100	80	4.55	0.54	3.88	97.14
16	1	200	50	4.99	0.76	3.80	91.40
17	1	200	65	4.99	0.76	3.86	92.57
18	1	200	80	4.99	0.77	3.87	92.94
19	2	0	50	4.32	0.18	3.62	88.03
20	2	0	65	4.32	0.21	3.62	88.70
21	2	0	80	4.32	0.27	3.70	91.92
22	2	100	50	4.76	0.35	3.91	89.41
23	2	100	65	4.76	0.41	3.80	88.47
24	2	100	80	4.76	0.46	3.85	90.55
25	2	200	50	5.20	0.59	5.30	94.08
26	2	200	65	5.20	0.63	4.33	95.31
27	2	200	80	5.20	0.67	4.34	96.37

Table 26(b). Percentage recovery as affected by different levels of straw, nitrogen, water and straw by nitrogen.

Straw (%)		Nitrogen (lbs/A) 0	100	200
		%		
		90.92	92.80	93.45
0	93.04	92.44	93.89	92.80
1	92.69	90.76	95.02	92.30
2	91.43	89.55	89.48	95.25

Soil Water (% of F.C.)	Percentage Recovery
50	91.25
65	91.90
80	94.01

Table 27. Mean square values for soil organic matter after second spring wheat, third spring wheat and third ryegrass.

Source of Variation	df	Second Wheat	Third Wheat	Third Ryegrass
Block	3	.005	.002	.013
Straw	2	3.29**	5.92**	4.49**
Nitrogen	2	.566**	1.36**	.08**
Straw x Nitrogen	4	.01	.159**	.01
Water	2	.182**	.025**	.04*
Straw x Water	4	.129**	.104**	.08**
Nitrogen x Water	4	.085**	.249**	.05**
Straw x Nitrogen x Water	8	.054**	.051**	.15**
Error	78	.004	.005	.01
Total	107			

*Significant at .05 probability level.

**Significant at .01 probability level.

Table 28. Soil organic matter percentage following second spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/ A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		%					
0	0	2.58	2.46	2.75	2.60		
	100	2.72	2.82	2.80	2.78		
	200	2.69	2.78	2.96	2.81	2.73	
1	0	2.82	2.62	3.01	2.82		
	100	3.24	3.00	3.01	3.08		
	200	2.94	2.85	3.44	3.07	2.99	
2	0	3.24	3.24	3.13	3.20		
	100	3.46	3.38	3.41	3.42		
	200	3.37	3.42	3.34	3.37	3.33	
Mean Water		3.01	2.95	3.09			
N x W	N_0	2.88	2.77	2.96			2.87
	N_{100}	3.14	3.07	3.07			3.09
	N_{200}	3.00	3.01	3.24			3.08
S x W	S_0	2.66	2.68	2.83			
	S_1	3.00	2.82	3.15			
	S_2	3.35	3.35	3.29			

Table 29. Soil organic matter percentage following third spring wheat as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/ A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		------------	%	------------	------------	------------	------------
0	0	2.07	2.13	1.91	2.03		
	100	2.68	2.35	2.18	2.40		
	200	2.18	2.25	2.31	2.24	2.23	
1	0	2.01	2.62	2.44	2.35		
	100	3.11	2.89	2.93	2.98		
	200	2.60	2.72	2.88	2.74	2.69	
2	0	3.01	3.02	2.81	2.95		
	100	3.20	3.09	3.06	3.11		
	200	2.99	3.04	3.11	3.05	3.04	
Mean Water		2.65	2.68	2.63			
N x W	N_0	2.36	2.59	2.39			2.44
	N_{100}	2.99	2.77	2.72			2.83
	N_{200}	2.59	2.67	2.77			2.68
S x W	S_0	2.31	2.24	2.13			
	S_1	2.57	2.74	2.75			
	S_2	3.06	3.05	2.99			

Table 30. Soil organic matter percentage following third ryegrass as affected by three levels of straw (S), nitrogen (N) and soil water (W) and their interaction means.

Straw (%)	Nitrogen lbs/A	Soil Water (% of field capacity) 50	65	80	Mean S x N	S	N
		-----	----- %	-----	-----	-----	-----
0	0	2.27	2.77	2.60	2.55		
	100	2.74	2.58	2.55	2.62		
	200	2.66	2.70	2.68	2.68	2.62	
1	0	3.06	2.88	3.13	3.02		
	100	2.89	3.27	3.03	3.06		
	200	3.18	2.81	3.25	3.08	3.06	
2	0	3.18	3.42	3.17	3.25		
	100	3.42	3.34	3.36	3.37		
	200	3.25	3.46	3.24	3.32	3.31	
Mean Water		2.96	3.02	3.00			
N x W	N_0	2.83	3.02	2.96			2.94
	N_{100}	3.02	3.06	2.98			3.02
	N_{200}	3.03	2.99	3.06			3.03
S x W	S_0	2.55	2.68	2.61			
	S_1	3.04	2.99	3.14			
	S_2	3.28	3.40	3.26			

the effect of fertilizer N as evidenced by the mean square values (Table 27). Horner et al. (1960) found that a combination of straw plus nitrogen maintained organic matter more effective than either one applied alone, especially in the high precipitation area. In comparing the amount of soil organic matter at the end of this experiment (Table 30) with the beginning, it was found that straw incorporated into soil can influence the amount of soil organic matter greatly. If the straw were not added to soil, organic matter declined, but when straw was added either at 1 or 2%, organic matter was maintained. The addition of nitrogen fertilizer also maintained the amount of soil organic matter. Water levels had the least influence on soil organic matter levels but differences were still significant. Soil water levels at 65 and 80% of field capacity increased soil organic matter more than the 50% field capacity level.

SUMMARY AND CONCLUSIONS

A greenhouse experiment was conducted from December 1978 to April 1980 to study the effect of straw and nitrogen fertilization on nitrogen availability to spring wheat and ryegrass plants. The objective of this study was to investigate the effect of straw on dry matter yield and nitrogen uptake of spring wheat and ryegrass, and the effect of straw on nitrogen content and organic matter of the soil. Results obtained were analyzed statistically to determine the factors significantly affecting dry matter yield, nitrogen uptake and soil organic matter.

A randomized block design with four replications was used in the experiment. Each replication was composed of 27 treatments which include a factorial arrangement of three levels of straw, nitrogen fertilizer and water.

Experimental results obtained from this study supported the following conclusions:

1. For the first two croppings of spring wheat, straw depressed dry matter yield when no nitrogen fertilizer was applied, but when nitrogen was applied, straw aided in increasing dry matter yield. In the third spring wheat cutting, increasing level of straw gave higher dry matter yield both with and without nitrogen application. It was concluded that nitrogen immobilization following straw application was responsible for the initial yield suppression, but that later mineralization of nitrogen from the straw and soil acted to increase dry matter yield.

2. In the ryegrass cropping sequence, straw depressed dry matter yield at all nitrogen levels of the first cutting. In the second and third cutting, there were inconsistencies in dry matter yield resulting from levels of straw incorporation. Increasing soil water also reduced dry matter yield of the third ryegrass cutting. Since the first ryegrass crop generally utilized more than the

equivalent amount of fertilizer nitrogen added as ammonium nitrate, nitrogen mineralization supplied most of the nitrogen taken up by the succeeding crops. Therefore, the conclusion was made that any factor, such as decomposing straw or a greater than optimal soil water content, which reduced mineralization of nitrogen would also have a negative effect on dry matter production.

3. Nitrogen uptake closely followed the trend of dry matter yield.

4. Total soil nitrogen decreased slowly following each successive crop. Addition of straw and fertilizer nitrogen reduced the rate of decrease, while the effect produced by the different levels of soil water was inconsistent.

5. Incubated nitrogen also decreased slowly as crops were grown. Increasing straw helped to increase levels of incubated nitrogen since the straw acted as a source of potentially mineralizable nitrogen. Neither fertilizer nitrogen nor soil water had a significant effect on incubated nitrogen.

6. Adding straw increased the soil organic matter content. Although the magnitude of these changes were small, straw acted to stimulate both immobilization and mineralization of nitrogen. These two opposing processes differentially influenced the production of each succeeding wheat and ryegrass crop.

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Appendix Table 1. Treatments used in the experiment.

	Straw (%)	Nitrogen (lbs/A)	Soil Water (% of field capacity)
1	0	0	50
2	0	0	65
3	0	0	80
4	0	100	50
5	0	100	65
6	0	100	80
7	0	200	50
8	0	200	65
9	0	200	80
10	1	0	50
11	1	0	65
12	1	0	80
13	1	100	50
14	1	100	65
15	1	100	80
16	1	200	50
17	1	200	65
18	1	200	80
19	2	0	50
20	2	0	65
21	2	0	80
22	2	100	50
23	2	100	65
24	2	100	80
25	2	200	50
26	2	200	65
27	2	200	80