To the Graduate Council:

I am submitting herewith a thesis written by John Hurst Lyle entitled "Yields and Nutrient Relationships of Corn Grown in Small Grain-Legume Cover Crops." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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YIELDS AND NUTRIENT RELATIONSHIPS OF CORN GROWN IN SMALL GRAIN-LEGUME COVER CROPS

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ABSTRACT

Rising energy costs and high soil erosion losses are causing many farmers in West Tennessee to turn to no-tillage methods of production. This study, conducted during the growing season of 1980 at Milan, Tennessee, evaluated the effects of utilizing a legume in the no-till mulch on the growth, yield, and nutrient relationships of corn (*Zea mays* L.). Corn planted into a hairy vetch (*Vicia villosa* Roth.) and wheat (*Triticum aestivum* L.) mixture under both conventional and no-tillage was compared to no-tillage into a wheat alone mulch and to a check plot consisting of corn grown by conventional tillage into bare ground. These four treatments were compared at rates of 56, 112, and 168 kg/ha of nitrogen as NH_4NO_3. Tissue samples for dry matter weight and elemental analysis were taken of the wheat and wheat-vetch cover crops before corn planting and of the corn at five dates during the growing season. The corn was planted on April 30 and harvested September 12.

The dry matter yield and N content of the wheat-vetch cover crop was lower than expected. This resulted in a very low N contribution from the mulch.

Stover weight values were similar for all treatments across sampling dates at the non-zero N rates

and the rate of dry matter production declined during the latter part of the growing season. These results reflect the severe moisture stress during this period.

There appeared to be some immobilization of N under the no-till mulches. The WNT (wheat, no-tillage) treatment required the most supplemental N fertilization to reach its yield maximum. Also, the stover dry matter yield of both no-till treatments was lower than the conventional during the early part of the growing season.

The analysis of variance for grain yields indicates that tillage was necessary to release the legume N and that there did not appear to be any priming effect from the addition of inorganic fertilizer N. These conclusions follow from the significant F value for the WVC vs. WVNT comparison and its insignificant interaction with N rates.

Stover N content was significantly increased by additional fertilizer N. In some comparisons between treatments and between N rates, when dry matter and grain production were low there was a concomitant increase in the N content of the stover.

There were significant decreases in the P and K percentages of the stover as the supplemental N rate was increased. These percentages also declined with increasing dry matter production.

A concentration effect caused by low dry matter production at the low N rates during the first half of the growing season resulted in significantly higher stover P% values for the no-tillage treatments. A comparison of the data on stover yield and phosphorus uptake reveal that the wheat-vetch residue released available phosphorus at the 0 and 56 kg/ha N rates under both tillage situations.

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CHAPTER I

INTRODUCTION AND LITERATURE REVIEW

American agriculture is currently faced with several serious natural resource conservation problems. The high levels of production necessary to maintain economic solvency for many farmers are often opposed to the goals of reducing petroleum consumption, decreasing soil losses, and improving water quality.

Nowhere is this conservation dilemma more evident than in the area of loess derived soils in West Tennessee, the region of most intensive crop production in the state (for example, 80% of the soybean acreage in the state in 1980 was in West Tennessee (75)). A typical corn production system in West Tennessee (continuous corn silage yielding 4700 kg/ha, no winter cover, on a Memphis soil in Shelby County, 4% slope 150 ft. long, on the contour) will result in more than 18 tons/acre/year of soil loss (42). It has been estimated that at least two-thirds of the cropped acreage in West Tennessee is sloping upland subject to erosion and that the annual erosion rate in the region is ten times the national average (75). The high cost of nitrogen fertilizers and the susceptibility of the soils to soil erosion are two of the most significant production problems faced by farmers in the area growing non-leguminous crops such as corn or grain sorghum.

The research project discussed herein examines agronomic practices that attempt to achieve simultaneously the goals of improved fertilization efficiency and reduced soil losses. These practices include minimum tillage into a mulch and the use of grass-legume winter cover crops. Their efficacy was measured by the yield response of a subsequent corn crop at various supplemental nitrogen levels.

Nitrogen use on corn in the U.S. has increased sixteen fold since 1945 and along with hybrid varieties is one of the principal reasons for the 240% increase in average corn yields over that period (58). In 1980 fertilization of corn acreage took 40% of the total nitrogen fertilizer used at an average rate of 151 kg/ha (26).

About 95% of the nitrogen fertilizer produced in the U.S. comes from synthetic anhydrous ammonia, the production of which requires natural gas or some other fossil fuel (13). Price increases for these fuels following the oil crises of 1973-74 have resulted in rapidly rising prices for nitrogenous fertilizers, the price of anhydrous ammonia having increased three fold from 1970 to 1980 (26). Production of all nitrogenous fertilizers used 0.5% of the 1974-75 total U.S. energy consumption and agricultural ammonia production consumed 2% of the total natural gas used that year (13). American agricultural production as a whole represents approximately 3% of total U.S. annual energy consumption (1).

Phillips _et_. _al_. (55) note that nitrogen fertilizer represents almost one half of the energy required in a typical corn production system in Kentucky. There is much disagreement over whether this energy is used efficiently. Pimental (58) has calculated a 24% decrease in energy returned to energy consumed in corn production from 1945 to 1970. Steinhart and Steinhart (69) note a similar decrease in energy use efficiency in the U.S. food system overall while a more recent analysis by Smil _et_. _al_. (66) concludes that the energy efficiency of U.S. corn farming has not declined.

Nevertheless, the desirable conservation and economic consequences of petroleum use reduction are clear. Pimental (58) showed that seeding and turning under a legume yielding 149 kg/ha of N would save 3.7 million kcal/ha. This estimate did not take into account the relative inefficiency of legume N in comparison to inorganic fertilizer N. Unpublished data from Fribourg (as quoted by Sutherland _et_. _al_. (73)) show legume residue N to be only 65-85% as effective as inorganic N in increasing corn yields. Another study found legume N to be anywhere from 16-92% as effective as inorganic N (71). Results from a 1964-1974 Alabama study (21) revealed that vetch can replace 100-135 kg N/ha for corn and cotton. A seven year study in Georgia found no significant difference in corn yields between vetch at 0 kg/ha N and the maximum yield for continuous corn obtained with 90 kg/ha fertilizer N (2). Earlier studies in the Southeast have shown winter legumes to be equal to 27-106 kg/ha of inorganic N for corn production (3, 19, 43).

That the value of legumes as green manure is the addition of nitrogen to the succeeding crop has long been known but it was not until the 1880's that the Germans Hillriegel and Wilfarth proved that this addition was the result of biological fixation of atmospheric nitrogen by bacteria living in nodules on the roots of the legume (41). The benefits of green manuring were known by the Chinese as long as three thousand years ago and were also familiar to the ancient Greeks and Romans (56). The practice continued in the Mediterranean countries but fell out of favor in Northern Europe as farming rotations changed in the Middle Ages (56). Early 19th Century agricultural reformers such as John Taylor and Edmund Riffin reawakened interest in the use of legumes as vegetable manures to renovate "exhausted soils" (22). In America the use of legumes as green manures was pioneered in Virginia and Maryland by the same men who led the fight for our nation's independence. In a letter he wrote to President Washington in 1796, Jefferson says that:

> I look forward with considerable anxiety to the success of the winter vetch, for it gives us a good winter crop, and helps the succeeding summer one. It is something like doubling the produce of the field (27).

By the early 20th Century green manuring had become a common practice in American agriculture, continuing until the early 1960's when inexpensive synthetically fixed nitrogen had become widely available.

The use of legumes as winter cover crops and vegetable manures was most widely practiced in the U.S. in the Southeast where corn and cotton growing on the highly weathered and low organic matter content soils of the Piedmont and Coastal Plain responded well to this practice. By 1940 over 13 million acres were in such crops (60).

Many benefits have been attributed to the use of green manure cover crops. Among these are adding nutrients, especially N; conserving mineral nutrients against leaching and concentrating them in the surface soil; improving the physical condition of the soil, including increasing the organic matter content, available water holding capacity, and infiltration rate, decreasing the bulk density, and improving aggregation; reducing soil erosion losses; and providing winter forage (8, 60, 62, 67). Russell (62) points out that green manures cannot do all these things simultaneously; indeed, they may accomplish none. Some of the difficulties associated with their use include the cost and difficulty of establishment, depletion of soil moisture, adverse effects on stand establishment of the subsequent crop, and a possible increase in diseases and pests (60).

These relative merits of green manuring were extensively researched at southern experiment stations, especially in the period prior to World War II and the development of the synthetic nitrogen industry. The very early studies, though still useful, have several drawbacks (43). Yield response of corn and cotton to a species of legume was compared only to other legumes or a control plot with no treatment; only rarely were they compared to plots receiving nitrogen fertilizer alone or a legume and nitrogen fertilizer, and then only at very low rates. Many of the experiments were conducted before statistical tests of significance were in common use. Open pollinated corn varieties, inferior to later hybrids in yield and other agronomic characteristics, were used in yield response trials. Certain legume species have also since been improved, especially in such characteristics as cold hardiness, reseeding ability, and early herbage production (23). Finally, alternative methods of disposition of the green manure and planting of the corn crop were seldom considered.

The legumes most often tested were Austrian winter peas, crimson clover, and hairy vetch. Corn yield response data from early experiments in Alabama (3), Mississippi (19), Virginia (38), and other states indicated that hairy vetch is the most beneficial of these winter legumes. Great variations in the yield of the winter legumes themselves have been reported. Yields of vetch in early studies from Alabama (3) and Florida (46) ranged from 4500 to 9000 kg green weight. In a later North Carolina study vetch dry matter yields varied from 2240 to 6050 kg/ha over a 5 year period (82).

These early studies also showed that the amount of nitrogen fixed depends on the crop and the amount of growth. Duggar (25) found that hairy vetch supplied 150-227 kg/ha N and that the amount varied with the amount of growth. In experiments in Georgia to determine the best dates of seeding and harvest of winter legumes vetch sown on October 15 and harvested April 1 yielded

3100 kg/ha dry matter. Any combination from 5 dates of seeding and 2 dates of cutting which resulted in a shorter growing season also resulted in lower yields (70).

One early review on the use of winter legumes for green manure attributed their yield improving ability to not only added nitrogen but also to other "unexplained factors which persist after the fertilizing material of the plant has disappeared" (46). Indeed, some workers have noticed long term effects. Kamprath (43) observed a positive growth response over a 4 year period following a vetch cover crop. An Alabama study observed a 1000 kg/ha increase in corn yield the third year after turning vetch (72). Adams _et_. _al_. (2) in Georgia found that the effect of vetch was significant at the 0 kg/ha supplemental N rate, and approached significance at the 90 kg/ha rate, four years after discontinuing the experiment. Most other studies have found little residual effect (3, 32, 67).

Long term benefits of winter legume cover crops have most often been attributed to their effects on the physical condition of the soil (45, 57). Obenshain and Gish (53) observed that increases in the plastic range and the sticky point of a Virginia soil were closely correlated to increases in organic matter content from winter legume cover crops. Data from Lutz _et_. _al_. (45) show that significant increases in percentage of pores drained at 10 and 60 cm tension, in total porosity, and penetrometer resistance were produced by leguminous winter cover crops but note that yield increases were no greater than those obtained from fertilizer nitrogen. Beale _et_. _al_. (6) found that the organic matter content and aggregation of a Piedmont soil were significantly increased by a mulch tilled vetch-rye mixture although yields were not significantly improved. Other workers have also observed improved structure from small grain-legume cover crops (28). Experiments on winter cover crops in North Carolina have shown that vetch plus high N fertilization improved the organic matter content on low content soils and maintained the level on soils originally high in organic matter (43). Data from New Jersey, however, show that despite the incorporation of 21 metric tons/ha of vetch over 5 years there was no gain in organic carbon or water holding capacity, although the rate of loss of organic carbon under continuous corn was decreased (67). McVickar _et_. _al_. (47) found that after 4 years of winter cover crops on a sandy soil there were no significant increases in organic matter content or water holding capacity. Rogers and Giddens (60) quote an 8 year experiment in Georgia which found no increase in organic matter from a green manure crop and conclude that such crops will not influence organic matter content under continuous cultivation. Giddens _et_. _al_. (36) found that although rye fertilized with 180 kg/ha of N for six years increased soil organic matter, nitrogen content, pore space, and aggregation, yields of corn following rye were still only 60% as high as when the N was applied directly to the corn.

Researchers in Georgia reasoned that the main contribution of vetch green manure was its nitrogen addition because increasing supplemental N rates up to 180 kg/ha resulted in no significant increase in grain production when corn followed the vetch (2). Further support for the conclusion that the enhancement of corn yields by green manuring is the result only of an increase in the available nitrogen supply is given by data from Shrader _et_. _al_. (64). These workers were able to construct a common nitrogen response curve to estimate corn yields from long term rotations with legumes and concluded that yields differed only because of differences in available nitrogen.

The soil saving benefit of legume or grass and legume winter cover crops was noted often in early reviews but without quantification (3, 9). It was attributed to the effects of a dense ground cover reducing the energy of raindrop impact and increasing water infiltration and to a supposed increase in organic matter content and improved physical properties (9, 46, 57, 60). Data from a 1932-1935 experiment in Iowa shows an 84% decrease in soil loss from plots on which sweet clover had been turned under which was attributed to an improvement in infiltration rate as a result of an increase in the organic matter content (52). Beale *et. al.* (6) found that average annual soil losses from conventionally tilled corn plots with no cover crop were twice that from plots where a vetch and rye cover crop had been grown and six times that from vetch and rye plots under mulch tillage. It has now been shown conclusively, however, from data by Wischmeier (83) and others that most rainfall erosion occurs during the intense thunderstorms of the summer growing season. In one South Carolina study more than 80% of a year's soil loss occurred in July alone (6). Rogers and Giddens (60) observed that fall planted legumes may make insufficient growth before the onset of winter rains and quote a Georgia experiment in which soil erosion was greater on land sown to a winter cover crop than on land left in corn stubble.

The various political and economic pressures to reduce soil losses, improve water quality, and decrease labor, time, and fuel consumption have prompted many farmers to adopt crop production practices that preserve crop residues on the soil surface (80). A 1979 survey of farmers conducted by the Soil Conservation Service found that 26% of the cropped acreage in the United States received some form of reduced tillage but only 2.5% was farmed by no-tillage methods (81). In Tennessee 5% of the cropped acreage was no-till farmed. The present experiment was designed to test the hypotheses that the beneficial effects of reduced tillage could be enhanced by its application with a nitrogenous green manure mulch resulting in a corn production system that would produce higher yields with reduced soil erosion through more efficient use of both nitrogen and water without substantially increasing costs.

It is now well documented that planting corn into a surface mulch with the minimum tillage necessary for seed placement may reduce soil losses to near zero (55). Researchers in Virginia (51), Kentucky (55), Ohio (80), and other states have consistently shown higher yields for no-till versus conventionally tilled corn. Triplett and Van Doren (79) found this to be true at both high and low nitrogen rates. Improved yields from no-tillage have most often been related to improved moisture conditions resulting from lower evaporation and higher infiltration under the mulch cover (24, 51, 79).

The use of minimum tillage also results in changes in the chemistry of the soil. Workers in Kentucky have shown that after five years of continuous corn the soil under no-till had lower pH and higher exchangeable Al, organic C, and organic N (12).

The changes in the physical and chemical properties that occur when soil is not turned and mixed by tillage also alter the soil microbial environment (24). This causes a shift in the microbial population and a concomitant change in the nitrogen economy of the soil. Tillage is generally thought to increase microbial populations (24, 74). In a survey of microbial populations in soils from seven long term tillage experiments across the U.S., Doran (24) found that the proportions of microbial types in no-till soils represented a lower potential rate of mineralization and nitrification and a higher potential for denitrification as compared to conventionally tilled soils. The larger fungal populations found in the surface of some no-till soils would also lower N availability by increasing the amount of immobilization of inorganic N (35). Researchers in Washington, however, concluded that the increased N requirements in systems utilizing surface crop residues could not be caused by immobilization because less than 5% of the total C in surface straw becomes soluble and enters the soil (18). Researchers at TVA postulated that serious volatilization losses of N as NH_3 could occur from surface crop residues and showed that N uptake was lower from surface-applied alfalfa than from residue mixed with the soil (76).

The requirements for a cover crop used as a mulch in a minimum tillage system have been outlined by Shear (63): ease of establishment in the fall, winter hardiness, production of an adequate mulch before being killed in the spring, and persistence of mulch through the summer growing season. New vetch varieties bred by Donnelly (23) for use in the Southeast are particularly suited to use in minimum tillage systems as they produce a heavy spring growth which chokes out weeds and provides a heavy mulch which conserves soil moisture and is easily killed by dessicants at planting. Vetch is often grown in mixture with a winter annual grass such as oats, rye, or wheat which increases mulch yields (49, 50) and helps to support the weak stems of the vetch which increases seed yields (23). In a 1927-28 study in South Carolina a rye and vetch mixture alone produced a 1320 kg/ha corn yield and 1500 kg/ha with 10 kg N sidedressing while

Austrian winter peas provided 1570 and 1700 bushels respectively (17). A later study from North Carolina found a vetch and rye mixture to be equal to an average of 84 kg/ha inorganic N in production of corn grain (82). A corn yield response experiment in the same state showed an oats and vetch mixture to be inferior to vetch alone at the 0 N rate but equal at rates of 90-180 kg/ha supplemental N. The mixture produced corn yields equal to 180 kg/ha of inorganic N (43). In Georgia no significant difference in corn yields was observed between plots of crimson clover and a rye and crimson clover mixture across five tillage treatments at an N rate of 146 kg/ha (8).

Moschler et. al. (50) compared several winter cover crops for sod-planted corn in Virginia and found that the inclusion of crimson clover or hairy vetch in winter grain seedings slightly increased mulch forage but not grain yields. This may have been due to the elevation and resultant winter killing of the legumes (63). In a Georgia experiment on the effect of various methods of seedbed preparation (including direct seeding without tillage) and green manure crops (rye, crimson clover, and a mixture) no significant interactions were found indicating that no advantage resulted from the additional growth of the cover crop made possible by direct seeding of the corn (8). A ten year study at Clemson University showed that at an average N fertilizer rate of 84 kg/ha a vetch and rye mixture mulch tilled gave yields equal to or greater than plowed mulched corn (82). In Delaware minimum tillage corn planted into a rye and hairy vetch mulch produced grain yields comparable to those obtained by 112 kg/ha of fertilizer N (49). One-third of the total N in the mulch cover was taken up by the corn in a single season with approximately 90% of this derived from cover crop top growth. In Florida hairy vetch provided almost all the N required for corn and grain sorghum with yields from minimum tillage exceeding those from conventional tillage (34).

In a study evaluating the yield response of corn to supplemental N following an alfalfa meadow under plowed and no-till conditions, Triplett et. al. (78) found no interaction of tillage and N, indicating that tillage was not necessary to release the N contained in the legume yields of greater than 90 quintals/ha were produced without added N.

In addition to the soil and moisture conservation benefits of no-till farming in general, there are other possible advantages to direct seeding into a leguminous mulch. Corn planting may be delayed, allowing the legume or grass and legume mixture to approach maturity and N fixation to be maximized. The winter crop may also be harvested for forage before planting of the summer crop (8).

CHAPTER II

MATERIALS AND METHODS

This experiment was conducted at the Milan Field Station in West Tennessee from the fall of 1979 through the summer of 1980. The soil was a Memphis silt loam (fine-silty, mixed, thermic, Typic Hapludalf) with 0-2% slope. Sixteen cover crop - nitrogen fertilizer rate treatment combinations were replicated four times in a split-split plot design (44). Five sampling dates were the main treatments, four supplemental nitrogen fertilizer rates were the split treatments, and four winter cover crop/tillage method combinations were the split-split treatments. These combinations were: wheat-vetch, conventional tillage (WVC); wheat-vetch, no-tillage (WVNT); wheat, no-tillage (WNT); and no winter cover, conventional tillage (Check). There were four corn rows 102 cm apart within the 4.1 by 9.1m split-split plots.

Lime was applied at the rate of 2.24 metric tons/ha and uniform applications of 39 kg P and 74 kg K per hectare were made prior to the sowing of the cover crops on October 27, 1979. Seeding rates were 100 kg/ha wheat and 40 kg/ha vetch for the wheat-vetch treatments and 100 kg/ha wheat for the wheat alone treatments. The wheat (*Triticum aestivum* L.) variety was "Arthur" and the vetch used was Hairy vetch (*Vicia villosa* Roth.).

The cover crops were killed on April 30 by a combined application of 1.68 kg active ingredient/ha of glyphosate (*N*-(phosphonomethyl) glycine), 1.65 kg active ingredient/ha of atrazine (2-chloro-4(ethylamine)-6 (iso-propylamine)-s-triazine), and 2.24 kg active ingredient/ha of Lasso (2-chloro-2', 6'-diethyl-N-(methoxymethyl) acetanilide). A treatment of 0.56 kg active ingredient/ha of Paraquat (1,1'-dimethyl-4, 4'-bipyridinium dichloride) with surfactant on April 8 had proved insufficient to kill all growing vegetation.

Prior to corn planting, top growth samples for elemental analysis and dry matter weight were taken from $1m^2$ quadrats of 10 wheat-vetch and 10 wheat alone plots randomly chosen from those 48 plots which had some form of winter cover.

Corn hybrid Pioneer 3184 treated with 11 kg Furadan/ha was planted on April 30 following disc and roller harrow cultivation of the conventionally tilled plots. The seeding rate was approximately 49,000 kernels per hectare. Each plot contained 4 rows 102cm apart with the center two rows serving as the sampling unit and the outer two rows as border rows. Nitrogen as ammonium nitrate was hand broadcast at the desired rates at planting.

Corn stover samples were removed at five dates during the growing season (May 28, June 10, June 19, July 15, and Sept. 12). The samples were dried in a forced air oven at 70° C, weighed, and ground in a Wiley Mill to pass a 2mm sieve in preparation for analysis of N, P, and K.

Corn grain was hand harvested at the full dent stage from 7.6m lengths of the two center rows. Grain yield was calculated from field weights and expressed as kg/ha on the basis of 15.5% moisture. Samples of grain were dried and ground for elemental analysis as above.

Samples of the cover crop top growth, corn stover, and corn grain were ashed for N analysis using an H_2SO_4-H_2O_2 wet oxidation procedure and NH_4-N was determined colorimetrically after reduction by alkaline phenol (77). Samples for P and K were ashed by the HNO_3-$HClO_4$ wet oxidation technique of Gieseiking et. al. (37). Phosphorus content was determined colorimetrically as PO_4 by an adaptation of the vanadomolybdophosphoric yellow color method of Jackson (40) as described for use on the Technicon Auto-Analyzer by Steckel and Flannery (68). Potassium content was analyzed by flame emission on a Perkin-Elmer Model 5000 spectrophotometer (20).

Analyses of statistical significance were applied to the elemental percentages and mulch dry weight data for cover crop top growth; dry matter weight and elemental percentages of corn stover at the five sampling dates; N, P, and K percentages of corn grain; and corn grain yield. All tests were conducted at the 5% probability level using the Statistical Analysis System package on an IBM 370 computer (4). Duncan's New Multiple Range Test was used to test for differences among treatment means after establishing significance through the analysis of variance and appropriate F tests.

CHAPTER III

RESULTS AND DISCUSSION

Yield and Composition of Winter Cover Crops

Dry matter production, elemental composition, and total N, P and K contents of the top growth of the two cover crop treatments, a wheat-vetch mixture and wheat alone, are shown in Table 1. Two-tailed t tests were used to test for significant differences between means for each characteristic analyzed.

The average mulch dry matter production for the wheat-vetch plots was almost twice that of the wheat alone plots. The mixture also contained a significantly higher percentage of N and K but a similar percentage of P as the wheat alone plots. The wheat-vetch treatment produced three times the total N and twice as much total P and K as the wheat alone treatment.

The considerable variation in mulch dry matter production of the two treatments is not unusual for temporary winter crops grown in the Southeast (8). Mulch production for both treatments was low compared to data from other experiments. In an early experiment in Georgia a vetch-oats mixture produced a yield of 2423 kg/ha (70) while in one North Carolina trial the same mixture produced 3472 kg/ha (82) and in another averaged

Table 1. Total mulch weight, elemental composition, and amounts of N, P and K supplied by winter cover crops.

Cover crop	weight of aerial veg.	% N	Total N	% P	Total P	% K	Total K
	kg/ha		kg/ha		kg/ha		kg/ha
Wheat-vetch	1814	1.9	35	0.8	14	3.0	56
c.v. (%)	23	27.8	44	19.7	28	12.1	35
Wheat	908	1.1	10	0.8	7	2.5	23
c.v. (%)	26	19.6	29	24.0	49	4.0	27
Significance (5%)	*	*	*	n.s.	*	*	*

2923 kg/ha over twelve years (43). In more recent Delaware work a rye-vetch mixture yielded 7928 kg/ha of top growth, over four times the mulch production of the wheat-vetch treatment in the present experiment (49). Moschler et. al. (50) in Virginia found that the inclusion of vetch increased mulch production only slightly over that of rye. This may have been the result of winter killing of the vetch.

The average dry matter production of wheat in this experiment was also low in comparison to other published data on small grain mulch yields. In Georgia oats produced 2062 kg/ha (70) and rye averaged 3423 kg/ha dry matter production (8). Average rye mulch dry matter yields in Delaware were 4586 kg/ha (49).

Poor vetch growth in the wheat-vetch mixture is shown by the low and highly variable data for N percent. This factor combined with low dry matter production resulted in an average N contribution of only 34.8 kg/ha from the mulch top growth. Hairy vetch top growth alone normally averages approximately 3.5 - 4% N (56, 67). The top growth of vetch from the wheat-vetch plots in this study contained 3.14% N, slightly lower than the average. Assuming that the difference in mulch production between the wheat-vetch and wheat alone treatments is the vetch growth (i.e., wheat growth similar in the two treatments), then the N contribution from the vetch in the mixture was only 24.7 kg/ha (34.8-10.1). Other experiments have shown a similar difference in N percent between vetch alone and vetch-small grain mixtures but have higher percent N values for both and much higher values for N contribution. In two North Carolina experiments a vetch-oats mixture averaged 2.98% and 3.04% N respectively and produced 87 and 105 kg/ha of N respectively (43). A rye-vetch mixture in Delaware averaged 2.00% N and produced 158.5 kg/ha N (49). This data illustrates that while the value of 1.9% N for the wheat-vetch mixture in this experiment was below average for such mixtures, the main cause of the low N contribution in the present experiment was low dry matter production, particularly in the vetch.

A similar conclusion follows from the data for the wheat plots. The value of 1.12% N is slightly lower than the 1.31% for rye in a North Carolina trial (82) and higher than the 1.00% N for rye in Delaware (49). Winter wheat grown for green manure in New Jersey averaged 1.63% N (67). The total N contribution for the wheat mulch is significantly lower than the N contribution of the top growth of small grains in other experiments (7, 49, 67). Again, this low total N value is more the result of poor vegetative growth than low N percent.

The C:N ratio is a valuable way to evaluate the availability of nitrogen from organic materials (14, 15, 61). Assuming the dry matter to be 40% carbon, the C:N ratios of the residues in this experiment are 21:1 for the wheat-vetch mixture and 36:1 for the wheat residue. The threshold C:N value below which mineralization is expected to occur is generally though to be about 20-22:1 (10, 18). It appears that the wheat residue would definitely limit N release while the value for the mixtrue is unclear. Bartholomew (5) cautions that differences in the resistance of organic materials to decomposition limit the utility of C:N ratios and proposes N content as a better measure of N availability with the critical concentration falling between 1.0 and 1.3% by weight. The latter index seems to indicate a lower immobilization potential for the wheat residue than does the C:N method. This index also places the wheat-vetch residue definitely above the threshold value necessary for mineralization to occur.

The wheat-vetch treatment produced almost twice as much total P as the wheat plots but there was no significant difference in average P percentage for the two cover crop treatments. Therefore the difference in P contribution is due entirely to the significantly higher mulch production of the wheat-vetch treatment.

The significantly higher K percentage of the wheat-vetch treatments combined with their higher mulch production resulted in twice as much total K as in the wheat treatment.

Stover Dry Matter Yield

Tests of significance for the factorial and interaction effects in the data for corn stover dry weight sampled throughout the growing season are shown in Table 15 (Appendix). All three factorial effects (sampling date, nitrogen rate, and cover crop treatments) were significant at the 5% probability level. The three two-way interactions were also significant. The effect of the three-way interaction was not significant.

The effect of the interaction involving cover crops and nitrogen rates on corn stover dry weight is shown in Table 2. At the 0 N rate the stover weight values of the conventionally tilled plots were similar and significantly higher than those for the no-tillage plots. The same was true for the 56 kg/ha rate although the disparity was not as great. Stover dry weight means for the Check, WVC, and WVNT plots were similar at the non-zero N rates and significantly higher than the values at the 0 rate. The stover weight maximum was not reached until 112 kg/ha supplemental N in the WNT plots.

Table 2. Effect of cover crop treatments and supplemental N, across sampling dates, on corn stover dry weight.

Cover crop treatment	Nitrogen fertilizer rate, kg/ha 0	56	112	168
	kg/ha			
No winter cover (Check)	1035°	1537^{ab}	1574^{ab}	1714^{ab}
Wheat-vetch, conv. till	1034^{e}	1482^{ab}	1695^{ab}	1742^{a}
Wheat-vetch, no-tillage	612^{f}	1131^{cde}	1338^{bcd}	1368^{abc}
Wheat, no-tillage	460^{g}	1079^{de}	1533^{ab}	1459^{ab}

Note: Means followed by the same letter are not significantly different at the 5% level.

The trend for the stover weight to increase as the sampling date advances is shown in the two-way tables of means for the two significant interactions involving sampling date (Tables 3 and 4) and is also shown graphically in Figs. 1-4 (pgs. 32-35). The means of the sampling date * cover crop interaction (Table 3) show that there were significant differences between all consecutive sampling dates for each cover crop treatment. The conventional tillage plots had significantly higher stover weights than the no-tillage plots through the first three sampling dates (May 28, June 10, and June 19. At the last two samplings only the WVC plots had significantly higher stover weight values than the no-tillage plots.

The interaction between sampling dates and nitrogen rates is shown in Table 4. The three non-zero rates of supplemental N had similar stover weight values at each sampling date. Stover weights for the non-zero N rates were higher than the 0 rate at all but the first sampling date.

The trend of increasing stover weight with time is further illustrated by the graphs in Figs. 1 - 4 where the four cover crop treatments are graphed over the growing season at each of the four N rates. Treatment trends in stover weight at the 0 N rate are apparent by

Table 3. Effect of sampling date and cover crop treatment, across N rates, on corn stover dry weight.

	Sampling date				
Cover crop treatment	MAY 28	JUN 10	JUN 19	JUL 15	SEP 12
	kg/ha				
No winter cover (Check)	79^{i}	752^{a}	1717^{e}	5251^{d}	7568^{ab}
Wheat-vetch, conv. till	56^{j}	698^{g}	1590^{e}	6641^{b}	9044^{a}
Wheat-vetch, no-tillage	36^{k}	431^{h}	1105^{f}	5371^{d}	6597^{b}
Wheat, no-tillage	42^{k}	436^{h}	967^{f}	4996^{d}	6469^{bc}

Note: Means followed by the same letter are not significantly different at the 5% level.

Table 4. Effect of sampling date and supplemental N, across cover crop treatments, on corn stover dry weight.

Sampling date	Nitrogen fertilizer rate, kg/ha			
	0	56	112	168
	kg/ha			
MAY 28	33^{h}	54^{h}	58^{h}	65^{h}
JUN 10	305^{g}	591^{f}	790^{f}	686^{f}
JUN 19	695^{f}	1379^{e}	1674^{e}	1804^{e}
JUL 15	3367^{d}	5850^{bc}	6574^{ab}	7264^{ab}
SEP 12	4166^{cd}	7739^{ab}	9409^{a}	9615^{a}

Note: Means followed by the same letter are not significantly different at the 5% level.

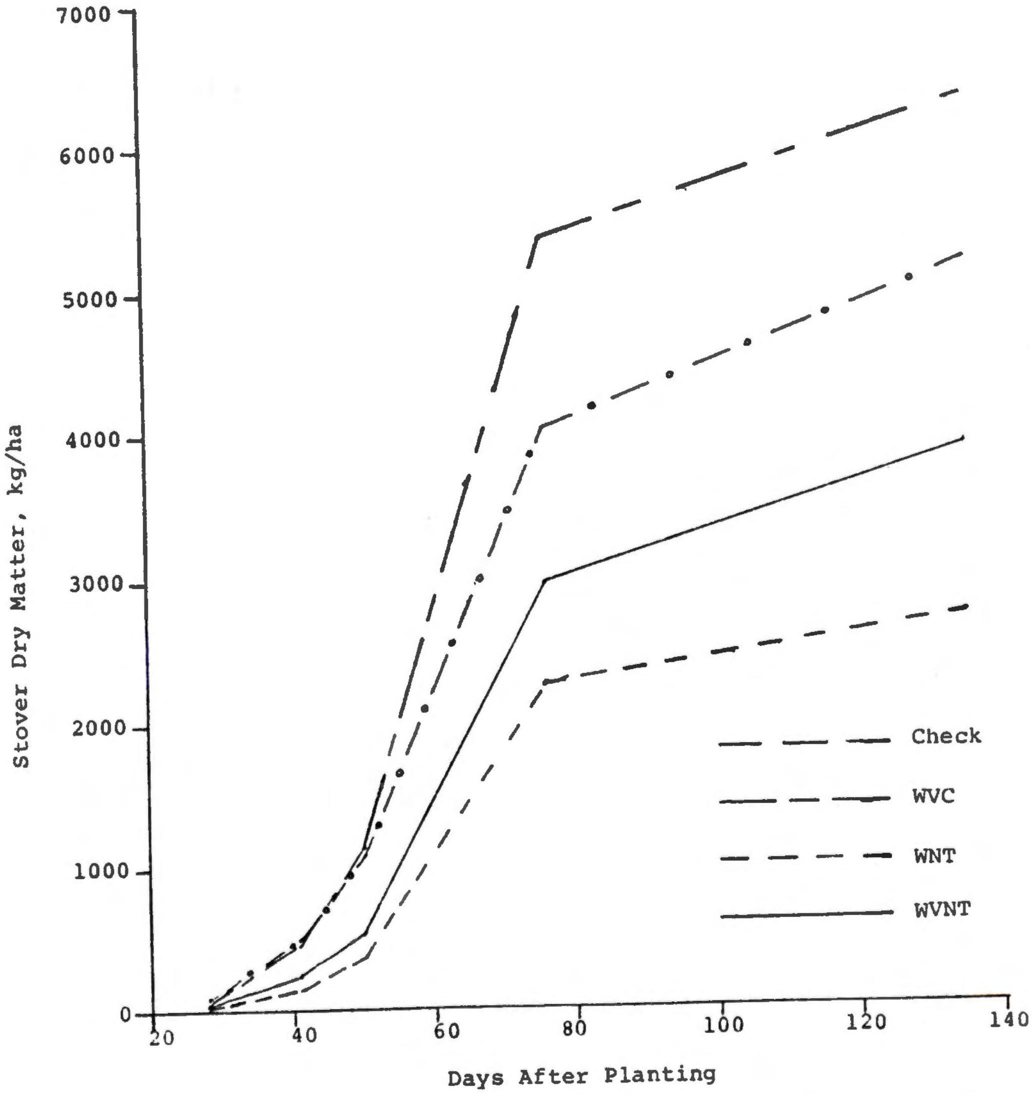

Figure 1. Corn stover dry matter production at the 0 kg/ha N rate.

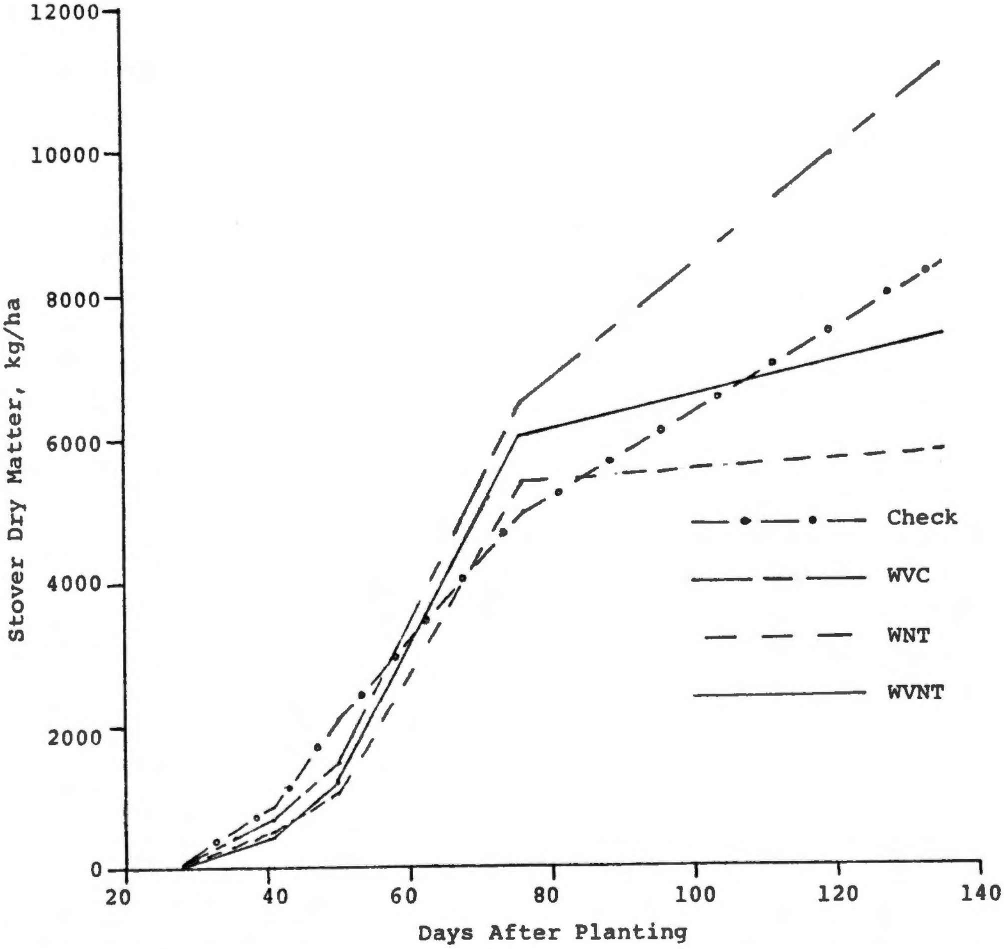

Figure 2. Corn stover dry matter production at the 56 kg/ha N rate.

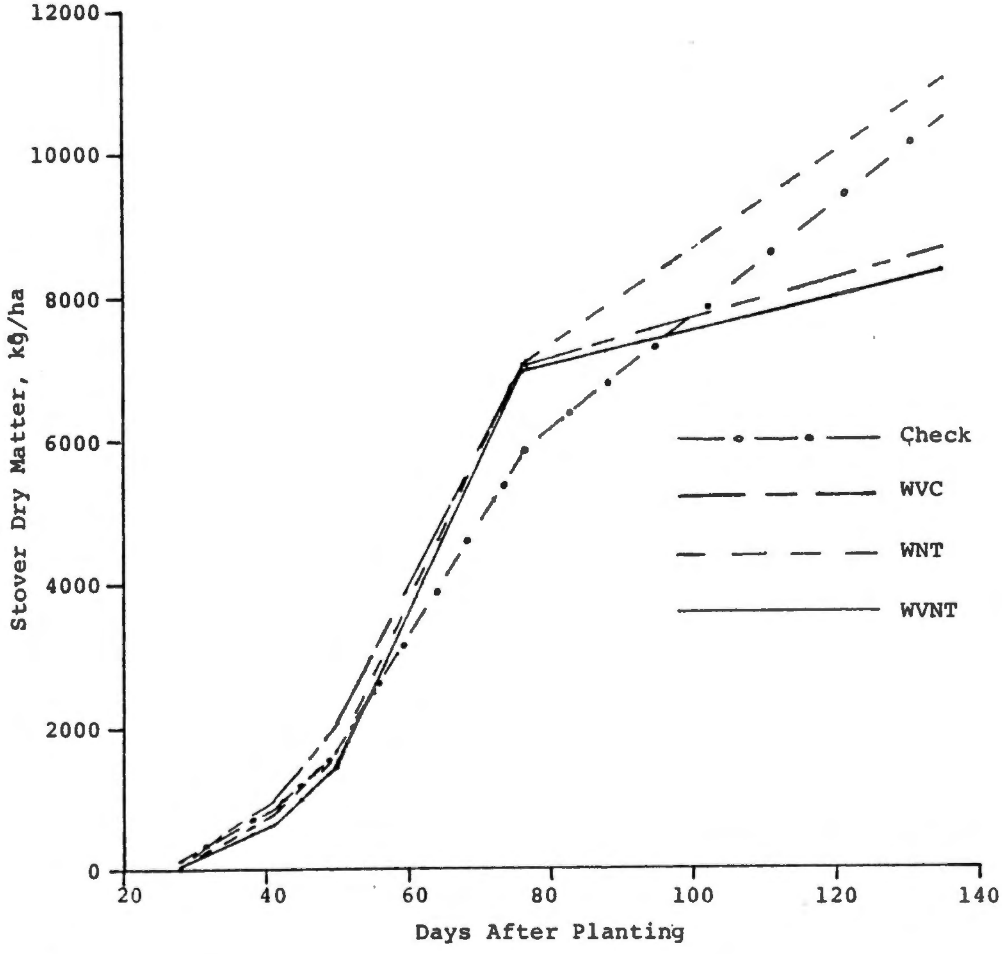

Figure 3. Corn stover dry matter production at the 112 kg/ka N rate.

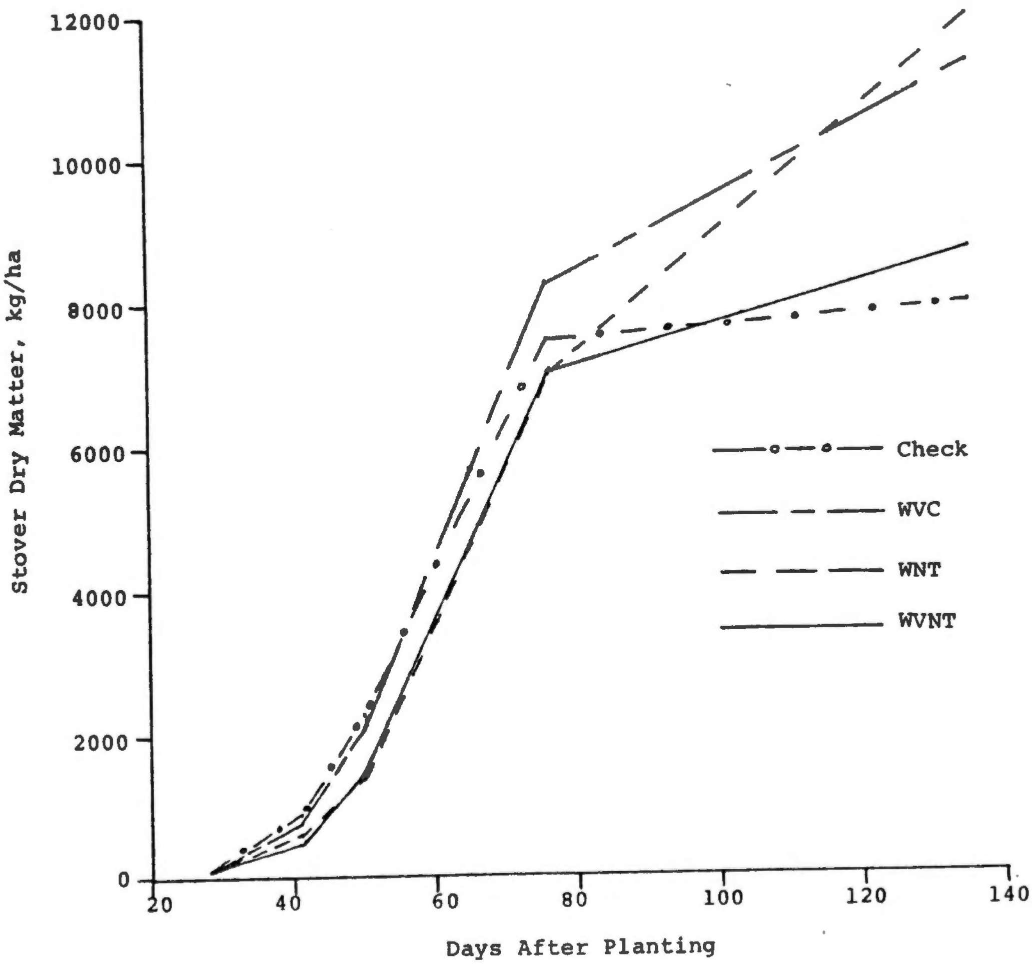

Figure 4. Corn stover dry matter production at the 168 kg/ha N rate.

only the second sampling (41 days after planting). At this point the two conventional tillage treatments had similar values which were higher than those for the two no-tillage treatments. This order was preserved through harvest although the values were more disparate.

The trend for corn stover weight is similar at the 56 kg/ha N rate. As can be seen from Table 4 and Figure 2 final stover weight values were almost twice as high at this N rate as at the 0 rate. Differences between treatments were not apparent until the July 15 sampling at the 56 kg/ha rate. From this point until harvest the two conventional tillage treatments increased at a much faster rate than did the no-tillage treatments.

There was very little difference in stover weight through the fourth sampling between treatments at the 112 kg/ha N rate with the exception that at this sampling date the Check was much lower than the other treatments. By harvest, however, the Check and WNT treatments had increased very rapidly and had higher stover weights than the two wheat-vetch treatments. The Check and WNT plots at the 112 kg/ha rate showed a marked increase in stover weight over the 56 kg/ha N rate while values for the WVC decreased and those for the WVNT remained approximately the same as at the 56 kg/ha rate.

At the 168 kg/ha N rate the stover weight values of the WNT and WVNT plots were again similar through the July 15 sampling. After this point the WNT plots increased in weight to where, along with the WVC plots, they were much higher at harvest than the WVNT and Check plots. Unlike its trend at the 112 kg/ha N rate, the Check showed only a very slight increase in stover weight from the 76th day until harvest (135th day) at 168 kg/ha supplemental N. Values for the WNT and WVNT plots at harvest were similar to those at the 112 kg/ha rate while those for the WVC were higher and those for the Check were lower at harvest at the 168 kg/ha N rate than at the 112 kg/ha rate.

The similarity of stover weight values for each treatment at the three non-zero N rates (values for the WNT treatment were similar at 112 and 168 kg/ha) reflects the ceiling imposed on growth by moisture stress. That the WNT did not reach its maximum stover weight until 112 kg/ha N suggests that N was being immobilized under the wheat mulch but that overall lack of N did not limit growth. This conclusion is also supported by the decrease in the rate of dry matter accumulation between the last two sampling dates. Under favorable conditions this rate should remain almost constant (39).

It is interesting to note from Table 3 that the no-till plots produced significantly less dry matter than the conventional plots through the first three sampling dates. Rainfall data for this period (Table 22, Appendix) imply that there was sufficient moisture for crop growth through the month of June. It is likely that little N was mineralized under the no-till plots and that N was limiting growth during this stage.

Another important observation from Table 3 (p. 30) is that the dry matter production in the WVC treatment was lower than the Check (but higher than in the no-till plots) through the first two samplings but significantly higher by the fourth. That the wheat-vetch residue was lower in nitrogen content than expected was mentioned above. It is entirely possible that the C:N ratio of the residue when first incorporated was above the critical point or threshold for liberation (mineralization) of inorganic N and that the microbial population did not reduce the rate below this point until after June 19 in the WVC plots. The mixture of the substrate with the soil could have enhanced the achievement of this minimum ratio as compared to the no-till plots. It is likely, then, that the onset of severe moisture stress occurred before this point (change from immobilization to mineralization of N) could be reached in the WVNT treatment and thus the expected benefits of the legume in the mulch were not demonstrated.

Phosphorus Percentage and Total Phosphorus Uptake

The analysis of variance for the phosphorus percentage of corn stover data is shown in Table 16 (Appendix). Main plots (sampling date), split plots (nitrogen rate), and split-split plots (cover crop) all had a significant effect at the 5% level on the P% of corn stover. The effect of sampling dates on P% varied significantly across the four N rates and the four cover crop treatments. Similarly, there was a significant difference in the comparative response of the corn crop, as measured by the P% of the stover, to the cover crop treatments at different N fertilizer rates. Finally, the three-way interaction involving the relative effect of the cover crop treatments at various combinations of N rate and sampling date was significant.

The two-way interaction involving split plots (nitrogen rates) and split-split plots (cover crops) is shown in Table 5. There were significant differences between all treatments at the 0 N rate with the WNT plots having the highest P% and the Check the lowest.

All treatments showed a significant decrease in phosphorus percentage as supplemental N rates were raised

Table 5. Effect of cover crop treatments and supplemental N, across sampling dates, on phosphorus percentage of corn stover.

	Nitrogen fertilizer rate, kg/ha			
Cover crop treatment	0	56	112	168
		%		
No winter cover (Check)	0.31^{d}	0.23^{gh}	0.22^{h}	0.24^{fgh}
Wheat-vetch, conv. till	0.38^{c}	0.27^{ef}	0.25^{fgh}	0.27^{ef}
Wheat-vetch, no-tillage	0.49^{b}	0.29^{de}	0.26^{efg}	0.27^{ef}
Wheat, no-tillage	0.58^{a}	0.30^{de}	0.24^{fgh}	0.25^{fgh}

Note: Means followed by the same letter are not significantly different at the 5% level.

to 56 kg/ha. At this rate the Check had significantly less stover P% than the other three treatments.

Only the WNT plots decreased in stover P% as N rates were further increased to 112 kg/ha. As with the 56 kg/ha N rate, the Check had significantly lower values than the other plots.

There was no further decrease in stover P% for any treatment as N rates were raised from 112 to 168 kg/ha and there were no significant differences between treatments at this N rate.

The sampling date * cover crop interaction is shown in Table 6. The phosphorus percentage values decrease as the growing season progresses. With only one exception, there were significant differences between all consecutive sampling dates for each cover crop treatment. There were some differences between treatments at each sampling date.

The no-tillage treatments were significantly higher in stover P% than the conventional treatments at both the May 28th and June 10th samplings. At the latter date the Check plots had the lowest P% values.

At the June 19th sampling the wheat-vetch treatments were similar and intermediate between the Check with the lowest P% and the WNT treatment with the highest.

Table 6. Effect of sampling date and cover crop treatment, across N rates, on phosphorus percentage of corn stover.

Cover crop treatment	Sampling date				
	MAY 28	JUN 10	JUN 19	JUL 15	SEP 12
			%		
No winter cover (Check)	0.39^{cd}	0.30^{f}	0.24^{h}	0.22^{h}	0.12^{j}
Wheat-vetch, conv. till	0.47^{b}	0.36^{de}	0.28^{fg}	0.24^{h}	0.13^{j}
Wheat-vetch, no-tillage	0.53^{a}	0.41^{c}	0.30^{f}	0.25^{gh}	0.17^{i}
Wheat, no-tillage	0.53^{a}	0.41^{c}	0.35^{e}	0.24^{gh}	0.17^{i}

Note: Means followed by the same letter are not significantly different at the 5% level.

There were no significant differences among treatments at the July 15 sampling. At harvest (Sept. 12) the no-tillage plots were higher in P% than the conventionally tilled plots.

Phosphorus percentage means for the sampling date * nitrogen rate interaction, averaged across cover crop treatments, are shown in Table 7. Again, P% values tended to decrease as the growing season progressed. Stover P% decreased as N rates were raised from 0 to 56 kg/ha for all sampling dates except the first (May 28). For all sampling dates there were no further significant decreases in P% as N rates were increased.

Values for the June 10th and 19th samplings were statistically similar at all N rates, as were the values for the June 19th and July 15th samplings. Only at the 112 and 168 kg/ha N rates were there significant decreases in P% values from July 15 to harvest.

The effect of the three-way interaction involving sampling dates, nitrogen rates, and cover crop treatments on the phosphorus percentage of corn stover may be at least partially examined in Figs. 5 - 8. The decreasing trend of stover P% over time is shown for the cover crop treatments at each of the four nitrogen rates. Comparisons between cover crop means and the other factors were separated by an LSD (least significant

Table 7. Effect of sampling date and supplemental N, across cover crop treatments, on phosphorus percentage of corn stover.

Sampling date	Nitrogen fertilizer rate, kg/ha			
	0	56	112	168
		%		
MAY 28	0.56^{a}	0.47^{ab}	0.44^{bc}	0.44^{bc}
JUN 10	0.55^{ab}	0.32^{de}	0.30^{defg}	0.31^{def}
JUN 19	0.47^{abc}	0.25^{efgh}	0.21^{fghi}	0.25^{efgh}
JUL 15	0.36^{cd}	0.20^{hi}	0.20^{ghi}	0.20^{fghi}
SEP 12	0.26^{defgh}	0.13^{ij}	0.10^{j}	0.10^{j}

Note: Means followed by the same letter are not significantly different at the 5% level.

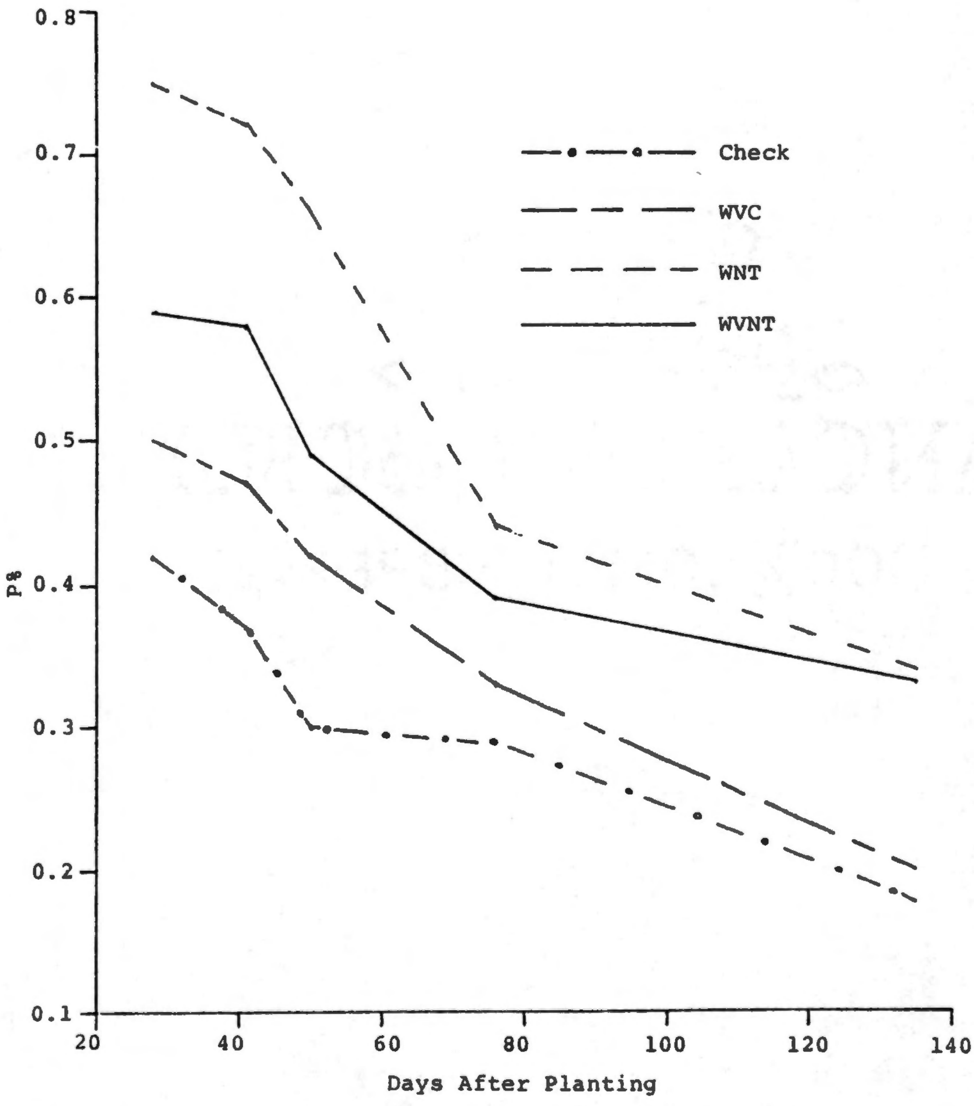

Figure 5. Phosphorus percentage of corn stover at the 0 kg/ha N rate.

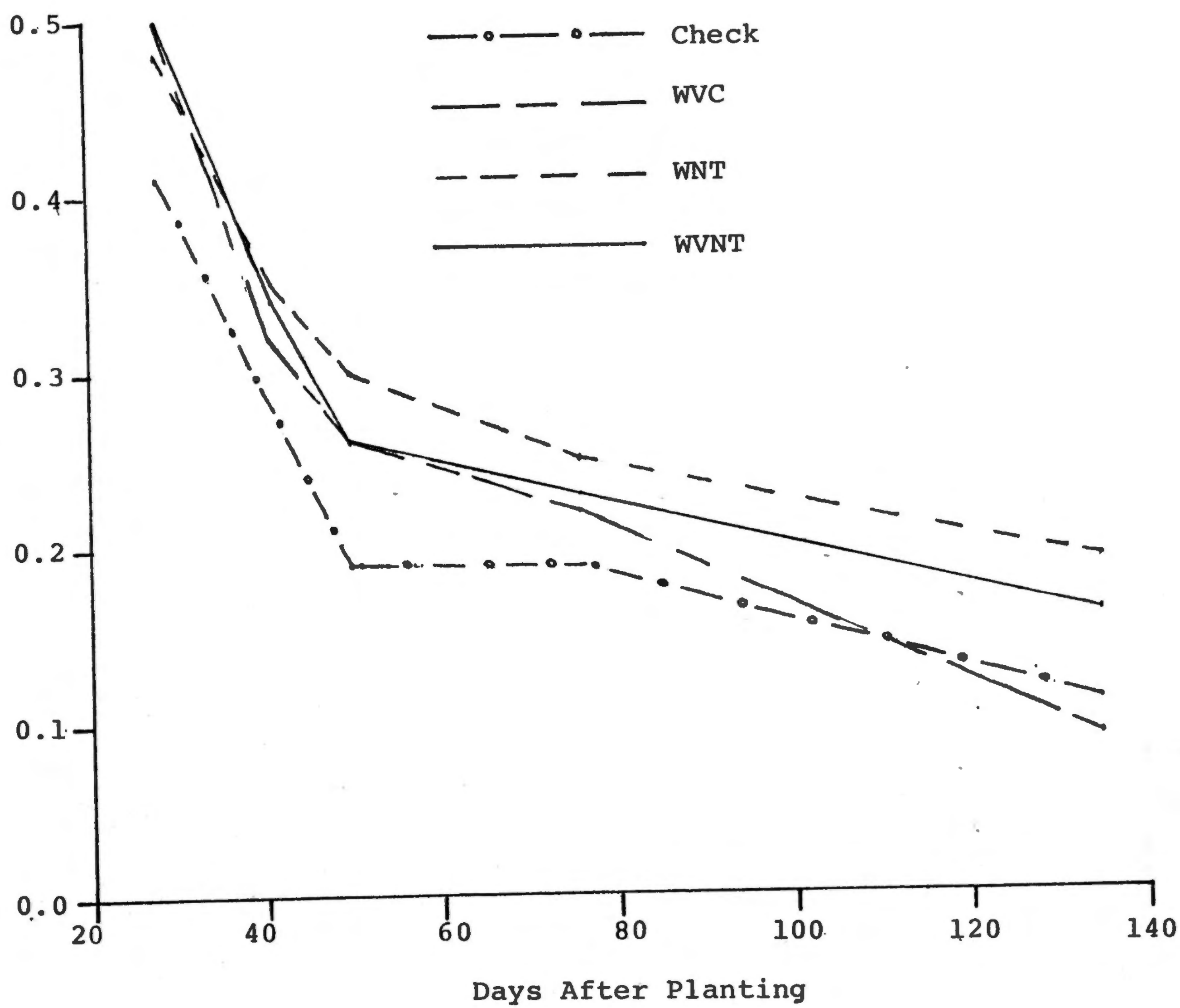

Figure 6. Phosphorus percentage of corn stover at the 56 kg/ha N rate.

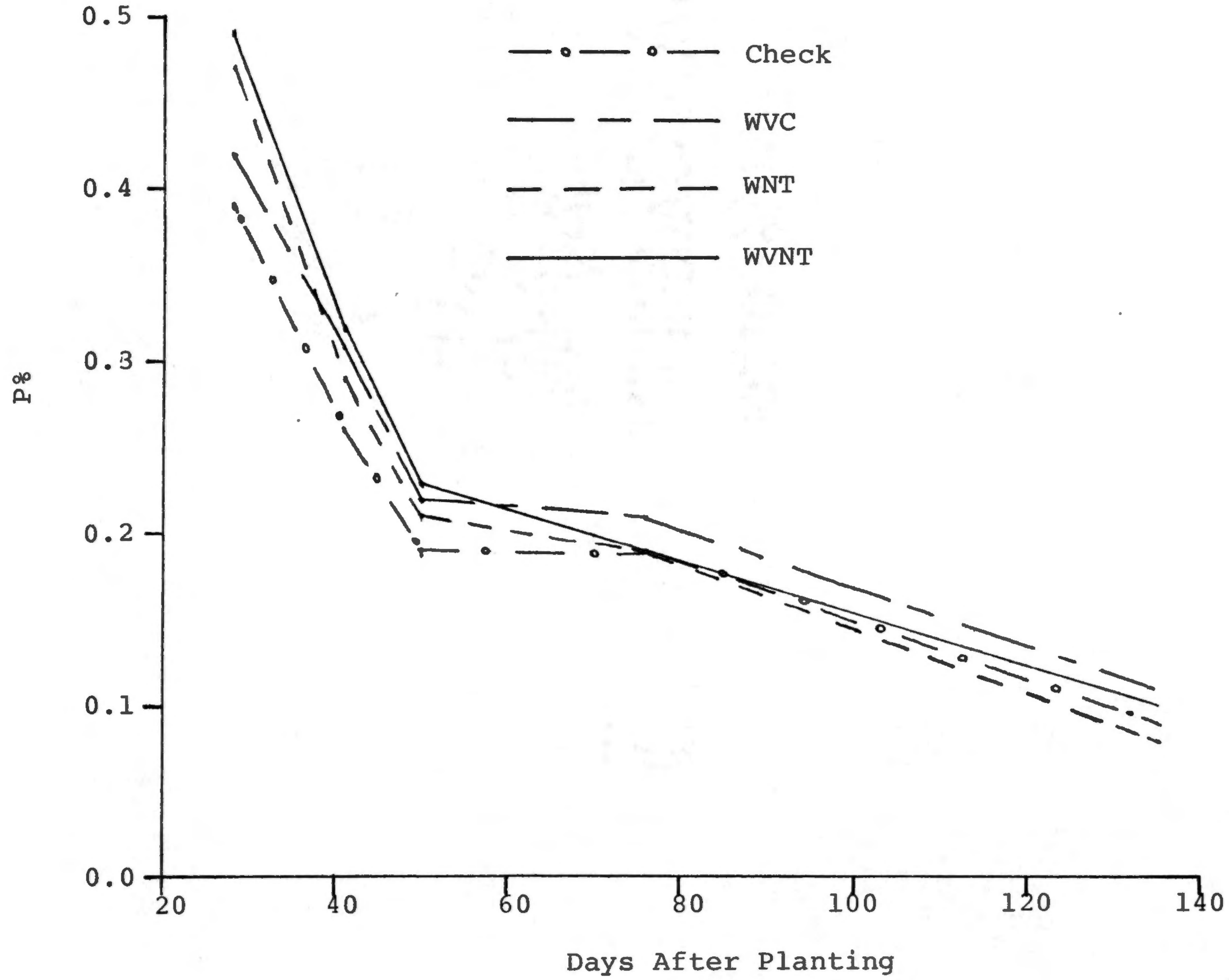

Figure 7. Phosphorus percentage of corn stover at the 112 kg/ha N rate.

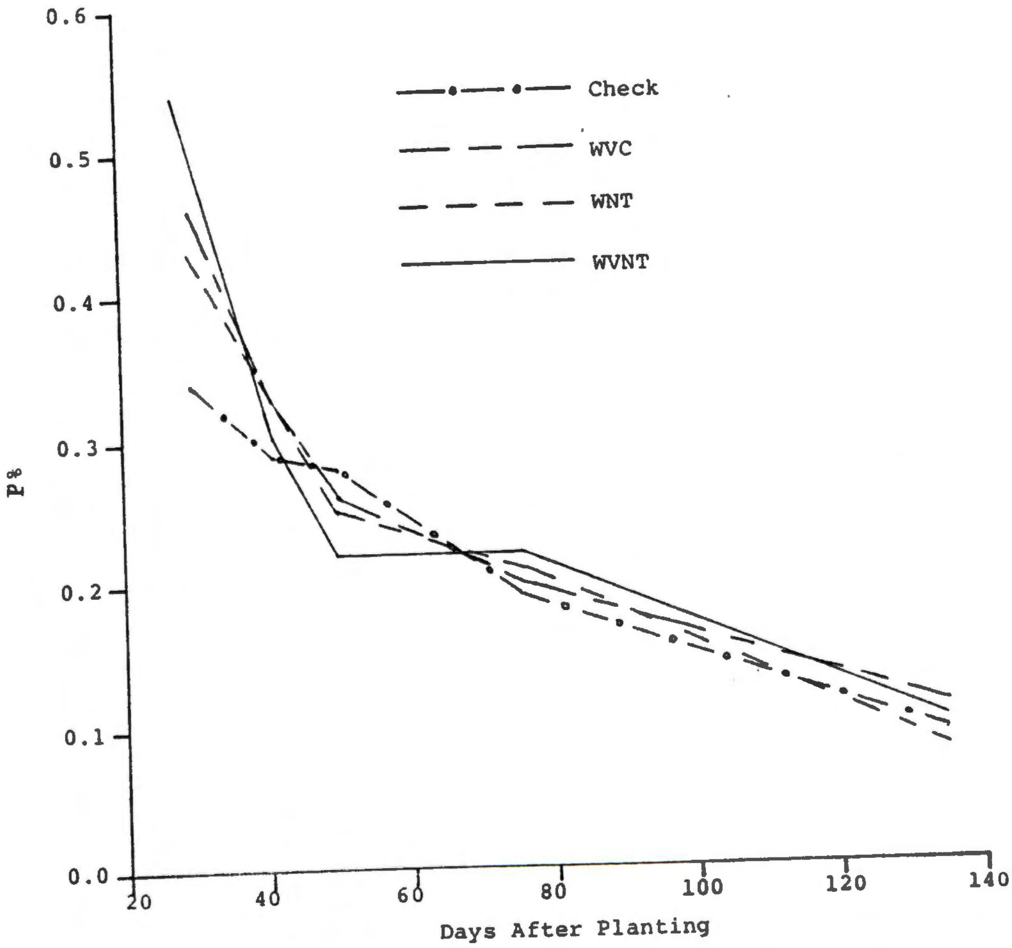

Figure 8. Phosphorus percentage of corn stover at the 168 kg/ka N rate.

difference) test using the appropriate standard error for the factor means being considered (44). Tests were performed on data transformed by the formula Log_{10} (P% + 1). The LSD at the 5% probability level between cover crop means at the same N rate and sampling date was 0.0198; between N rate means for the same sampling date and the same or different cover crop, 0.023; between sampling date means for the same or different N rate or cover crop, 0.023.

Differences in P% between the cover crop treatments are readily apparent at the 0 and 56 kg/ha N rates. At the 0 N rate significant differences occurred between all treatments at the first sampling date (May 28). By harvest (Sept. 12) the two no-tillage plots had similar values which were significantly greater than those for the conventional tillage plots.

As supplemental N was increased to 56 kg/ha the P% values significantly decreased for all cover crop treatments at all but the first sampling date. Again, at harvest, the no-tillage plots were significantly higher in P% than the conventionally tilled plots.

The WNT and WVNT plots decreased in P% at harvest as the N rate was increased to 112 kg/ha. There were few meaningful differences in P% between the cover crop treatments over the growing season at the 112 and

168 kg/ha N rates. There were some differences at the first sampling for both rates but none for the last two smpling dates. There was little change in the P% trend for cover crops as N rates were increased from 112 to 168 kg/ha.

Overall the trend over time of the P% of corn stover grown on the four cover crop treatments varied little between the three non-zero N rates with the exception that the values at harvest for the WNT and WVNT plots were significantly higher at the 56 kg/ha N rate than at the higher supplemental N rates.

The changes in P% over time at the three non-zero N rates follow similar patterns which reflect the occurrence of three important stages in corn growth (39). The marked decrease in P% from the first through the third sampling date corresponds to the rapid increase in dry matter as new leaves and stalk are produced. In many cases there was little decrease in P% from the third to the fourth sampling date. This probably represents the period from silking through tasselling and fertilization as the plant establishes the organs necessary for grain production. Finally, the marked decrease in P% from the fourth sampling date to harvest reflects the increased weight of the yield components - the husk, cob, and grain.

Published values for the critical nutrient concentration (i.e., that value above which no yield increase is expected from additional nutrient) of corn earleaf sampled at tasselling range from 0.25 to 0.30% P (29,48). Tasselling occurred in this experiment approximately 70-75 days after planting, just before the fourth sampling date. Table 6 (p. 42) shows the P% values for each cover crop treatment averaged for the four N rates. These values range from 0.22 to 0.25 %P at the fourth sampling date. Table 7 (p. 44), however, shows that the average P% value for the four cover crops at the 0 N rate (0.36%) is much higher than the value for the three non-zero N rates (0.20%). It would appear that there are phosphorus deficiencies at the non-zero N rates. However, elemental concentrations in this experiment were performed on whole plant tissue, not just earleaf, and since phosphorus is mobile and concentrates in growing tissues, it is likely that the lower values in this experiment are simply the result of the dilution of high %P leaf tissue with less concentrated stalk tissue.

The higher P% of the no-till treatments throughout the growing season at the 0 and 56 kg/ha N rates, is probably the result of a concentration effect. This idea is illustrated in Fig. 9 which shows the change in P% with dry matter accumulation for the four cover

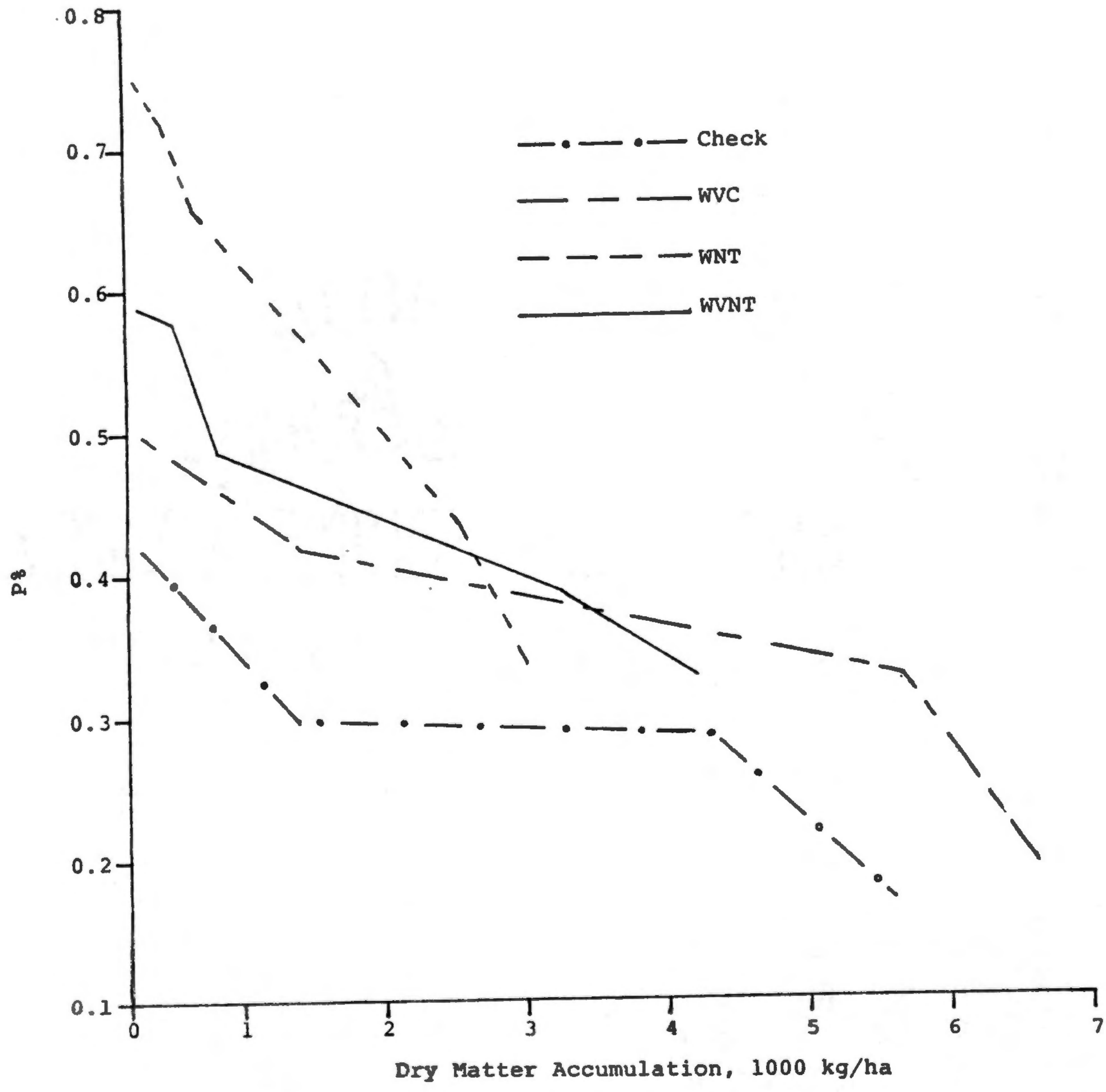

Figure 9. Effect of dry matter accumulation on phosphorus percentage of corn stover at the kg/ha N rate.

crop treatments at the 0 N rate. The higher slopes of the curves for the two no-till treatments indicate that their P% changed markedly as the dry weight of the plants increased. This graph also shows that these two treatments had much lower dry weight values. Thus, the significantly higher P% values seen for the no-till treatments in Figs. 5 and 6 (pgs. 45 and 46) result from the poor dry matter production from these treatments rather than the enhanced P uptake. The data for P uptake shown below support this conclusion. Some research workers, however, have found higher tissue P concentrations under no-till as compared to conventional tillage. Singh _et_. _al_. (65) found higher P concentrations in young corn plants grown under no-till conditions. Researchers in Ohio found higher P concentrations in tissue from no-till plots sampled at the 8-10 leaf stage but no differences when sampled at tasselling (79). They did not discuss any dilution effect.

Total phosphorus uptake is shown graphically in Figs. 10 - 13. Data for each of the four cover crop treatments is arranged according to the four supplemental nitrogen rates. The five sampling dates are shown according to the number of days after planting (April 30) that they represent. Differences in P uptake are not as

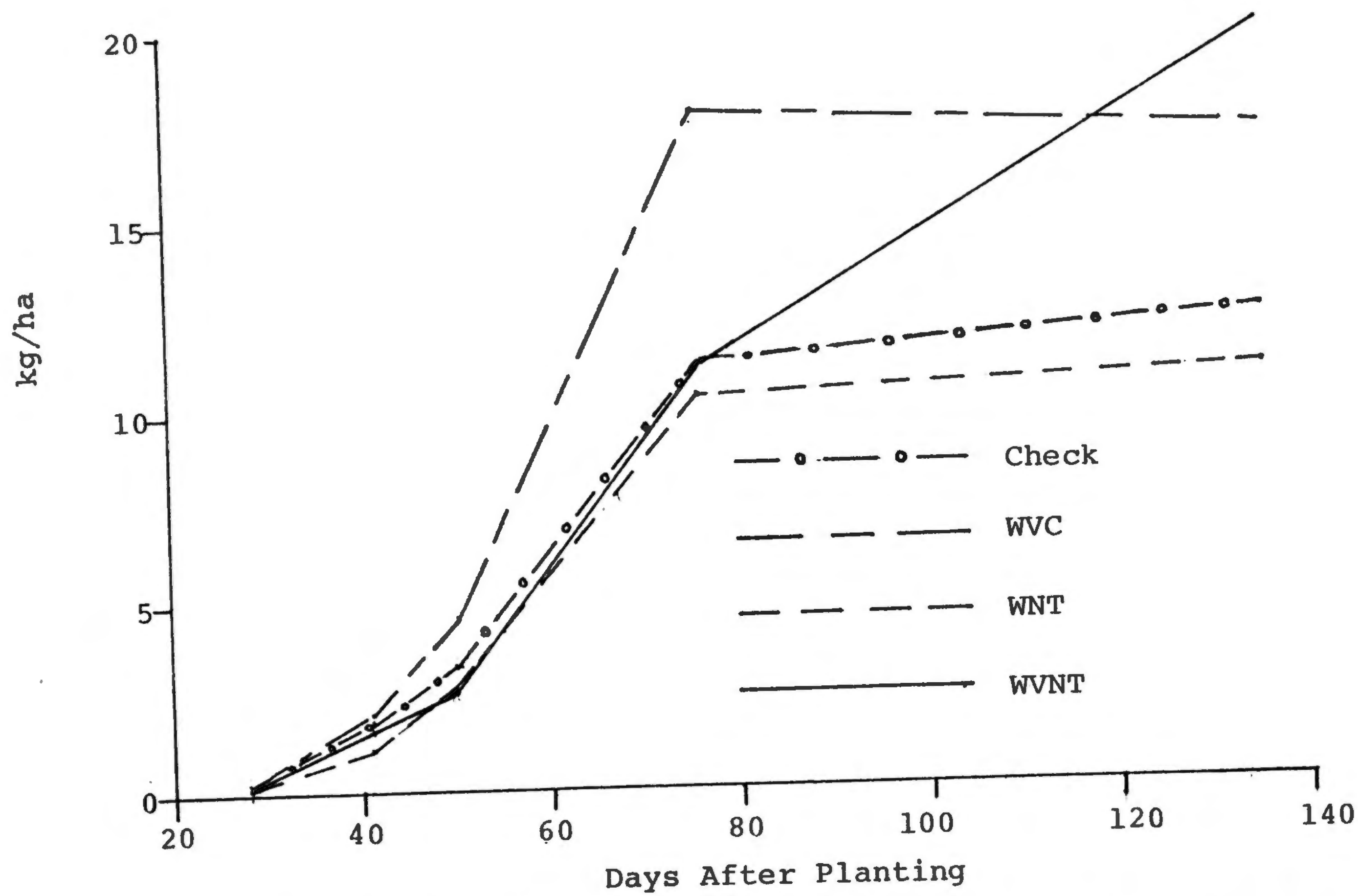

Figure 10. Total phosphorus uptake of corn at the 0 kg/ha N rate.

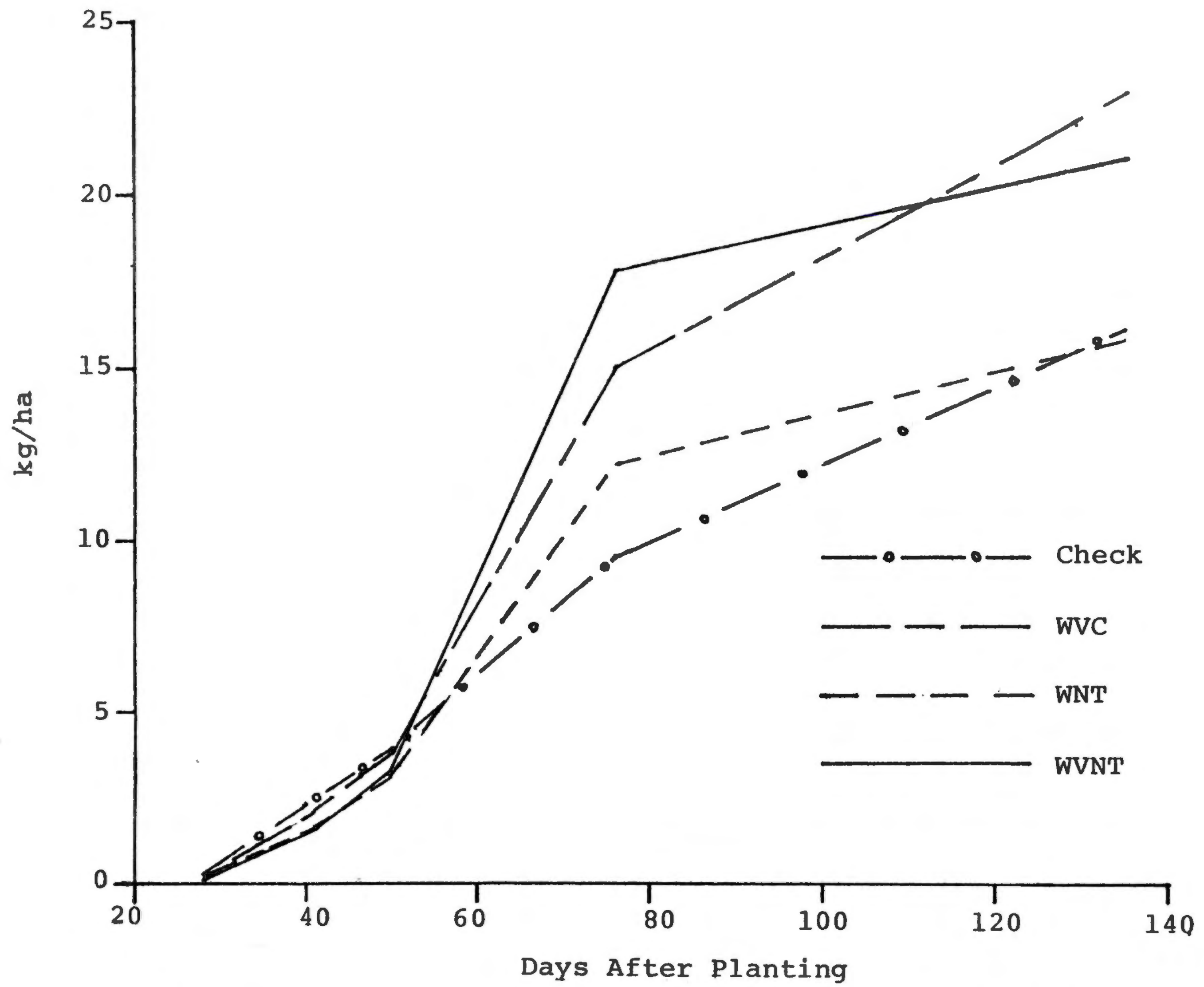

Figure 11. Total phosphorus uptake of corn at the 56 kg/ha N rate.

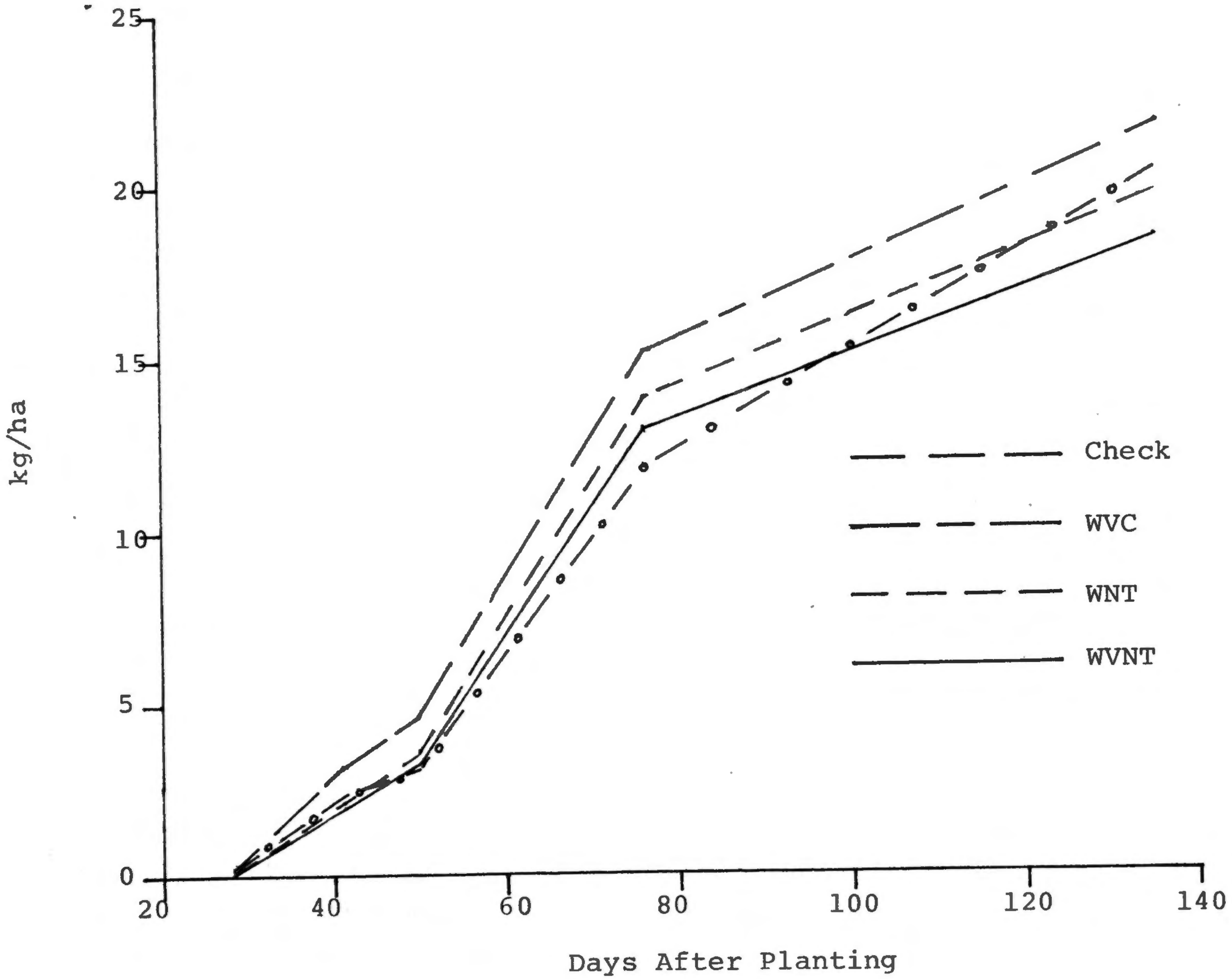

Figure 12. Total phosphorus uptake of corn at the 112 kg/ha N rate.

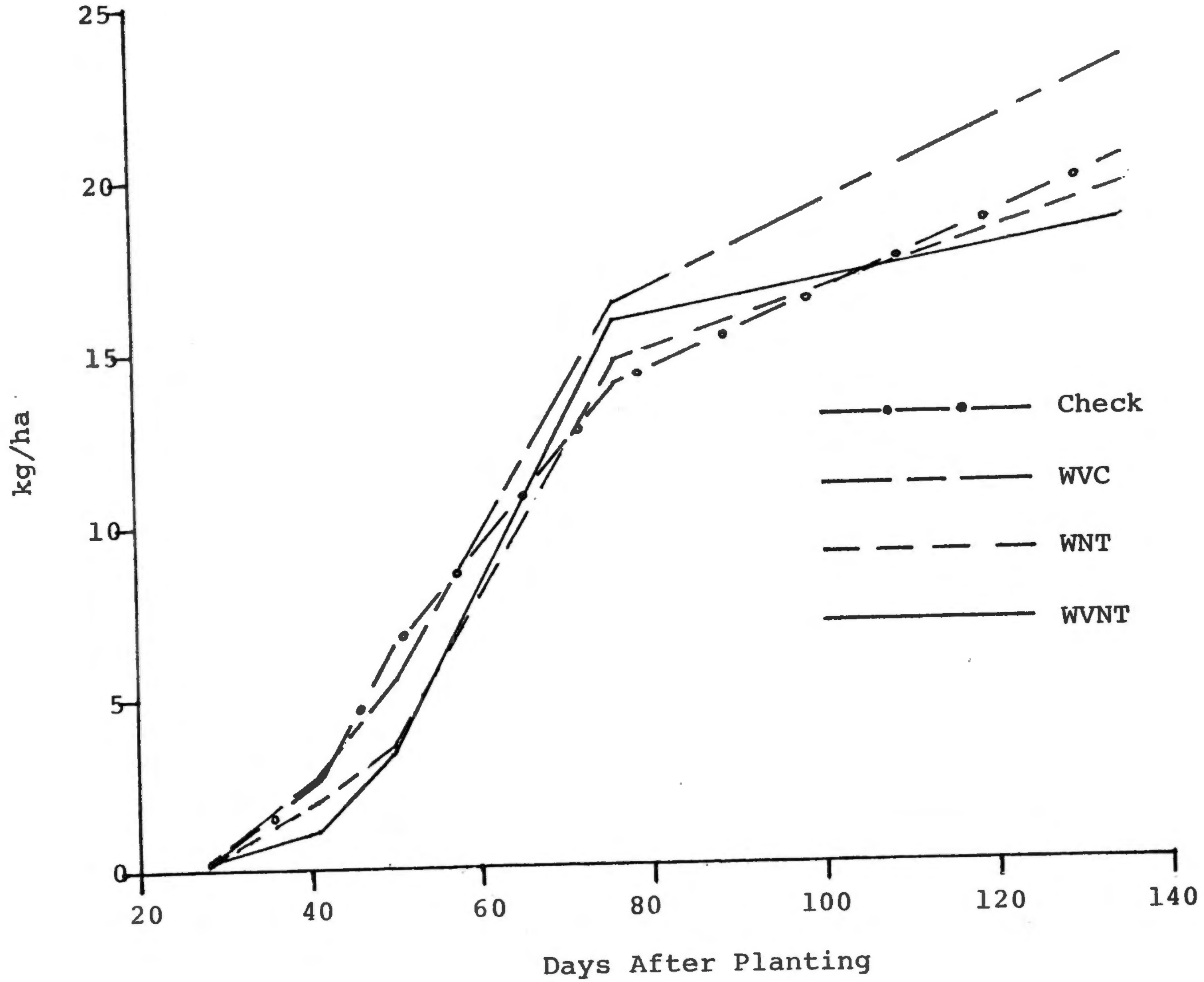

Figure 13. Total phosphorus uptake of corn at the 168 kg/ha N rate.

conspicuous as those for N uptake and treatment values for P uptake are similar at N rates above 0.

The WVC treatment has generally higher values than the other treatments over the four N rates. At the 0 N rate this is true until harvest where the WVNT treatment is slightly higher than the WVC. The Check and WNT treatments are similar and lower than the two wheat-vetch treatments at harvest at the 0 N rate.

These trends continue at the 56 kg/ha supplemental N rate. All treatments show similar P uptake up to 50 days after planting but are clearly different at the next sampling date, 76 days after planting. As with the 0 N rate, at harvest the two wheat-vetch treatments are similar and higher than the Check and WNT treatments.

Differences in P uptake between treatments are not as apparent, and the trends are different, at the two higher supplemental N rates. At both the 112 and 168 kg/ha N rates the WVC treatment has the highest values for P uptake but the WVNT has the lowest. This difference is relatively greater at the 168 kg/ha N rate. Phosphorus uptake for the Check and WNT treatments is conspicuously increased as supplemental N fertilization is increased from 56 to 112 kg/ha. Total uptake values for all four treatments vary little between the two highest supplemental N rates.

The higher P uptake values for the two wheat-vetch treatments at the 0 and 56 kg/ha N rates do not appear to be related to greater dry matter production (see Figs. 1 and 2, pgs. 32 and 33) and thus it appears that the wheat-vetch residue in both tillage situations released available phosphorus at these supplemental N rates. In a thorough study on the factors influencing the utilization of phosphorus from crop residues, Fuller et. al. (33) found the threshold phosphorus content of residues above which the phosphorus was not completely immobilized to be approximately 0.2%. They also noted that the phosphorus of residues high in total phosphorus was more readily available than that of residues low in phosphorus. As noted above in Table 1 (p. 23), the phosphorus content of the wheat and wheat-vetch residues was 0.75 and 0.76%, respectively, well above the threshold value. The lower uptake values in the wheat alone plots may partially result from their lower total mulch production. Fuller et. al. (33) also noted that the kind of residue affected phosphorus utilization from residues. At the time they were chemically killed the wheat was more mature (boot to early head stage) than the vetch (early bloom) and therefore probably contained a larger proportion of lignin, hemicellulose, and other decay-resistant constituents.

The four uptake graphs also confirm that the marked differences in P% trends over the growing season shown in Figs. 5 and 6 (pgs. 45 and 46) are not the result of enhanced uptake of phosphorus under the no-till plots but rather were merely a concentration effect derived from the poorer dry matter production of the no-till treatments.

Potassium Percentage and Total Potassium Uptake

The analysis of variance for the data on the potassium percentage of corn stover is presented in Table 17 (Appendix). The effects of sampling date, supplemental nitrogen fertilization, and cover crop treatment were all significant at the 5% level. All of the two-way interactions - sampling date * N rate, sampling date * cover crop, and N rate * cover crop - were also significant. There was no significant three-way interaction between sampling date, N rate, and cover crop treatments.

The two-way table of potassium percentage means for cover crop treatments and supplemental N rates is shown in Table 8. There was a trend for K% to decline as N rates increased. The no-till plots were statistically similar at all N rates except the 168 kg/ha where the WNT plots had lower values. The Check and WVC plots had

Table 8. Effect of cover crop treatment and supplemental N, across sampling dates, on the potassium percentage of corn stover.

	Nitrogen fertilizer rate, kg/ha			
Cover crop treatment	0	56	112	168
		%		
No winter cover (Check)	2.75^{ab}	2.73^{ab}	2.48^{cde}	2.35^{ef}
Wheat-vetch, conv. till	2.70^{abc}	2.90^{a}	2.46^{de}	2.38^{ef}
Wheat-vetch, no-tillage	2.71^{abc}	2.27^{efg}	2.22^{fgh}	2.02^{h}
Wheat, no-tillage	2.63^{bcd}	2.32^{efg}	2.13^{gh}	1.79^{i}

Note: Means followed by the same letter are not significantly different at the 5% level.

similar K% values at all N rates and were higher than the no-tillage plots at all but the 0 N rate.

There was no difference in K% between treatments at the 0 N rate. Only the no-tillage plots showed significant decreases as N rates were increased to 56 kg/ha. Conversely, only the conventional tillage plots significantly decreased in K% as N rates were further raised to 112 kg/ha. Only the WNT plots significantly decreased in K% as the supplemental N rate was increased to 168 kg/ha.

The effect of the sampling date * cover crop interaction is shown in Table 9. There was a trend for K% to decrease as the growing season progressed, illustrated by the significant decrease between all consecutive sampling dates for each cover crop (except for the WVNT treatment from June 19 to July 15). There were no differences in K% among cover crop treatments at the first sampling date. At the June 10 and 19 samplings the conventional tillage plots had similar K% values which were higher than those for the no-tillage plots. The only significant differences at the last two sampling dates involved the WNT plots which were significantly lower than the WVC plots at the July 15 sampling and lower than the WVC and Check plots at the Sept. 12 sampling.

Table 9. Effect of sampling date and cover crop treatments, across N rates, on the potassium percentage of corn stover.

Cover crop treatment	Sampling date MAY 28	JUN 10	JUN 19	JUL 15	SEP 12
			%		
No winter cover (Check)	5.31[a]	3.42[a]	2.33[a]	1.66[ab]	1.40[a]
Wheat-vetch, conv. till	5.12[a]	3.50[a]	2.16[a]	1.85[a]	1.45[a]
Wheat-vetch, no-tillage	5.11[a]	2.65[b]	1.82[b]	1.63[bc]	1.33[a]
Wheat, no-tillage	4.93[a]	2.64[b]	1.84[b]	1.48[c]	1.18[b]

[1]: Means within a column followed by the same letter are not significantly different at the 5% level.

[2]: LSD 5% between sampling date means for the same or different cover crop treatment, 0.0326; LSD 5% between cover crop means for same sampling date, 0.0296. Tests performed on data transformed by Log_{10} (K% + 1).

The significant interaction involving sampling date and nitrogen rate is shown in Table 10. As noted above, there was a trend of decreasing K% as the growing season progressed. All consecutive sampling dates at the 0 N rate had significantly different K% values. There were no significant differences between the last two sampling dates at the 56 kg/ha N rate and the last three sampling dates at both the 112 and 168 kg/ha N rates.

There were no differences in K% among N rates at the May 28, July 15, or Sept. 12 sampling dates. At the June 10 and 19 samplings the values for the 0 and 56 kg/ha N rates were significantly higher than those for the 168 kg/ha N rate.

Conclusions regarding the %K data are similar to those for the phosphorus data. The rapid decrease in K% through the first three sampling dates reflects the rapid increase in dry weight as stalk elongation and leaf emergence progress.

Similar conclusions also follow regarding the critical nutrient concentration. Most published critical values for %K at tasselling range from 1.7 to 2.0 %K (29, 48). Table 9 indicates that only the value for the WNT treatment falls very far out of this range. This is probably not the result of a tillage effect. Estes (30) found increased levels of tissue K under no-tillage.

Table 10. Effect of sampling date and supplemental N, across cover crop treatments, on potassium percentage of corn stover.

Sampling date	Nitrogen fertilizer rate, kg/ha			
	0	56	112	168
		%		
MAY 28	5.06[a]	5.29[a]	5.14[a]	4.94[ab]
JUN 10	4.01[bc]	3.33[cd]	2.66[de]	2.33[e]
JUN 19	2.82[de]	2.22[ef]	1.73[fg]	1.51[gh]
JUL 15	1.78[fg]	1.71[fg]	1.61[g]	1.53[gh]
SEP 12	1.14[h]	1.32[gh]	1.50[gh]	1.40[gh]

Note: Means followed by the same letter are not significantly different at the 5% level.

Tripplett and Van Doren (79) found higher levels of K from no-till as compared to conventional tillage at the 8-10 leaf stage but found no differences after tasselling.

The low K% values of the WNT treatment at the last two sampling dates is also not the result of a dilution effect as Table 3 (p. 30) indicates that it had equal or less dry matter production than the other treatments at this date. Escano _et_. _al_. (29) found a significant correlation between tissue N and K concentrations. It appears that the low tissue concentration of K in the WNT plots at late stages in the growing season is related to decreased N uptake resulting from the immobilization of N under the wheat mulch. This conclusion is supported by the N and K uptake data presented below.

Data for potassium uptake is shown graphically in Figs. 14 - 17 in the same format as that for phosphorus uptake. Although it is apparent that the cover crop treatments and supplemental N fertilization have significantly affected K uptake it is difficult to discern any clear and consistent trends within the data.

At the 0 N rate all but the WVNT treatment show a decline in K uptake from the next to the last (76th day) to the final (harvest) sampling and this treatment increases only slightly. At harvest the WVC and WNT

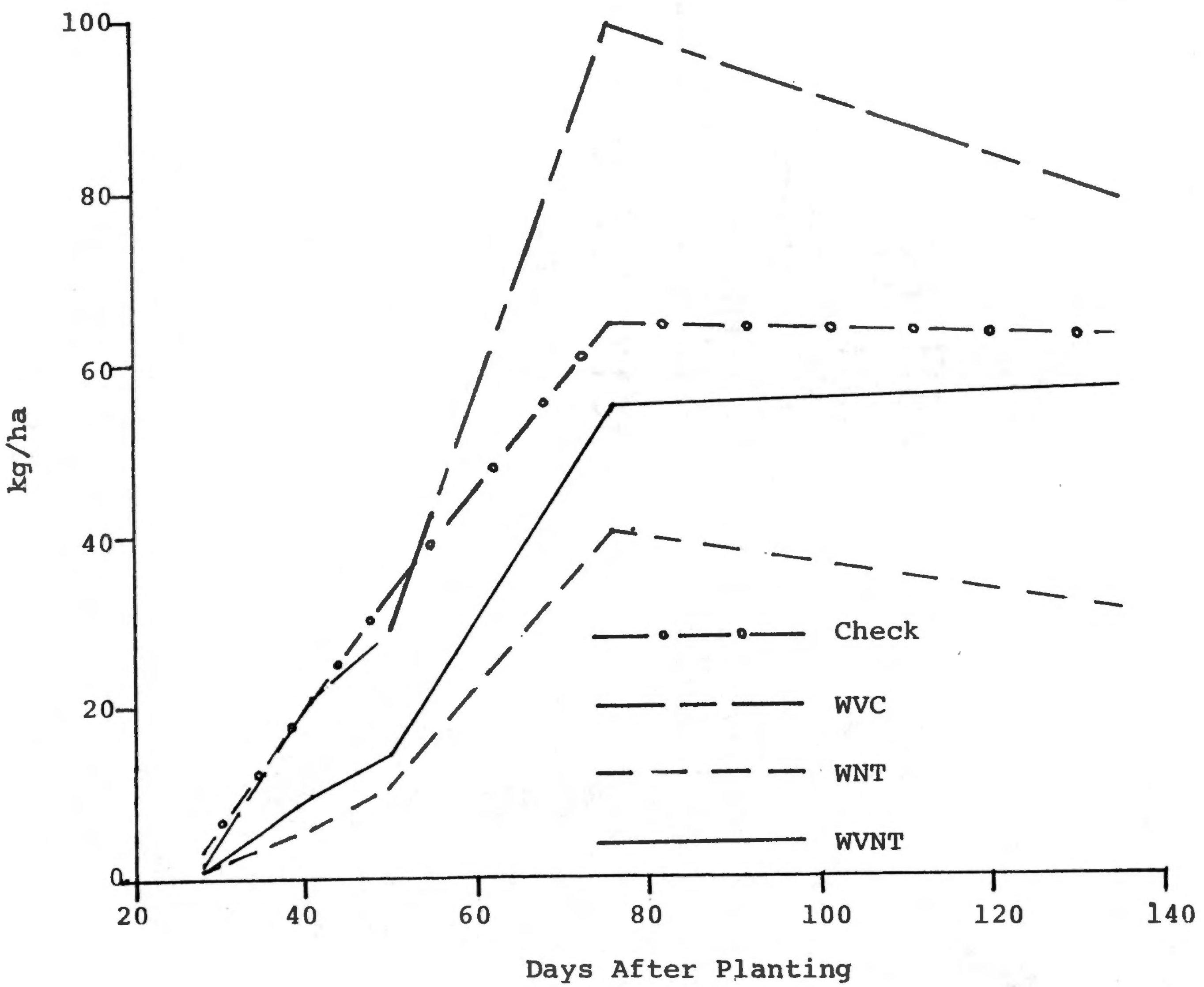

Figure 14. Total potassium uptake of corn at the 0 kg/ha N rate.

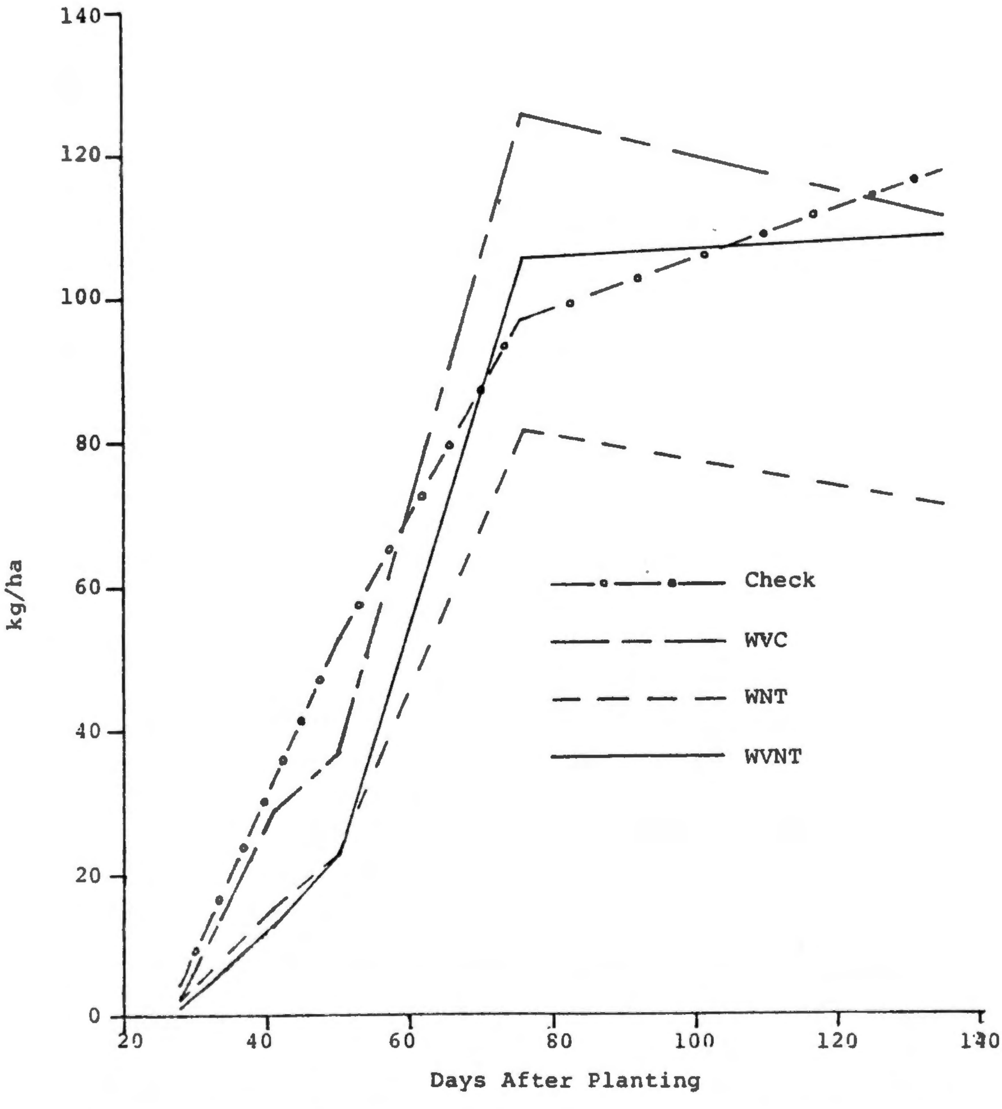

Figure 15. Total potassium uptake of corn at the 56 kg/ha N rate.

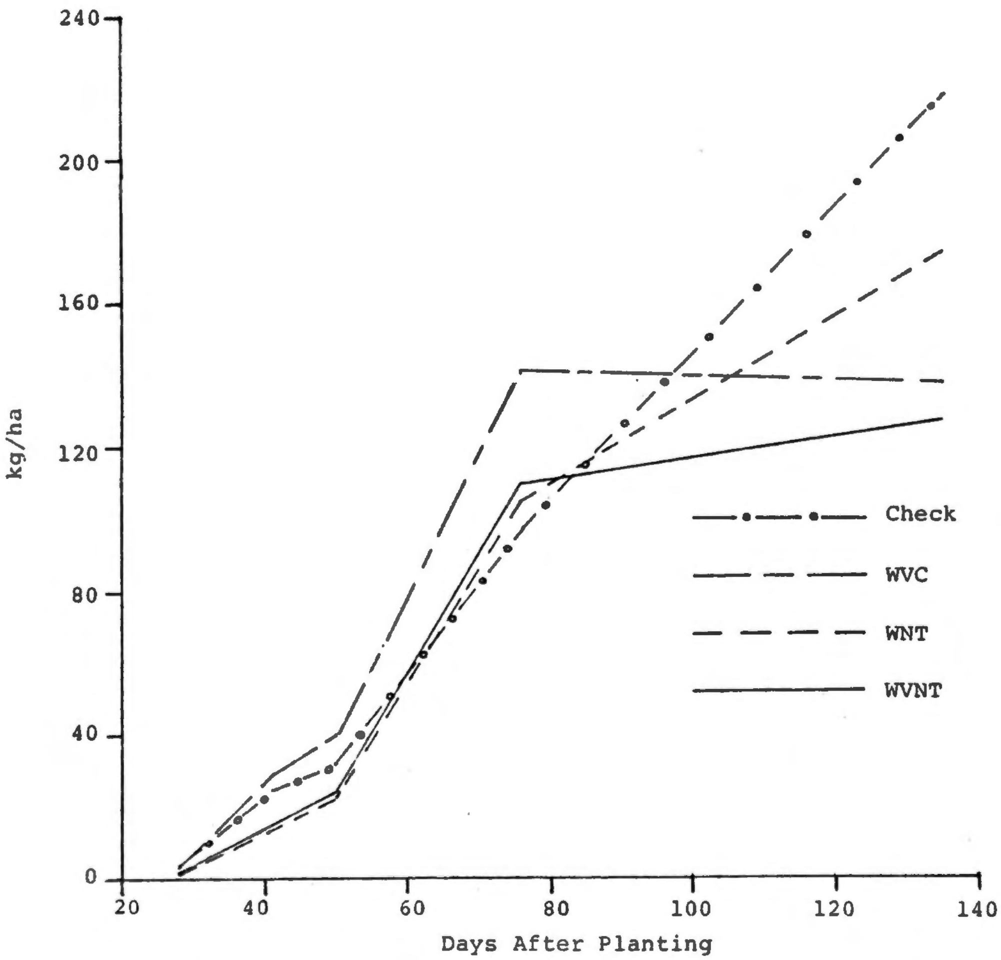

Figure 16. Total potassium uptake of corn at the 112 kg/ha N rate.

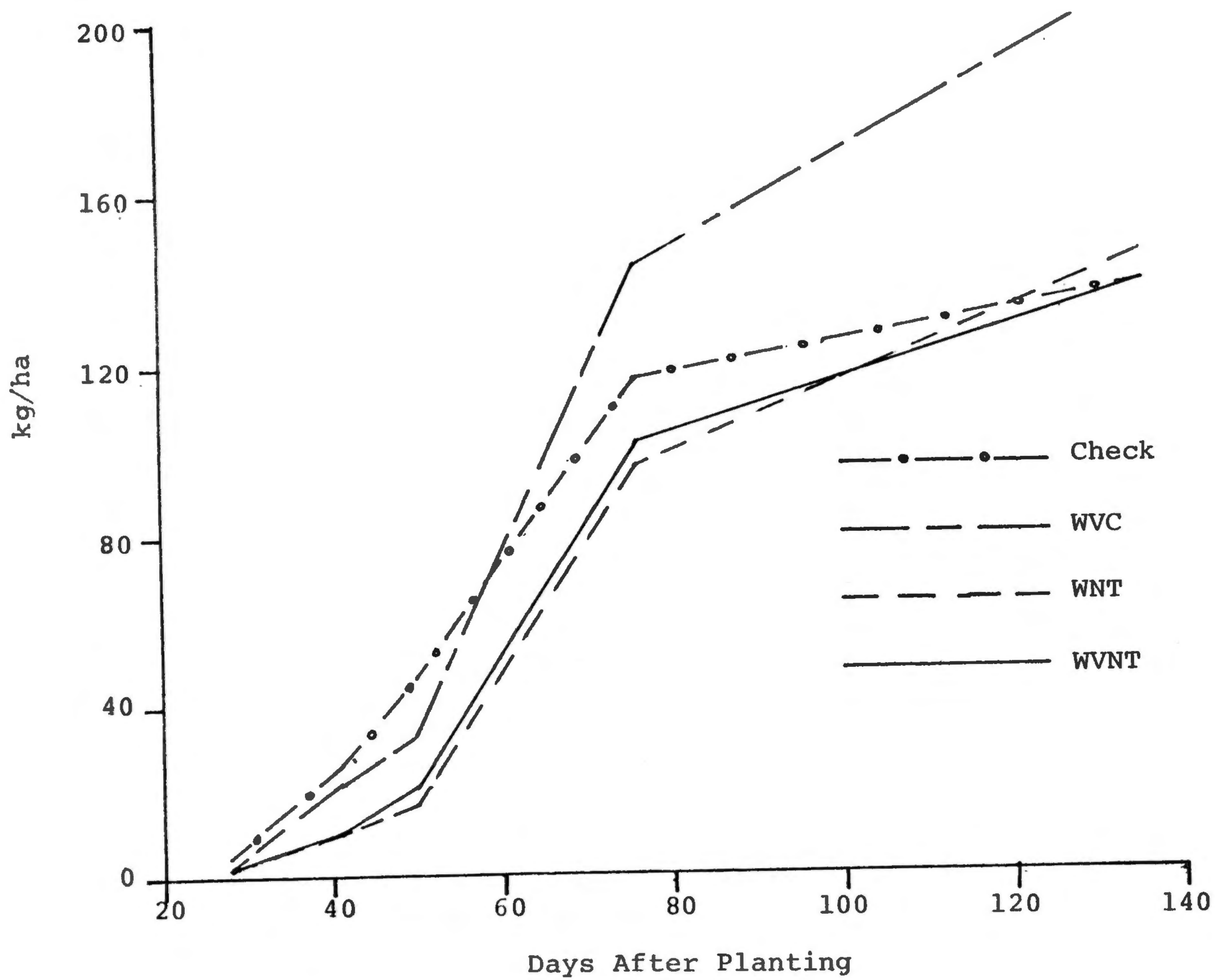

Figure 17. Total potassium uptake of corn at the 168 kg/ha N rate.

treatments have clearly the highest and lowest values, respectfully, while those for the the Check and WVNT are similar and intermediate. At this N rate differences are apparent early in the growing season.

Uptake values for all treatments are much higher at the 56 kg/ha N rate than at the 0 rate and the trends are similar to those at the lower rate. The Check, WVC, and WVNT treatments are similar and higher than the WNT treatment.

The foregoing patterns are disrupted as N fertilization is increased to 112 kg/ha. The WVNT treatment is the only one which does not show a marked increase in K uptake as the N rate increased. Potassium uptake values for the WVC and WVNT treatments decrease, and only slightly increase, respectively, from the fourth to fifth (harvest) samplings resulting in much lower values at harvest than the two other treatments. Both the WNT and Check treatments show large increases over this period.

Values for K uptake at the 168 kg/ha N rate are similar to those at the 112 kg/ha rate except that at harvest the WVC had more K uptake, and the Check had less, at the higher N rate. As is the case with the 0 and 56 kg/ha N rates, at harvest the WVC treatment had a much larger value than the other treatments which were all similar at 168 kg/ha N rate.

There is a reduction in total K uptake from the next to last to the last sampling dates for some treatments at all but the 168 kg/ha N rate. This may be the result of leaching of soluble K from plant tissues. It is also likely to have resulted from leaf drop, as it is known that the lower leaves of potassium deficient plants die prematurely (10).

The close relationship between potassium uptake and nitrogen status is illustrated by the 0 N rate graph in Fig. 14. The no-till plots were markedly lower in K uptake than the conventional plots, even at the very early sampling dates. This reflects the immobilization of N under the two no-till mulches. This relationship is also confirmed by the marked increase in K uptake with N fertilization.

Nitrogen Percentage and Total Nitrogen Uptake

The analysis of variance for the nitrogen percentage of corn stover data is shown in Table 18 (Appendix).

Differences significant at the 5% probability level in N% of corn stover were found between the effects of the five sampling dates; between the four supplemental nitrogen fertilizer rates; and between the four cover crop treatments. One two-way interaction, that between sampling date and nitrogen rate, and the three-way interaction involving the sampling dates, nitrogen rates, and cover crop treatments, were found to be insignificant at the 5% level. Both of the two-way interactions involving the cover crop treatments were significant; i.e., there were significant differences in the comparative response of the corn crop, as measured by N% of the stover, to cover crop treatments at various N rates at various sampling dates.

The effect of the cover crop * N rate interaction is shown in Table 11. The two no-tillage treatments had similar and higher stover N% values at the 0 rate than those for the two treatments receiving conventional tillage.

There were no increases in stover N% as supplemental N fertilizer rates were increased from 0 to 56 kg/ha for any cover crop treatment. There were also no significant differences among treatments at the 56/kg/ha rate.

All the treatments except the WNT showed a significant increase in stover N% as the supplemental N fertilizer rate was raised to 112 kg/ha. There were no significant treatment comparisons at this N rate.

Table 11. Effect of cover crop treatments and supplemental N, across sampling dates, on nitrogen percentage of corn stover.

	Nitrogen fertilizer rate, kg/ha			
Cover crop treatment	0	56	112	168
		%		
No winter cover	1.23[h]	1.36[gh]	1.57[bcdef]	1.64[bcde]
Wheat-vetch, conv. till	1.22[h]	1.39[gh]	1.70[bcd]	1.99[a]
Wheat-vetch, no-tillage	1.46[fg]	1.52[fg]	1.68[bcd]	1.99[a]
Wheat, no-tillage	1.49[fg]	1.37[gh]	1.49[defg]	1.75[b]

Note: Means followed by the same letter are not significantly different at the 5% level.

As N rates were increased from 112 to 168 kg/ha there was a significant increase in stover N% for the two wheat-vetch and the WNT treatments. The wheat-vetch plots had equivalent N% values at the 168 kg/ha N rate which were higher than those for the two non-vetch treatments.

The two-way table of means for the significant interaction involving the main plot (sampling date) and the split-split plot (cover crop) factors is shown in Table 12. There is a general trend for the nitrogen percentage to decrease as the growing season progresses. The difference between consecutive sampling dates is significant for each cover crop treatment at all dates. There were no differences in stover N% between treatments averaged across N rates at both the first and last sampling dates.

The N% value for the WVNT treatment at the second sampling date (June 10th) is significantly higher than those for both the Check and WVC plots. The WVC plots have a higher stover N% than the Check plots at the June 19th sampling. The WVNT plots have a significantly larger stover N% at the July 15th sampling than do the Check plots.

A comparison of tissue N% values in the present experiment to published critical N concentrations points

Table 12. Effect of sampling date and cover crop treatment, across N rates, on the nitrogen percentage of corn stover.

Cover crop treatment	Sampling date MAY 28	JUN 10	JUN 19	JUL 15	SEP 12
			%		
No winter cover (Check)	3.61[a]	1.91[b]	1.30[b]	0.89[b]	0.57[a]
Wheat-vetch, conv. till	3.60[a]	1.96[b]	1.64[a]	0.98[ab]	0.52[a]
Wheat-vetch, no-tillage	3.90[a]	2.25[a]	1.47[ab]	1.05[a]	0.58[a]
Wheat, no-tillage	3.57[a]	2.08[ab]	1.51[a]	0.95[ab]	0.48[a]

[1]: Means within a column followed by the same letter are not significantly different at the 5% level.

[2]: LSD 5% between sampling date means for the same or different cover crop treatment, 0.0337; LSD 5% between cover crop means for same sampling date, 0.0326. Tests performed on data transformed by: Log_{10} (N% + 1).

to the possibility of nitrogen deficiency. Most published values for the critical earleaf N concentration at silking or tasselling range from 2.8-3.0% N (29, 48). This time period corresponds in the present experiment to that just prior to or at the fourth sampling date (July 15) where the tissue N% averages slightly less than 1%. As mentioned above, total tissue was analyzed in this experiment and there exists the possibility of a dilution effect of N-rich leaf tissue with N-poor stalk tissue. It seems unlikely, however, that this effect could account for the almost three-fold difference in the present and published values.

One of the few significant differences in stover N% between cover crop treatments occurred at the 0 N rate where the no-till plots had higher values than the conventional plots. From the data on stover production, and similar to the conclusions for P and K percentages, it would appear that this is a concentration effect resulting from the low dry matter production on these plots. There was also a decrease in stover N% with time that followed a pattern similar to that for phosphorus.

It is interesting to note, unlike the data for P% and K%, that the N% values increase with increasing supplemental N fertilization. This is not the result of a concentration effect as dry matter production increased for all treatments from 0 to 56 kg/ha supplemental N. However, while N% values increased for all the treatments with each additional increment of fertilizer N (except for the Check from 112 to 168 kg/ha N and WNT from 56 to 112), stover weight did not increase with additional N after 56 kg/ha (except for the WNT treatment from 56 to 112 kg/ha N) as shown in Table 2 (p. 28). This increase in N% with increasing N fertilization also does not seem to be related to yield in any consistent manner (see Table 14, p. 93). These two facts point to the idea that nitrogen deficiency was not the only factor limiting yields but that insufficient moisture also inhibited growth and grain production.

The analysis of variance for the data on the nitrogen percentage of the corn grain is shown in Table 19 (Appendix). There were no significant treatment or interaction effects at either the 5 or 10% probability levels for the data on phosphorus and potassium percentages of corn grain.

There was no significant effect from both the treatments applied to the main plots (nitrogen rate) and the split-plots (cover crop). The two-way interaction between nitrogen rates and cover crops was significant at the 5% probability level.

The effect of this interaction is shown in Table 13. Corn grain N% values were statistically similar between N rates for each cover crop treatment except the WVNT. For this treatment the values at the 0 and 56 kg/ha N rates were similar and significantly lower than those at the two higher N rates. Similarly, there were no differences in the effect of the cover crop treatments for a given N rate with the exception that the WVNT plots had a significantly lower grain N% than the WNT treatment at the 56 kg/ha N rate.

Total N uptake at various sampling dates during the growing season is shown graphically in Figs. 18 - 21 in the same format as that for the potassium and phosphorus uptake date.

Differences in total N uptake between the cover crop treatments at the 0 N rate are apparent only 41 days after planting. Values for the WVC and Check treatments are similar and discernedly higher than the values for the two no-tillage treatments. The WVNT treatment approaches the Check in N uptake by the 76th day and shows a marked increase over the WNT treatment from that point through harvest at 135 days. This final sampling shows the WVC treatment to have taken up considerably more nitrogen than any of the other treatments.

Table 13. Effect of cover crop treatments and supplemental N on nitrogen percentage of corn grain.

Cover crop treatment	Nitrogen fertilizer rate, kg/ha			
	0	56	112	168
		%		
No winter cover	1.32[abc]	1.28[abc]	1.43[ab]	1.38[abc]
Wheat-vetch, conv. till	1.32[abc]	1.29[abc]	1.28[abc]	1.49[a]
Wheat-vetch, no-tillage	1.12[c]	1.18[c]	1.42[ab]	1.44[ab]
Wheat, no-tillage	*	1.46[ab]	1.23[bc]	1.37[abc]

Note: Means followed by the same letter are not significantly different at the 5% level.

* : Insufficient grain for analysis.

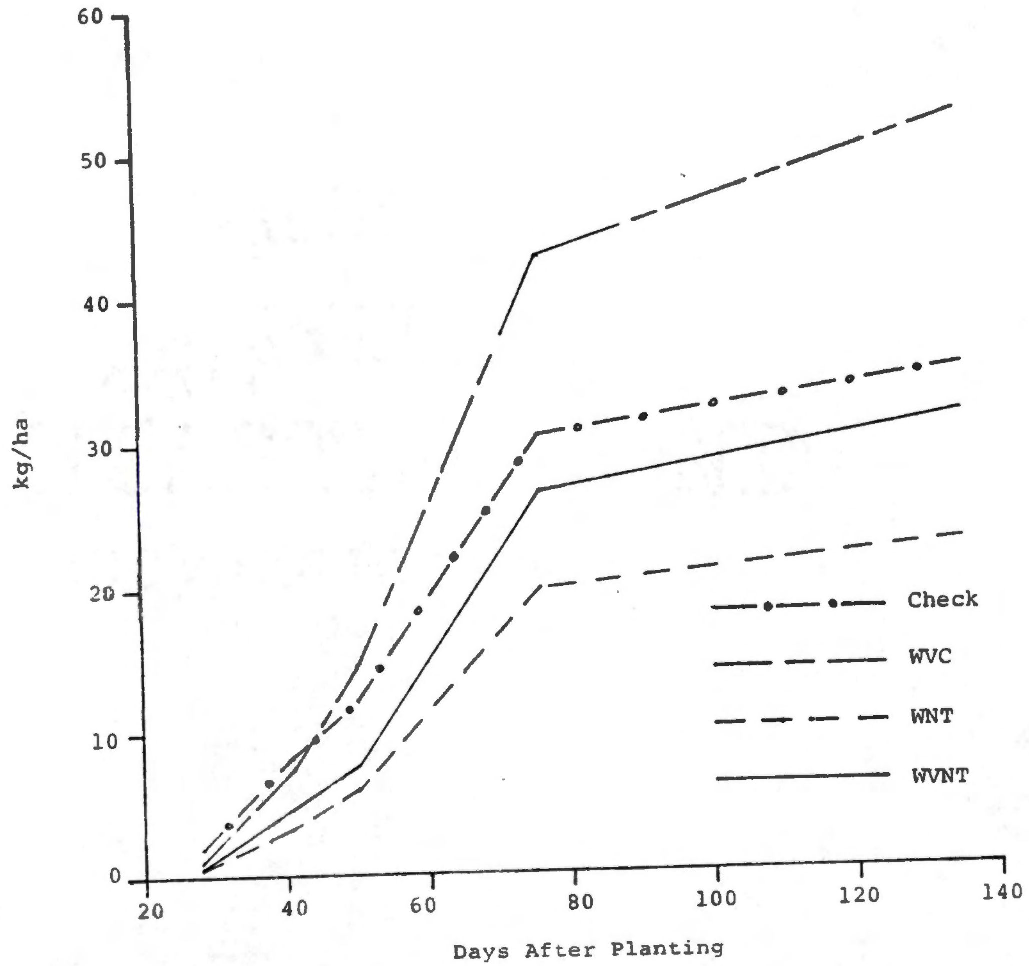

Figure 18. Total nitrogen uptake of corn at the 0 kg/ha N rate.

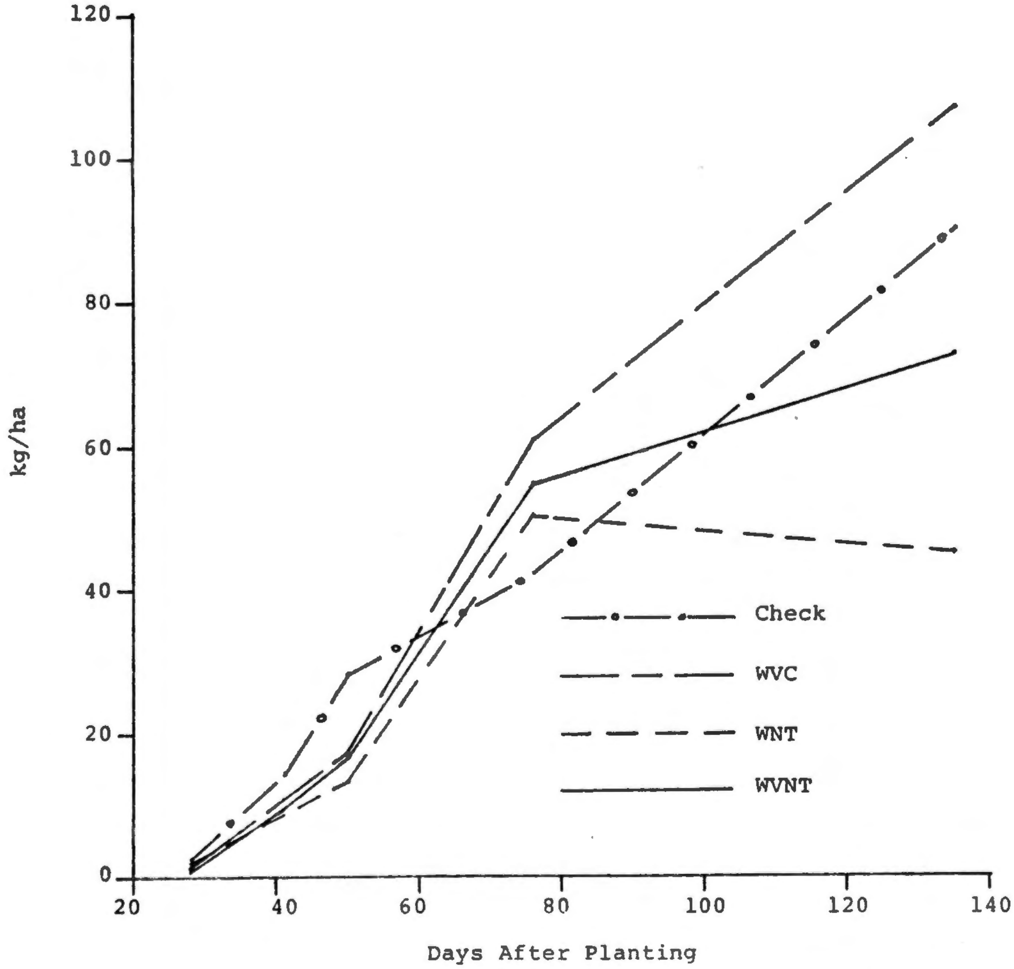

Figure 19. Total nitrogen uptake of corn at the 56 kg/ha N rate.

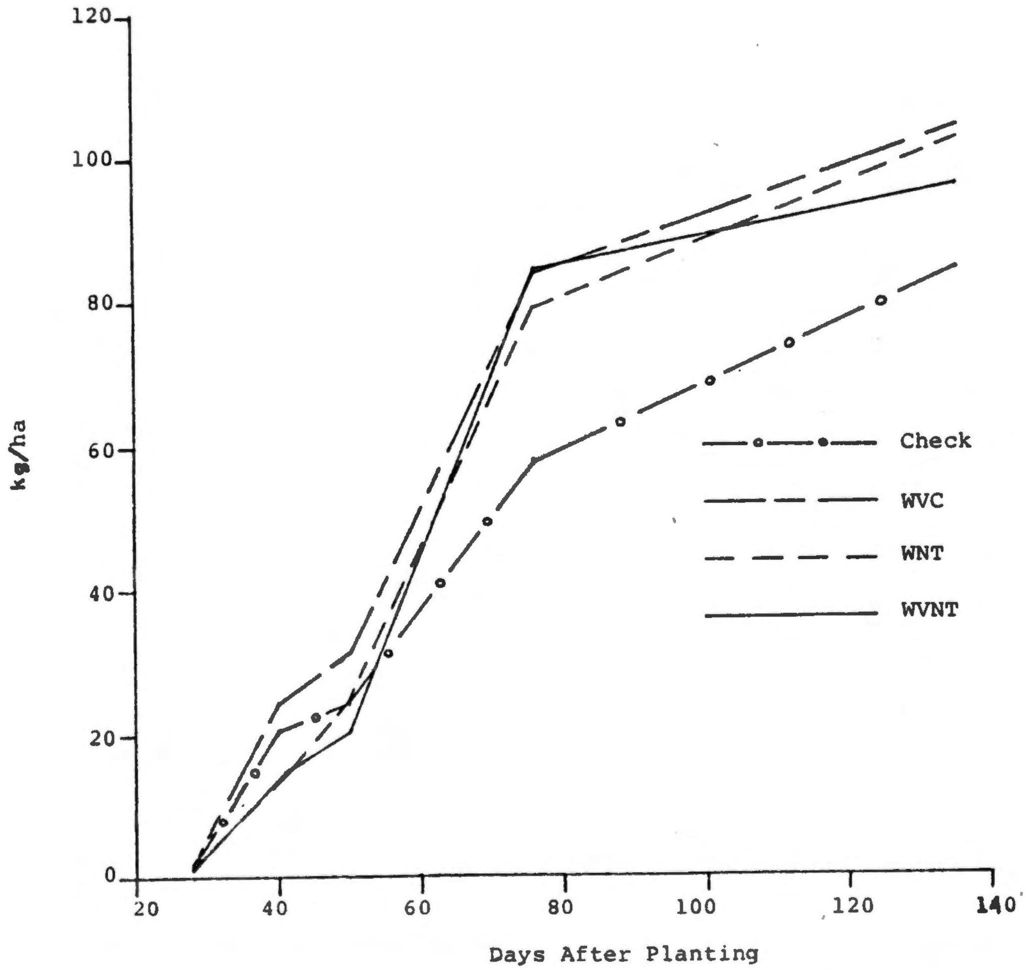

Figure 20. Total nitrogen uptake of corn at the 112 kg/ha N rate.

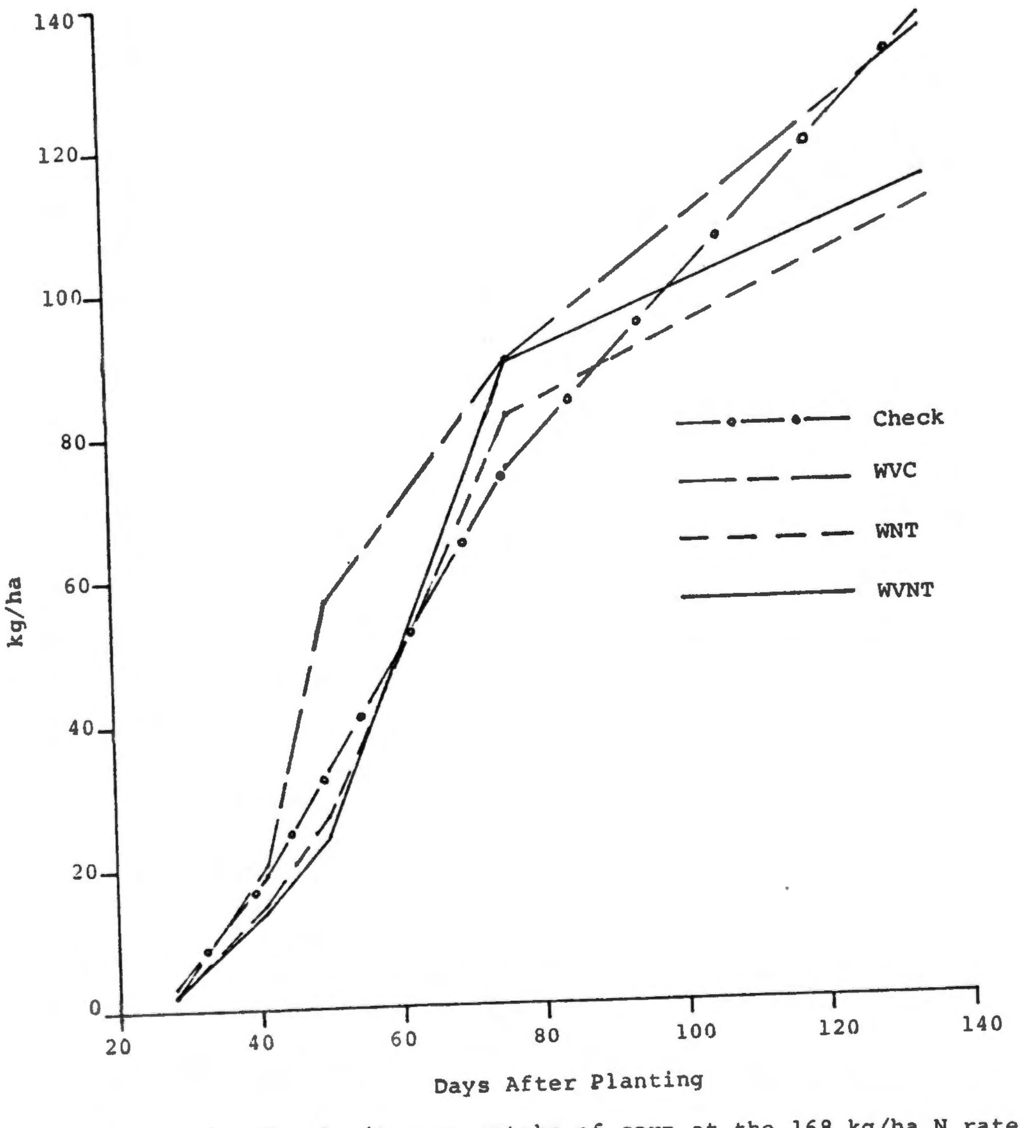

Figure 21. Total nitrogen uptake of corn at the 168 kg/ha N rate.

Total N uptake at the 56 kg/ha N rate is clearly higher than at the 0 rate for all treatments. The treatments have similar values through the first four sampling dates with the exception that the Check is markedly higher at 50 days and lower at 76 days after planting. As expected, at the fourth sampling date the two wheat-vetch treatments hvae the highest total N uptake. By harvest (Sept. 12) the Check has increased to where it and the other conventional tillage treatment (WVC) are higher than the two no-tillage treatments with the WVNT treatment clearly higher than the WNT treatment.

The Check treatment is also an exception at the 112 kg/ha N rate. The other three treatments show very similar N uptake values throughout the growing season at this N rate. The Check is clearly lower at the 76th day and is still lower, although to a lesser extent, at the final sampling date (harvest). Values for the WVC and Check at this rate are similar to their values at the 56 kg/ha N rate while the WVNT and WNT show marked increases in N uptake with the additional nitrogen.

All four treatments show an increase in uptake as supplemental N rates are increased from 112 to 168 kg/ha. The WVC treatment shows a markedly higher total N content at the 50th day than the other treatments. The WVNT treatment increased to become equal in N uptake to the WVC treatment by the 76th day but this trend does not continue until harvest. The Check is again the lowest treatment at the 76th day but increases rapidly form this point. By harvest the two conventional tillage treatments have similar and clearly higher values than the two no-tillage treatments.

It is interesting to compare the values for the N% of the stover (Table 11, p. 74) with the graphs for stover dry matter production (Figs. 1-4, pgs. 32-35) and total N uptake (Figs. 18-21) and the yields (Table 14, p. 93). In many comparisons between treatments or between N rates, N uptake increased markedly while yields and stover dry matter production did not. The result, in some cases, was a significant increase in stover N content. The two no-till treatments at the 0 N rate had similar yields to the Check treatment and much lower dry matter production which resulted in significantly higher N contents in the stover. A similar conclusion follows for the two wheat-vetch plots at the 168 kg/ha N rate. The Check and WVC treatments showed little or no increase in yields and stover dry matter production (but some increase in total N uptake) from the 112 to 168 kg/ha N rates while their stover N contents increased significantly over this range.

The enhancement of mineralization, and hence availability, of soil N by plowing is shown by the graphs for N uptake at the 0 and 56 kg/ha N rates (Figs. 18 and 19, pgs. 81 and 82). At the 0 N rate the WVC plots have much higher N uptake values after the 50th day after planting. Immobilization of N, or the lack of mineralization, is shown by the low values for the WNT plots at the 0 N rate. At the 56 kg/ha N rate the WVC and WVNT treatments follow similar trends up to the 76th day. After this point the WVC increases in N uptake at a faster rate, reflecting the surpassing of the threshold N concentration in the incorporated residue and the release of N. It is also important to note that the Check plots surpassed the WVNT plots in N uptake by harvest.

Broadbent (16) and others have reported that release by mineralization and plant uptake of soil N are increased by N fertilization and the addition of organic amendments. This so-called priming effect of supplemental N on the mineralization of soil N is illustrated in the graph for N uptake at the 112 kg/ha N rate. At the third sampling date the WVC plots have a greater N uptake than the WVNT. Both of the no-till treatments, however, have uptake trends similar to the WVC plots from this point on. It seems that the addition of N has "primed" mineralization, even under the no-till mulches, which showed marked increases in N uptake as supplemental N rates were increased from 56 to 112 kg/ha.

The effects of plowing and N fertilization on the availability of soil N are also shown by the uptake graph for the 168 kg/ha N rate. The WVC treatment is again much higher at the 50th day and again the WVC and WVNT treatments have similar values by the 76th day after planting. The combined effects of tillage and high supplemental N fertilization are shown by the much higher values for N uptake at harvest for the conventionally tilled plots. These differences correspond somewhat to yield differences (see Table 14, p. 93).

The apparent N recovery of corn for each of the sixteen cover crop-N rate treatment combinations is shown in Fig. 22. Total N is divided according to the method of Mitchell and Teel (49). This method does not take into account any priming effects from plowing, fertilization, or residue addition. This may not be a significant defect in that Olson (54) found that fertilizer did not alter the amount of soil N used and that there was no priming effect on mineralization of indigenous soil N in an experiment on irrigated corn in Kansas. The contribution of soil N is estimated by the Check plots at the 0 N rate. The lower values for N recovery in the no-till

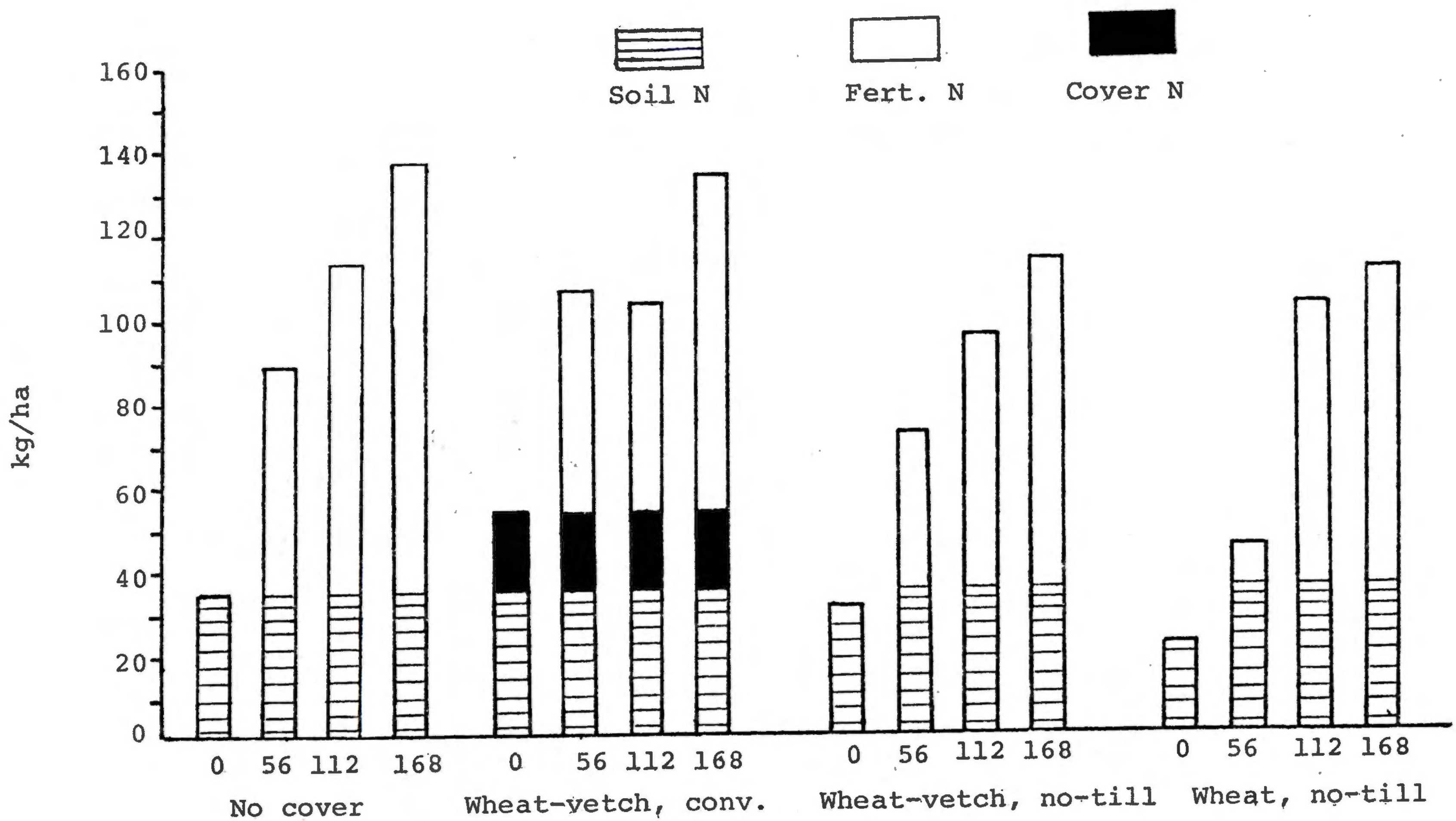

Figure 22. Apparent N recovery of corn dry matter as influenced by cover crops and N rates.

plots at the 0 rate represent a net recovery loss resulting from immobilization of N and/or the lack of stimulation of mineralization from plowing as may have occurred in the Check plots. This discrepancy results in the graph showing no apparent contribution of N from the wheat-vetch mixture under no-till conditions.

It is interesting to note that while there is an increase in N recovery from the 112-168 kg/ha N rates for all but the WNT treatment, there was not a corresponding significant increase in yield (see Table 14, p. 93). This corresponds to data from Olson (54) who showed that while there was no difference in the yield of irrigated corn in Kansas between 150 and 50 kg/ha N rates the higher rate did result in greater crop removal, denitrification, and downward movement.

Mitchell and Teel (49) found that on plots with no cover the apparent percentage of fertilizer N removed by corn was 67% at the 56 kg/ha N rate and only 41% at 112 kg/ha supplemental N. Data from the present experiment were similar (76 and 45%, respectively). The above authors also found that when a large amount of N was supplied by an oats-vetch cover crop under no-till conditions the apparent recovery of fertilizer N dropped to 23% and 10% for the 56 and 112 kg/ha N rates, respectively. In the present experiment the apparent recovery of fertilizer N from the WVC plots was 99%, 47%, and 50%, respectively, for the 56, 112, and 168 kg/ha N rates.

Data from a study on the fate of radioactively tagged nitrogen fertilizer applied to corn indicate that only about 25% of the N fertilizer at both high and low N rates was removed by the grain (54). Data from the present study show consistently higher values. At the 56 kg/ha N rate 46% of the N fertilizer was apparently recovered by the grain in the Check plots and 60% was removed from the WVC plots. These differences in fertilizer N recovery, from the published values and between treatments, reflect the inability of this method of calculating the apparent N recovery to adjust for an increase in the removal of soil N with N fertilization and organic amendments.

Grain Yield

The analysis of variance for the 1980 shelled corn yield data is shown in Tables 21 and 22 (Appendix). The effects of both the nitrogen rate (main plots) and cover crop treatment (split plots) factors were significant at the 5% probability level. The two-way interaction for these factors was also significant, indicating that there was a difference in the comparative yield response of the corn crop to the cover crop treatments at various N fertilizer rates.

Grain yields for the four cover crop treatments at the four supplemental nitrogen fertilizer rates are shown in Table 14 and are graphically represented in Fig. 23. Two distinct groups can be discerned in the yield data presented in the table and graph. The first or lower group is made up of all the treatments at the 0 rate and the two no-tillage treatments at the 56 kg/ha rate. The difference (approximately 1100 kg/ha) between the highest yield of the lower group and the lowest yield of the second group of cover crop-N rate combinations is almost equal to the difference (1400 kg/ha) between the highest and lowest yields of the higher group.

The WVC treatment was the highest producing treatment at the 0 N rate and reached its yield maximum, before any other treatment, at 56 kg/ha N (i.e. there were no significant differences between yields for the WVC treatment at 56, 112, and 168 kg/ha N). The other treatments were not significantly different from each other at the 0 N rate and all reached their yield maximum at 112 kg/ha supplemental N; i.e., there was no significant difference at the 5% level within a cover crop treatment between yields at 112 and 168 kg/ha N.

All cover crop treatments showed a significant increase in yields from 0 to 56 kg/ha of supplemental N. At this N rate the no-tillage treatments produced yields

Table 14. Effect of cover crop treatments and supplmental N on shelled corn yields.

Cover crop treatment	Nitrogen fertilizer rate, kg/ha 0	56	112	168
	kg/ha, 15.5% moisture			
No winter cover (Check)	962^{f}	3601^{c}	4368^{abc}	5025^{a}
Wheat-vetch, conv. till	1843^{de}	4275^{abc}	4561^{ab}	4520^{ab}
Wheat-vetch, no-tillage	805^{f}	2485^{d}	3582^{c}	3872^{bc}
Wheat, no-tillage	650^{f}	1730^{e}	4073^{bc}	3894^{bc}

Note: Means followed by the same letter are not significantly different at the 5% level.

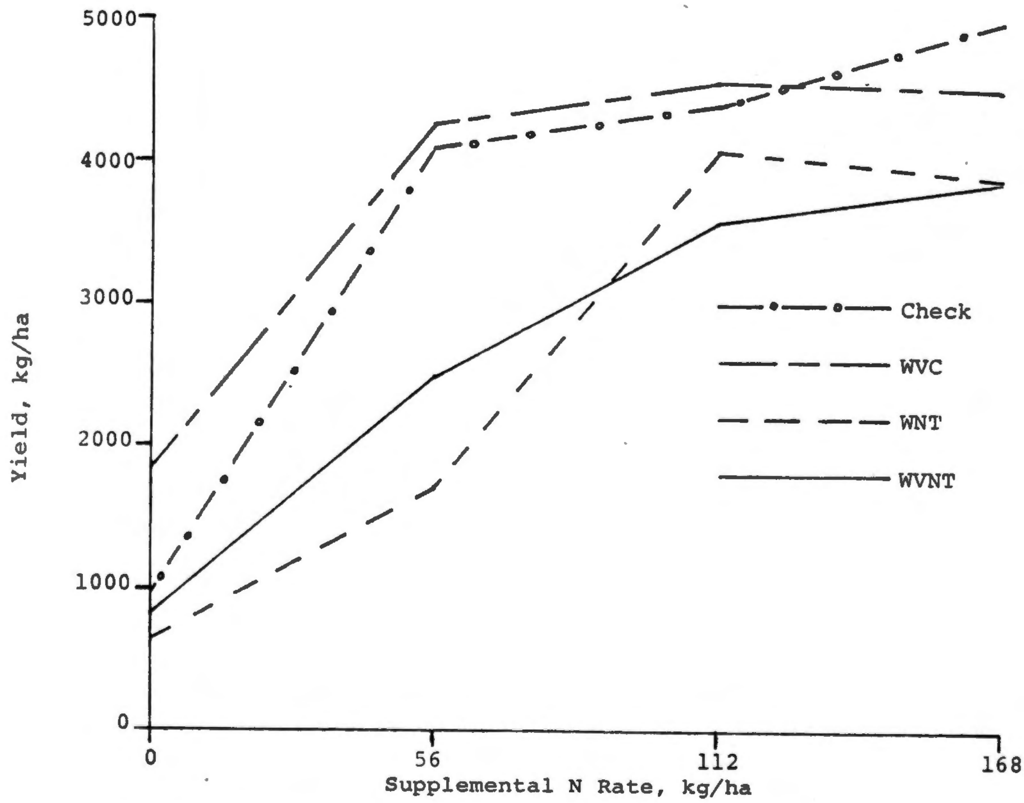

Figure 23. Effect of cover crops on corn yields across N rates.

which were significantly less than those from the conventionally tilled plots.

Yields significantly increased with the addition of another 56 kg/ha N in the two no-till treatments but did not increase over the 56 kg/ha N rate in the two treatments receiving conventional tillage. As was true at the 56 kg/ha rate, at the 112 kg/ha N rate the WVNT plots produced yields similar to those from the WNT but less than those from the WVC plots. Yields from the WNT, WVC, and Check plots were similar at at the rate of 112 kg/ha supplemental N.

None of the cover crop treatments demonstrated any significant yield increase when the supplemental N rate was further increased to 168 kg/ha. Yields for the Check plots were significantly greater than those for the two no-tillage treatments while yields for the WVC, WVNT, and WNT treatments were statistically similar at this N rate.

The effect of the four cover crop treatments is further examined by partitioning their three degrees of freedom into meaningful single degree of freedom components by the use of orthogonal coefficients (31). These comparisons and their associated sums of squares are shown in Table 22 (Appendix). The comparisons were: plots containing vetch (WVC + WVNT) versus those without vetch (WNT + Check); WVC versus WVNT; and WNT versus Check. It is clear that the latter two contrasts were significant and accounted for over 95% of the sums of squares for cover crops and that there was no difference in the comparative response of the corn crop, as measured by grain yields, to the vetch versus no vetch plots across the four N rates. These comparisons are made less meaningful, however, by the significant interaction which indicates that the effect of cover crop treatments varied with nitrogen rate. Therefore the sums of squares for interaction were partitioned into three components with 3 degrees of freedom for each, corresponding to the interaction of each single degree of freedom contrast with nitrogen rate (44).

There was a significant difference in the comparative response of the corn crop to vetch at the various N rates. The plots containing vetch produced much higher yields than the non-vetch plots at the 0 and 56 kg/ha N rates (518 and 715 kg/ha greater, respectively) and only slightly lower yields at the 112 and 168 kg/ha N rates (151 and 264 kg/ha lower, respectively).

Tillage method had a pronounced effect on the response of corn to wheat-vetch treatments which did not vary across the four N rates. As can be seen from Table 14, the WVC treatment had significantly higher yields than the WVNT at all but the 168 kg/ha N rate. The difference in yield between these two treatments ranged from 1038 kg/ha at the 0 N rate to 648 kg/ha at the 168 kg/ha N rate. The difference between these two differences is 390 kg/ha (98 kg/ha on a per plot basis) which is not significantly different from zero. Therefore the differences in the effect of tillage on the wheat-vetch treatments does not vary significantly among N rates, as is shown in Table 22 (Appendix).

The difference in corn yield between the two non-vetch treatments varied significantly between N rates. Table 14 indicates that although the Check plots produced higher yields at all N rates, the differences were significant and very large at the 56 and 168 kg/ha N rates.

That tillage was necessary to release the N contained in the legume residue during this growing season is suggested by the significantly lower yields for the WVNT plots versus the WVC plots at all but the 168 kg/ha N rate and lower yields than the Check at all non-zero supplemental N rates. This conclusion contrasts with that of Triplett _et_. _al_. (78) who found that tillage was not necessary to release the N contained in an alfalfa meadow. Mitchell and Teel (49) found that corn planted by minimum tillage into a rye-vetch mulch produced yields comparable to those from conventionally tilled check plots receiving 112 kg/ha supplemental N fertilizer.

Soil nitrate nitrogen and moisture data for this experiment from Stevens (pers. comm.) show higher nitrogen values and a greater moisture deficit under the WVC plots. The effect of tillage on yields is shown by the highly significant F value for the WVC vs. WVNT orthogonal comparison of Table 22 (Appendix). That this effect is the result of the influence of tillage on the nitrogen economy of the soil rather than the moisture balance is suggested by the lower moisture content under the conventionally tilled plots as compared to the no-till plots which were covered with a moisture conserving mulch. The lack of a significant interaction of this comparison with N rate suggests that the priming effect on the mineralization of soil N from incorporation of the residue was more important than that from the addition of fertilizer N.

The lack of response to added nitrogen above 56 kg/ha for the WVC treatment and above 112 kg/ha for the other treatments suggests that soil moisture rather than nitrogen limited yields at the higher N rates. Stevens (pers. comm.) reports that the soil moisture content of the conventionally tilled plots in this study was lower than the no-tillage plots at the 112 and 168 kg/ha N rates but attributed it to the conservation of moisture under the no-tillage mulch rather than to greater transpiration in the conventionally tilled plots. This conclusion follows from the data presented above which indicate that there were no significant differences among treatments in dry matter production at these N rates. The lack of an increase in corn yields in the no-till treatments at these N rates, despite their higher soil water contents, again suggests that incorporation of the residue was necessary for release of nitrogen. The nitrogen thus liberated in the WVC treatment did not significantly increase yields at supplemental N rates above 56 kg/ha because of insufficient soil moisture.

CHAPTER IV

SUMMARY AND CONCLUSIONS

The objective of the present experiment was to test the hypothesis that the beneficial consequences of a no-tillage corn production system would be improved by the inclusion of a legume in a small grain mulch. It was hoped that grain yields could be increased by this system without increasing the rate of N fertilization. Overall, data from this experiment indicate that this hypothesis did not prove correct under the conditions of the 1980 growing season. It was found that tillage was necessary for release of the N contained in the legume.

The above hypothesis was tested by a field experiment in a split-plot design with supplemental nitrogen fertilizer rates as the main treatments and four cover crop/tillage method combinations as the split treatments. A wheat-vetch cover crop under both conventional and no-tillage, and a wheat cover crop under no-tillage, were compared against a check plot consisting of conventional tillage into bare ground. The trial was conducted at the Milan Field Station in Milan, Tennessee, on a soil (Memphis silt loam, 0-2% slope) commonly found on the loess-mantled landscape of West Tennessee.

Top growth samples for elemental (N, P and K) analysis and dry matter weight were taken of the wheat and wheat-vetch cover crops prior to corn planting on April 30, 1980. These factors were also measured for tissue samples of the corn which were removed on May 28, June 10, June 19, July 15, and at grain harvest on September 12. Tissue samples were acid digested and analyzed for N and P on the Technicon "Autoanalyzer" and for K by flame emission spectroscopy.

The dry matter production and N contribution of the wheat-vetch cover crop was low and highly variable. The values for the wheat cover crop more closely approached expected values as reported in the literature.

Corn growth and yields were much lower than would have been anticipated during an average growing season. That a soil moisture deficit was at least partially responsible is shown by the data on stover dry matter production. Stover weights were very similar for all treatments at the non-zero N rates. Further evidence for this conclusion is that the rate of dry matter accumulation decreased during the latter part of the growing season. This was the period of greatest moisture stress.

Nitrogen appeared to be the major limiting factor, especially in the no-till plots. The wheat no-till treatment reached its maximum yield one increment of fertilizer N after all other treatments. This was probably the result of immobilization of N under the wheat mulch. Both no-till plots showed less dry matter production than the conventionally tilled plots during the early stages of the growing season when moisture was sufficient.

Analysis of the data on grain yields reflects the need for tillage to release the N contained in the no-till mulches. The WVNT (wheat-vetch, no-tillage) plots had significantly lower yields than the Check (no cover, conventional tillage) plots at both the 56 and 168 kg/ha N rates and lower than the WVC (wheat-vetch, conventional tillage) at the 56 and 112 kg/ha rates. The tillage effect is also demonstrated by the highly significant F value for the WVC vs. WVNT orthogonal comparison. The lack of significance for the interaction between this comparison and N rate suggests that there was no priming effect on mineralization of soil N from the addition of fertilizer N.

The P and K percentages of the corn stover declined with both increasing N rate and dry matter production. The N content of the corn rose significantly as the supplemental N rate was increased. The rapid decrease in the percentages of N, P and K through the first three sampling dates reflect the rapid increase in dry weight as stalk elongation and leaf emergence progress.

There appeared to be a relationship between the low N recovery and the N content of the stover. In some comparisons between treatments at a given N rate and between N rates for a given treatment, when the dry matter production, total N uptake, and yields were low, there was a significant increase in the N% of the stover. This relationship occurred with the two no-till plots as compared to the conventional plots at the 0 kg/ha N rate and with the two wheat-vetch plots from the 112 to 168 kg/ha N rates.

The no-tillage treatments had higher stover P% values at the lower N rates during the early part of the growing season. This appeared to be a concentration effect resulting from the lower dry matter production in these plots during this period.

A comparison of the data on dry matter production and total phosphorus uptake lead to the conclusion that the wheat-vetch residue released available phosphorus at the 0 and 56 kg/ha N rates. This effect occurred in both tillage situations.

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APPENDIX

Table 15. Analysis of variance for corn stover dry weight.

Source of variation	df	MS	F calc.	F tab. (5%)
Sampling date	4	36.8922	3803.22*	3.06
Rep. * sampling date (error a)	15	0.0097		
Nitrogen rate	3	1.6525	98.36*	2.82
Samp. date * N rate	12	0.0408	2.43*	1.98
Rep. * N rate Rep. * samp. date * N rate — error b	45	0.0168		
Cover crop treatment	3	0.4915	37.52*	2.66
Samp. date * cover crop	12	0.0414	3.16*	1.82
N rate * cover crop	9	0.0805	6.14*	1.94
Samp. date * N rate * cover crop	36	0.0144	1.10	1.49
Error c	177	0.0122		

*: Significant at the 5% level.

Table 16. Analysis of variance for phosphorus percentage of corn stover.

Source of variation	df	MS	F calc.	F tab. (5%)
Sampling date	4	0.1109	84.83*	3.06
Rep. * samp. date	15	0.0006		
Nitrogen rate	3	0.0650	162.50*	2.82
Samp. date * N rate	12	0.0013	3.25	1.98
Rep. * N rate Rep. * samp. date * N rate (error b)	45	0.0004		
Cover crop treatment	3	0.0131	65.50*	2.66
Samp. date * cover crop	12	0.0007	3.50*	1.82
N rate * cover crop	9	0.0050	25.00*	1.94
Samp. date * N rate * cover crop	36	0.0004	2.00*	1.49
Error c	177	0.0002		

*: Significant at the 5% level.

Table 17. Analysis of variance for potassium percentage of corn stover.

Source of variation	df	MS	F calc.	F tab. (5%)
Sampling date	4	1.7280	595.86*	3.06
Rep. * samp. date (error a)	15	0.0029		
Nitrogen rate	3	0.0751	34.14*	2.82
Samp. date * N rate	12	0.0361	16.41*	1.98
Rep. * N rate Rep. * samp. date * N rate — error b	45	0.0022		
Cover crop treatment	3	0.0567	31.50*	2.66
Samp. date * crop	12	0.0060	3.33*	1.82
N rate * crop	9	0.0067	3.72*	1.94
Samp. date * N rate * crop	36	0.0022	1.22	1.49
Error c	177	0.0018		

*: Significant at the 5% level.

Table 18. Analysis of variance for nitrogen percentage of corn stover.

Source of variation		df	MS	F calc.	F tab. (5%)
Sampling date		4	2.0251	698.31*	3.06
Rep. * samp. date (error a)		15	0.0029		
Nitrogen rate		3	0.0979	31.58*	2.82
Samp. date * N rate		12	0.0044	1.42	1.98
Rep. * N rate Rep. * samp. date * N rate	error b	45	0.0031		
Cover crop treatment		3	0.0101	5.32*	2.66
Samp. date * crop		12	0.0038	2.00*	1.82
N rate * crop		9	0.0061	3.21*	1.94
Samp. date * N rate * crop		36	0.0023	1.21	1.49
Error c		172	0.0019		

*: Significant at the 5% level.

Table 19. Analysis of variance for nitrogen percentage of corn grain.

Source of variation	df	MS	F calc.	F tab. (5%)
Nitrogen rate	3	0.0020	1.42	3.86
Rep. * N rate (error a)	9	0.0014		
Cover crop treatment	3	0.0002	0.34	
N rate * cover crop	8[1]	0.0016	2.52*	2.36
Rep. * N * crop (error b)	24[1]	0.0006		

[1]: Should be 9 and 36 df, respectively; result of missing data.

*: Significantly different at the 5% level.

Table 20. Analysis of variance for shelled corn yields.

Source of variation	df	MS	F calc.	F tab. (5%)
Nitrogen rate	3	9130.49	209.7*	3.86
Rep. * N rate (error a)	9	43.55		
Cover crop treatment	3	1448.56	23.3*	2.87
N rate * cover crop	9	215.08	3.5*	2.15
Error b	36	62.24		

*: Significant at the 5% level.

Table 21. Variance components for cover crop treatments and cover crop * nitrogen rate interaction for shelled corn yields.

				F	
Source of variation	df	SS	MS	calc.	tab. (5%)
Cover crop treatment	3	4345.69	1448.56	23.27*	2.87
(a) Vetch vs. no V	1	170.63	170.63	2.73	4.11
(b) WVC vs. WVNT	1	2520.50	2520.50	40.50*	
(c) WNT vs. Check	1	1654.56	1654.56	26.58*	
N rate * cover crop	9	1935.70	215.08	3.46*	2.15
N rate * (a)	3	713.13	237.71	3.82*	2.87
N rate * (b)	3	354.61	118.20	1.90	
N rate * (c)	3	867.97	289.32	4.65*	
Error b	36	2240.55	62.24		

*: Significant at the 5% probability level.

Table 22. Monthly precipitation data for Milan, Tennessee.

	MAY	JUNE	JULY	AUG.	SEP. 1-15	TOTAL
			cm			
Normal (34 yr. avg.)	10.72	10.87	11.23	8.99	4.39	46.20
1980 growing season	5.82	20.09	2.92	2.49	3.35	34.67
Departure from normal	-4.90	9.22	-8.31	-6.50	-1.04	-11.53

VITA

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