The Pennsylvania State University

The Graduate School

Department of Crop and Soil Sciences

# IMPROVING THE SYNCHRONY OF HAIRY VETCH (*VICIA VILLOSA*) NITROGEN RELEASE FOR CORN (*ZEA MAYS*) NITROGEN UPTAKE

A Thesis in

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by

Justine C. Cook



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The thesis of Justine C. Cook was reviewed and approved* by the following:

Robert S. Gallagher
Associate Professor of Cropping Systems
Thesis Advisor

Jason P. Kaye
Assistant of Professor of Soil Biogeochemistry

Jonathan Lynch
Professor of Plant Nutrition

David Sylvia
Professor of Soil Microbiology
Head of the Department of Crop and Soil Sciences

*Signatures are on file in the Graduate School

**ABSTRACT**

Leguminous green manure legume crops can often meet much of the nitrogen (N) demand of a succeeding crop. There may be, however, an asynchrony between N mineralization from green manures and crop N uptake, resulting in substantial nitrogen loss through leaching or denitrification. In our research, we hypothesize that this synchrony can be improved by manipulating the termination date of a hairy vetch (*Vicia villosa*) cover crop and the sowing date of the succeeding corn (*Zea mays*) crop. This will regulate the quality and quantity of the N in the vetch, the rate of N mineralization from the vetch residues, and the relative rate of N uptake in the corn. The study was located at the Russell E. Larson Agricultural Research Center in Rocks Springs, PA on Hagerstown soil. The vetch termination/corn planting dates chosen were May 4$^{th}$, May 15$^{th}$, and May 31$^{st}$. A 92 RM variety corn was planted into live vetch, which was then chemically terminated. Corn fertilized with ammonium nitrate was used in order to compare yields of legume derived N with a mineral N control.

The vetch biomass at termination was approximately 1500, 5000, and 7000 kg ha$^{-1}$ for the May 4$^{th}$, May 15$^{th}$, and May 31$^{st}$ planting dates, respectively. The N content of the vetch was 4% and did not vary among treatments. The May 31$^{st}$ vetch treatment had higher peak soil inorganic N content in the top fifteen centimeters and greater peak N flux rates, but did not have greater corn biomass or grain yields. The grain yields in the vetch treatments were comparable to the ammonium nitrate-fertilized grain yields, but slightly below the yield capability for the field site's soil type. A comparison of N inputs and outputs suggests that the vetch terminated on May 31$^{st}$ provided excess N, the May 4$^{th}$-terminated vetch was not a sufficient N source, and the May 15$^{th}$ vetch treatment probably achieved the best synchrony. We anticipate that these experiments will provide help provide management guidelines to improve the N-use efficiency of green manure systems and reduce nitrogen pollution.

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## Chapter 1

# Introduction

The recent years have been marked with increasing food and fuel prices, as the demand for commodities has steadily outstripped production capabilities. The ability of producers to satisfy the market demands has been tempered by production costs and environmental concerns. While the value of commodities has presented many producers with selling prices significantly higher than the past, the costs of production—especially those associated with fuel prices—have negatively affected the potential profits. This has been compounded by the acreage and nutrient application restrictions due to conservation programs. At this time, producers are faced with great pressure for high productivity and a social responsibility to uphold environmental quality. The current objective to satisfy production goals has been fueled by various strategies to increase yield and resource use efficiency. Most of these strategies, however, rely on Haber-Bosch nitrogen (HBN) sources, which may not be the most economic or efficient means to the end. Legume nitrogen (N) is an exciting alternative to HBN that can not only meet crop N needs, but provide external benefits to the producer and the ecosystem. The efficiency of legumes, however, is debatable, and management practices that can improve their value in a cropping system are needed before any significant adoption by mainstream producers can be expected.

### Increases in Crop Production

The last fifty years has seen a tripling of global food production (Mosier et al. 2004), with United States cereal grain production reaching historic levels in 2007 (FAO 2007). In 2007, the United States produced the greatest portion of corn in the world, contributing 44% to the global total (ENS 2002). This is a culmination of the last ten years in which corn production has increased over a million bushels (NCGA 2007). This increase is the result of a combination of factors, mainly: greater demand, cultivar development, and improvements in agronomic management.

Corn, specifically grain corn, has many uses within the global economy. The United States Department of Agriculture Economic Research Service has reported livestock feed as the largest sink for corn grain in the U.S., with food and industrial products following (2008). Rising grain prices, however, have precipitated a decline in livestock production; consequently, corn consumption within that sector declined by nine percent. Despite this, total domestic use of corn grain and its by-products grew by thirty percent between 2001 and 2007—reaching ten billion bushels (ERS 2008). The consistent increase can be partly attributed to the ongoing investments in biofuel technology. The number of corn bushels devoted to ethanol has increased by 112% between 2002 and 2007, with a 30% increase in the last two years (NASS 2007). In comparison to the trend in corn grain consumption, acreage devotion has not had significant changes—approximately a three percent difference between 2002 and 2007. Corn production has been able to keep pace with consumption, despite acreage limitations, due in part to hybrid research and development.

Over the last fifty years, the average yield for grain corn increased approximately 1.5% per year in the United States (Tollenaar and Wu 1999). These authors maintain that the majority of corn yield improvements are due to the increased stress tolerance of hybrids that have been developed over the last half decade. This stress tolerance has been isolated in the improved "resource capture and use" of the newer hybrids. For example, Tollenaar and Migus (1984) found that newer hybrids had greater root biomass when compared to older hybrids—allowing for greater access to soil moisture and nutrients. This, in conjunction with the strides in insect and disease resistance, protects yield during stressful climatic conditions or periods of increased crop growth. The recent completion of genome mapping of corn opens up more possibilities for stress tolerant varieties, which could lead to higher yield potential for the crop (ENS 2008). Although genetic improvements may have had the greatest influence on increased yields, the exact contribution is difficult to ascertain due to the interacting effects of nutrient management (Tollenaar and Wu 1999).

Effective nutrient management has also contributed to yield improvements by ensuring sufficient nutrient supply and encouraging greater resource use efficiency. Long term research has shown that inadequate fertilization causes unfulfilled yield potentials (Addiscott et al. 2005). Researchers have isolated numerous strategies that allow crops to utilize N in an economically and environmentally profitable manner, including the following: pest management, tillage practices, and fertilization timing and application technique. Each has its own mechanism affecting crop nutrient use efficiency, such as reducing competition, stimulating supply, or reducing losses, but the overall effect is usually integrative. For example, while tillage affects both the N release timing and recommended application rate, it can also affect crop nutrient acquisition through its impact on mycorrhizal network proliferation (Merckx et al. 1990). In a study of the integrative effects of crop rotation and N rate on corn grain yield, Stanger and Lauer (2008) found that more complex rotations tended to boost yields with a decreased dependence on N amendments when compared to less complex rotations. The potential for augmenting grain production without increasing resource use or acreage devotion is an exciting prospect, but complexity of resource capture and use efficiency by crops is still a major issue in fertility management.

**The Importance of N**

Proper fertility management is a fundamental component of a profitable production system. Adequate crop nutrition is important for crop health, grain quality, and soil conservation. N is a crucial component of many compounds within the crop including amino acids and ATP (Bockman 1990). Without a sufficient supply, corn growth is stunted and the transition into the reproductive stage is delayed or does not occur. If there is sufficient N available, the rate of cell proliferation and chlorophyll content is much greater (Havlin et al. 2004). This results in crops with increased leaf area and photosynthetic activity, which produces greater levels of photosynthate for greater yields. If N is not available during corn's period of rapid growth, it will decrease the amount available for translocation during grain fill—ultimately decreasing yields (Bockman 1990). While soil does have N reserves, the indigenous supply usually is not enough to support long term cultivation, and nutrient mining can cause soil erosion and quality degradation (Addiscott et al. 2005).

Crops utilize the most easily extractable nitrogen sources, but have access to a number of available N pools. As previously mentioned, soil has an indigenous N supply, which is predominately sequestered in organic matter; other pools include aerial deposition, organic amendments, and inorganic amendments (Addiscott et al. 2005). Unlike the latter sources, the soil organic matter (SOM) pool is not in a plant available form—the N is bound to organic molecules and must be mineralized for crop uptake to occur (Bockman 1990). Depending on the soil type, SOM can supply a significant portion of required N to the crop, but it is also important for preserving soil structure and preventing soil losses, and, therefore, its conservation is crucial. While some N enters the system through aerial deposition, originating predominately from industrial combustion or manure emissions, not only is the potential input highly variable, it is not sufficient to replenish spent indigenous pools or support significant crop production—it has been estimated to account for 30 kg N $ha^{-1}$ of crop uptake in some areas (Addiscott et al. 2005). It is, therefore, necessary to use N amendments to support agriculture at the current production scale (Havlin et al. 2004). The N amendments most commonly used can be classified as either organic or inorganic, although the N provided is ultimately the same. Organic amendments can include animal manure and green manure, which is unprocessed plant material that is either applied to the soil or not removed from the soil with the purpose of nutrient enhancement for the following crop (Addiscott et al. 2005). Neither of the manures could be considered "controlled inputs" due to the variability in the amount of N and its form contained in any application. This is one of the reasons that many producers opt for inorganic amendments—specifically, Haber-Bosch N (HBN).

Despite the variety of fertility sources available, HBN use largely predominates in agriculture, especially grain production. It's estimated that 169 megatons of N is added to global cropland every year, almost half of which is HBN—twice the amount of the second ranked amendment: legume N (Cassman et al. 2002). A 2002 survey reported that 85% of the corn acreage in the US Corn Belt is fertilized with HBN (Mosier et al. 2004), which amounts to about 30 million acres (ERS 2002). Due to this wide-scale use, about 40% of the global population depends on HBN for meeting nutritional requirements (Crews and Peoples 2004). The convenience of this controlled input is compromised by its efficiency inconsistencies and environmental effects.

**Concerns with HBN**

While fertilizers have contributed to increases in global food production, there are still concerns regarding its promotion and large-scale use. Many producers find the reliability of fertilizer N content convenient, but increases in both its production costs and demand have led to accessibility issues. Also, the unreliability of actual N availability to the crop has lead to some cropping practices that are undesirable—such as purposely applying fertilizer in excess to insure adequate recovery by the crop, called “insurance N” (Mosier et al. 2004). The quantity of N used by a producer is not usually influenced by external factors such as pollution, which can lead to unforeseen issues in the future.

One of the dominant issues with fertilizer is its association with fossil fuel availability and price. On average, nutrient inputs comprise approximately a quarter of production variable costs (Gareau 2004), which was $157 per acre between 1997 and 2001 for corn (Foreman 2006). The cost of fertilizer is the highest single percentage of operating costs (Foreman 2006) and the price of fertilizer is dependent upon energy prices (Bohlool et al. 1992). Increasing populations and energy demands have resulted in a marked strain on fossil fuel stocks (Crews and Peoples 2004), with the price index for crude oil rising over 500% since 1992 (ERS 2008). This close association between farm operating costs and fuel costs is not desirable in a time of fossil fuel stock instability.

In addition to the undesirable economic effects of fossil fuel reliance, HBN products also have generally low fertilizer recovery, or N used per unit applied, which implies an increase in N losses. After decades of research on corn fertilizer recovery improvement through best management practices, farm trials have still reported low values with only marginal improvements. For example, despite a 14% increase in fertilizer recovery between 1980 and 2000, fertilizer N use is still cited at below 50% (Mosier et al. 2004). While some of the unused N can be stored within the soil, a significant portion can leave the cropping system through volatilization or leaching (Cassman et al. 2002).

The amount of N leached from cropland has tripled over the span of thirty years because of over-fertilization and increased production (Crews and Peoples 2004). Fertilizer production introduces quadruple the amount of reactive N that is created by fossil fuel combustion (Howarth et al. 2002), half of which is transported to non-agricultural ecosystems through leaching, atmospheric deposition, and runoff (Mosier et al. 2004). Currently, nitrate groundwater contamination has been confirmed in thirty-one states and it is suspected of another six (Tollenaar and Wu 1999). In addition to contaminating groundwater supplies, leaching leads to acidification of soil and eutrophication of coastal waters (Sylvia et al. 2005). It is estimated that two-thirds of the United States' coastal waters have anoxic conditions due to eutrophication (Howarth et al. 2002). The excess N being introduced to forests, coastal waters, and the atmosphere also may have unforeseen negative effects, which encourages initiatives including alternative fertility management strategies.

**Legume Fertility**

Legumes are frequently used in organic and low-input systems as a source of N and OM (Peoples and Craswell 1992). Biologically-fixed N (BFN) currently accounts for twenty percent of the total N used on cropland (Clark et al. 1995). Under ideal management, legumes can potentially contribute 200 kg N $ha^{-1}$ $yr^{-1}$, but that is dependent upon the species, soil properties, and climatic conditions (Ledgard 2001). Some agronomists suggest that legume N production could not be extensive enough to replace fertilizer N (Crews and Peoples 2004), but it has been found that diverse nutrient sources actually improve NUE (Mosier et al. 2004). Therefore, although legumes may not provide the quantity of N offered by HBN fertilizers, it is possible that less BFN is lost from the system, allowing the crop to benefit from a comparable amount of N. In addition to the potential efficiency benefits, there are distinct economic and environmental advantages to using a legume winter cover crop as a green manure.

Legumes must be correctly managed in order for the economic benefits of their utilization to become apparent. For example, inoculation, soil pH regulation, and phosphorus amendments have been shown to aid in legume N production and successive crop NUE (Crews and Peoples 2004). Under proper management, Drinkwater et al. (1998) found that the economic profitability of a BFN fertilized corn system is comparable to that of HBN fertilized or manure. A 2005 review of legume versus fertilizer N sources found similar results (Crews and Peoples 2005). In addition, legume seed makes up a relatively small percentage of variable operating costs—about two percent (Gareau 2004). This means that fluctuations in its cost are not as detrimental to the producer when compared to fertilizer price variation. If environmental externalities are also considered, legumes are a very profitable investment for many cropping systems.

Legumes have been used throughout history to improve soil quality and boost yields. The legume residue replenishes the mineralizable N pool in the soil (Mosier et al. 2004), which is hypothesized to encourage high NUE because the OM acts as a bank of N that is released in moist, warm conditions (Cassman et al. 2002)—conditions that are also favorable for plant growth, when the nutrients are most needed. Despite being considered an "uncontrolled input," organic systems using BFN have not been found to have great variability in yields due to this constant cycling of OM by microbial processes (Ledgard 2001). In addition to increasing crop NUE, legumes can reduce common crop issues through the following mechanisms: allelopathic effects on the weed seedbank, interruption of pest or disease cycles, and elevated microbial activity (Peoples and Craswell 1992). Also, the mulch-like cover that green manures can provide has a positive effect on soil moisture conservation (Clark et al. 1995). These benefits are contingent upon proper management, however. When a green manure is applied, the pattern and quantity of N release is questionable—BFN, like HBN, can be lost in large amounts depending on management and field conditions.

**Concerns with BFN**

Legume-based fertility offers increased organic matter, greater microbial activity, and soil water retention—all of which contribute to high yields and soil health. The increased storage of N within the SOM fraction, however, can leave a pool of N vulnerable to loss. If N is provided in excess of crop needs, whether mineralized from organic residues or directly applied in inorganic forms, it is vulnerable to loss (Rosecrance et al. 2000, Crews and Peoples 2005, Baggs et al. 2000).

A cited benefit of using green manures is the increase in OM accumulation under no-till management (Burke 2002). In addition to the accumulation of OM, more BFN is sequestered in OM than HBN (Drinkwater 1998). This coupling of carbon and BFN creates dependence between BFN release and OM decomposition (Groffman et al. 1987). The introduction of fresh residue increases the abundance and activity of soil macro fauna, which then graze on the high quality residues—increasing the availability of organic N (Rosswall 1984, Shuster et al. 2002). When N enriched OM is decomposed, there is a release of the stored N in both mineral and organic forms—both of which are vulnerable for loss if the timing is not in sync with crop needs (Evans et al. 2004).

Mitigating N loss and inefficiency can be problematic when exact inputs and movements of BFN are dependent on many factors and largely unpredictable. For example, Cherr et al. (2006a) reported a green manure nitrogen contribution of 115 kg $ha^{-1}$ in 2002 but only 44 kg $ha^{-1}$ in 2003. Another study reported N fixation differences in the order of 20 times between wet and dry years (Ledgard 2001). These differences are largely due to the impact of rainfall and temperature on the growth of the green manure (Peoples and Craswell 1992), but there can be differences even within similar years (Groffman et al. 1987). The release pathway of BFN further complicates the prediction of its release—it must be cycled through microbial biomass.

Researchers have tested multiple biochemical quality components as indicators for rate and decomposition, but the N release characteristics are dependent on the stage of decomposition and residue type (Bending et al 1998).

The underlying issue is an unneeded stock of inorganic N accumulating within the soil profile (Crews and Peoples 2004). This is considered asynchrony: a mismatch in timing between N supply and N demand (Grandy 2006). Most N losses can be attributed to asynchrony (Crews and Peoples 2004), which can be in the form of over fertilization or N mineralization in excess of what is expected—when the crop does not have the capacity to utilize all of the provided N (Mosier et al. 2004). Synchrony can be enhanced through several management techniques, which leads to improved efficiency and maximized yields (Sainju et al. 2007).

**Synchrony and N loss**

Research has conflicting results in regard to the levels of N losses between HBN and BFN (Mosier et al. 2004), but it is a common theme that N loss occurs when the size of the plant available N pool exceeds crop N uptake, regardless of the N origin (Cassman et al. 2002). The greatest N losses are typically during time periods when crop demand is absent or very low: late fall, early spring, and winter (Crews and Peoples 2004, Drinkwater et al. 1998). Synchrony can be defined as the optimization of timing between N supply and N demand. If N supply and demand coincide in the cropping system, NUE is much greater and N loss is reduced. In terms of a green manure, N supply is based on both the quantity and release pattern of the N. The N demand of the subsequent crop is generally dependent upon growth stage requirements (Gastal and Lemaire 2002). Previous studies have found that the quantity and release pattern of N, as well as the growth stage timing, can be manipulated through the termination and planting dates, respectively.

Researchers have manipulated N release timing by double-cropping the legume with a cereal grain, adding high carbon material to green manure residue, or altering the termination date of the legume (Crews and Peoples 2005). These practices modify the C/N ratio of the residue, which alters the amount of N released and the rate of release. The first two methods, however, can lead to a C/N ratio exceeding a critical point, which causes immobilization to exceed mineralization—depressing N supply and yields. While delaying the termination date could increase the C/N ratio of the residue, the overall N contribution to the subsequent crop is greater due to the greater biomass available (Wagger 1989). This author reported greater corn growth and higher yields under a hairy vetch terminated later, compared to an earlier date. The termination date in this study had a corresponding corn planting date, and the effect of planting date on N uptake cannot be ignored when discussing synchrony.

The effect of planting date on N uptake is largely dependent on temperature and its effect on growing degree day (GDD) accumulation. Corn has certain periods of rapid growth associated with growth stages, during which N uptake is accelerated (Bockman 1990). Growing degree days, units of time based on thermal conditions, can be used to estimate growth stage progression (Russelle et al. 1984). The basis of GDD calculation is a minimum and maximum air temperature that is favorable to crop growth (Hoeft et al. 2000), which means that days vary in their GDD content depending on temperature fluctuations. In addition, Nielson et al. (2002) and Russelle et al. (1984) found that corn planted later required less GDDs in order to reach certain critical growth stages, such as V6. This would affect the timing of crop N uptake throughout the growing season.

The integrative effect of delaying the winter cover crop termination date of hairy vetch, which alters decomposition factors, and the subsequent delay in corn planting date, which alters plant N uptake, could improve the synchrony of a legume fertility system. The objectives of this study were to determine the effects of termination date on (1) hairy vetch biomass and N content and (2) soil N content, and the effects of corn planting date on (1) corn biomass accumulation and (2) corn N uptake. In addition, the combined effects of termination/planting date on corn grain yields and N loss susceptibility were evaluated. In our research, we hypothesize that synchrony can be improved by manipulating the termination date of a hairy vetch (*Vicia villosa*) cover crop and the sowing date of the succeeding corn (*Zea mays*) crop. This will regulate the quality and quantity of the N in the vetch, the rate of N mineralization from the vetch residues, and the relative rate of N uptake in the corn.

# Chapter 2

## Materials and Methods

### Field History

The field experiment was located at Russell E. Larson Agricultural Research Center in Rocks Springs, PA. The vetch (*Vicia Villosa* Roth) treatments were established in July and August of 2006 as a randomized complete block design with four replicates on a well drained, Hagerstown silt loam, which is expected to support yields of approximately 9400 kg $ha^{-1}$ (Duiker 2007). The northern half of the site is under a 0 to 3% slope, whereas the southern half has a 3 to 8% slope. The site was managed under no-till for one year before the vetch was no-till seeded into barley that been harvested in June of 2006. The vetch was established on three different days at two possible seedling rates—originally as a part of a vetch planting date/rate study. The original study was aborted, with the plots' purpose redirected to the synchrony experiment. Aboveground biomass samples were taken for all vetch plots on April 30, 2006, in order to ascertain if the seedling rate/planting date treatments produced significantly different vetch stands after overwintering. Analysis of variance showed that spring vetch biomass was not significantly affected by the different treatments at the 0.05 probability level. A subset of plots for this experiment was selected from the original experiment based on similar vetch biomass levels in early May of 2007. A limited number of non-vetch plots were interspersed within the vetch plots and were used as inorganic N fertilizer reference plots.

**Experimental Design and Implementation**

Twelve treatments, replicated four times, were established in order to study the synchrony of legume fertility management. The four replicates were blocked in order to account for field variability in soil properties and topography. Two blocks, treatments arranged within each block from west to east, were placed on the north half of the field and the other two blocks, also arranged west to east, were placed on the south half of the field. The subset of vetch plots that were chosen for this experiment, each measuring 63 $m^2$ (13.7 m by 4.6 m) , were randomized within each block and for each of the three vetch treatments, one fallow plot was chosen as a control. The control for each vetch treatment consisted of the three fertilizer levels, which necessitated one plot to be split into three 14 $m^2$ (3 m by 4.6 m) subplots. The three fertilizer levels, all using ammonium nitrate ($NH_4NO_3$), were a 0 N addition, 84 kg N $ha^{-1}$ side-dress, and 168 kg N $ha^{-1}$ side-dress, and the side-dress was applied just prior to the V6 corn growth stage. The corn planting dates, and corresponding vetch termination dates, were May 4$^{th}$, May 15$^{th}$, and May 31$^{st}$ of 2007. The corn variety chosen was DKC42-95, which is a Roundup Ready$^{TM}$ variety with Bt protection. This short season variety requires a growing season of approximately 2320 GDD, which meant it could fit the range of planting dates chosen. The corn was planted into either live vetch or bare plots in 30 inch rows with a John Deere 1780 no-till planter. The seeding rate was approximately 29,000 plants per acre, with the expectation of 5-10% failed germination.

The vetch for each planting date was terminated two to four days after corn planting, meaning that the vetch for each corn planting date was killed at a different growth stage, biomass level, and climatic environment. The vetch was terminated with an herbicide mixture of 0.28 kg a.i. 2,4-D $ha^{-1}$ and 1.12 kg a.i. Glyphosate $ha^{-1}$, which was applied at a rate of 187 L $ha^{-1}$. At the time of vetch termination, no corn had emerged in any treatment. On May 4$^{th}$, 30 lbs $P_2O_5$ and 120 lbs $K_2O$ per acre were broadcast over all treatments, and no additional nutrient applications were made. The N side-dress was hand-broadcasted to the first planting date plots on May 30th, second planting date plots on June 7th, and to the third planting date plots on June 21st—the corn plants were between V2 and V4 growth stage at the point of application. All plots were sprayed with the aforementioned herbicide mixture, at the same rate, on July 1st to reduce weed pressure. Plant biomass and soil cores were sampled throughout the growing season in order to follow the patterns of nitrogen release and uptake.

## Sample Collection and Analysis

### *Hairy Vetch Biomass and Nitrogen Content*

The April 30th vetch collection and collections on May 14th and 29th were used to determine dry biomass and N content of the vetch before termination. Two composite samples of vetch were taken per plot using a sickle—the plants were cut flush to the soil from within a one square foot area. The biomass was dried at 55°C for at least 48 hours, and ground to 0.5mm on a Wiley Mill. Combustion analysis was performed on a LECO-CHNS elemental analyzer to quantify the total C and total N concentration of the tissues. The vetch was also processed using the Post Harvest Stalk $NO_3^-$ Test in order to determine its $NO_3^-$ and $NH_4^+$ content.

### *Inorganic Soil Nitrogen*

Soil samples were taken on May 3rd, 14th, and 29th in order to determine baseline soil N concentrations before vetch termination. The soil was then sampled weekly in May and June, bimonthly in July and August, and once in September and November. Six composite samples were collected per plot at the 0-15 cm and 15-30 cm depths, and three composite samples were collected at the 30-60 cm depth. The soil was processed according to the 2M KCl method for $NH_3^+$/$NO_3^-$ (Keeney and Nelson 1982) and analyzed using automated colorimetric procedures

(Lachat Instruments 2003). The preplant and post harvest soil samples were processed on a LECO-CHNS for total C and total N. In addition, potentially mineralizable N (PMN) was determined for the vetch treatments and 0 N controls through the aerobic laboratory incubation method (Hart et al. 1994). For this test, six composite samples of the top 3 cm of the soil were collected on December 19, 2007.

*Corn Biomass Accumulation and Grain Yield*

Aboveground biomass of corn from each vetch treatment was collected approximately one month after their respective planting dates. Five plants were sampled from the plots every 10 days in order to track the growth and N uptake of the plant. The control plots were sampled once a month, two plants per plot. The corn biomass was treated in the same manner as the vetch biomass for processing and analysis. An area of 8 $m^2$ was harvested in November from the vetch treatments and 10 plants were collected from the fertilizer treatments—the ears were separated and their biomass was corrected to 15.5% moisture in order to determine yield.

## Data Analysis

The statistical analysis for this study was performed with SAS software (2003), version 9.1 of the SAS System for Microsoft. The vetch biomass, vetch total N content, vetch inorganic N concentration, corn population, and grain yield data were analyzed using Fischer's Least Significant Difference test in order to determine treatment differences.

The soil inorganic N content in the vetch treatments, separated by depth to avoid unbalanced data, was tested with the Analysis of Repeated Measures in the MIXED procedure. Planting date, N source/rate, sample date, and their interactions were considered fixed effects and replication was considered a random effect. The differences of the Least Squared Means were compared for each planting date at each date.

The corn N content throughout the growing season was divided into the following GDD categories (calculated and accumulated from each planting date): 400-600, 600-800, 1000-1200, 1200-1400, 1800-2000, and greater than 2000. The GDD categories were treated as time points within the growing season. N flux rates were calculated using the corn N content over time data, according to the procedure outlined in Lynch and White (1992). The linear interpolation was performed in SigmaPlot, using a cubic spline interpolation program. The corn N content and flux rates were analyzed using the MIXED procedure of SAS. Statistical significance was based on a probability level of 0.05 for each analysis.

# Chapter 3

# Results

## Vetch Biomass and N Content

The vetch aboveground biomass at termination differed significantly between the three treatments. The May 15$^{th}$ vetch treatments' biomass was almost triple that of the May 4$^{th}$ treatments' and the May 31$^{st}$ treatments had more than quadruple the May 4$^{th}$ biomass. The vetch terminated on May 31$^{st}$ had accumulated approximately 1.5 times more biomass than the vetch terminated on May 15$^{th}$ (Figure **3-1**).

Based on visual observations, the vetch biomass differences at the three termination dates affected the ground cover provided by the crop. The first termination date was at an early stage of biomass accumulation after spring growth initiation, without complete ground coverage. By the May 14$^{th}$ vetch termination date, the vetch was still in the vegetative growth phase but had full ground cover. The vetch terminated on the last date was between thirty to fifty percent flowering and the vetch stand was very dense.

The differences in vegetative growth stage and biomass at termination were not reflected in the N concentration, inorganic N fraction, or C/N ratio of the vetch residues. The average N concentration of the vetch residue at the three termination dates was approximately 4%, putting the potential N contribution for the three termination dates at 60.7, 210.5, and 304.9 kg ha$^{-1}$, from earliest to latest date, respectively.

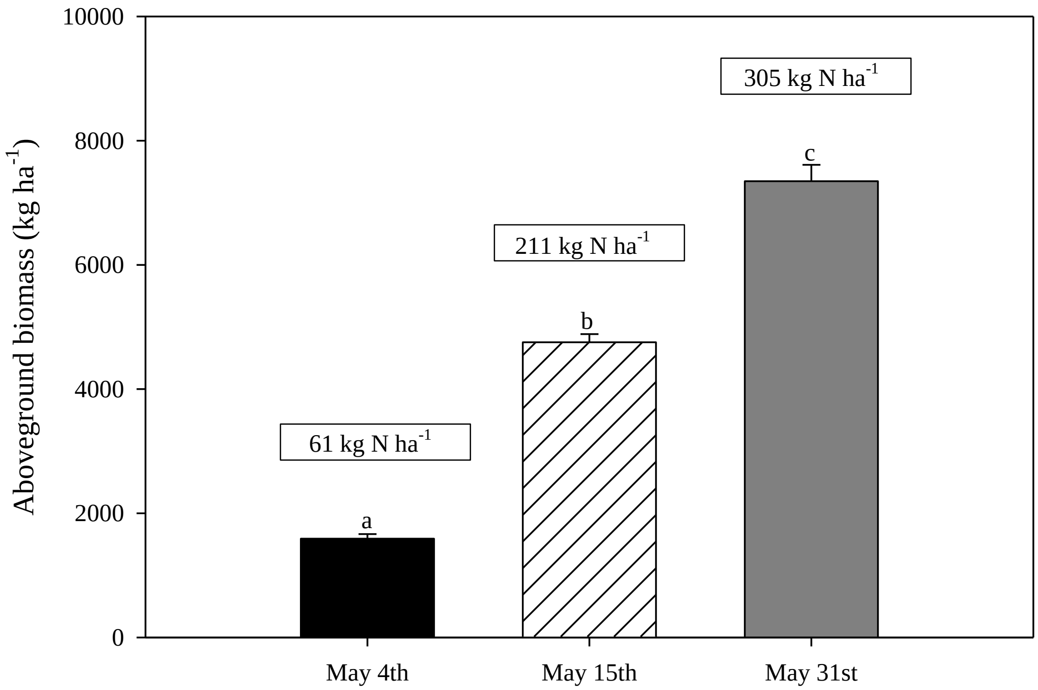


Figure **3-1**: Average vetch aboveground biomass for the three treatments (May 4th, May 15th, May 31st) and the average N content of the residues (kg ha$^{-1}$) based on the 4% N concentration in the vetch tissue.

Bars with different letter designation are significantly different at $P = 0.05$; bars with the same letter designation are not significantly different.

**Soil N Content**

There were significant differences in soil inorganic N ($NO_3^- + NH_4^+$), depending on planting and/or sampling date, or their interaction (Table **3-1**). The general trend in the top fifteen centimeters was a release of approximately 10 to 15 kg ha$^{-1}$ immediately after termination, followed by a large flush over the period of four weeks, tapering off into low quantities (Figure 3-2). The inorganic N availability in the May 4$^{th}$ and May 15$^{th}$ planting date vetch treatments was similar throughout most of the growing season, but there were differences between the three planting date vetch treatments at certain points in the growing season (Table **3-2**).

Specifically, the quantity of inorganic N found in the top 15 cm of the vetch treatments was significantly different on three dates: May 31$^{st}$, June 26$^{th}$, and July 5$^{th}$. On only the second of those three dates were the May 4$^{th}$ and May 15$^{th}$ treatments significantly different from each other—those treatments were not found to be different from each other, but from the May 31$^{st}$ treatment on the other two dates. The first date of difference, May 31$^{st}$, was post-vetch termination for the May 4$^{th}$ and May 15$^{th}$ treatments and pre-vetch termination for the May 31$^{st}$ treatment. The second date of difference was the peak soil inorganic N content for the May 15$^{th}$ and May 31$^{st}$ treatments, which was one week after the May 4$^{th}$ treatment's peak N availability. The peaks for the May 15$^{th}$ and May 31$^{st}$ treatments were 59 and 78 kg N ha$^{-1}$, respectively, while the May 4$^{th}$ treatment reached a peak of 53 kg N ha$^{-1}$. The May 31$^{st}$ treatment continued to have a significantly greater inorganic N content, when compared to the other two treatments, a week later on July 5$^{th}$. The three treatments then followed a similar pattern of decreasing soil inorganic N content over time. The last sampling event, November 30$^{th}$, which was post-corn harvest, showed very low inorganic N values—with many plots containing none. PMN results showed less than 12 kg N $ha^{-1}$ mineralized after the incubation for the three vetch treatments, which had results that were similar to each other and to the 0 N control (Figure **3-3**).

The pattern of inorganic N availability was similar in the second sampling depth, 15 to 30 centimeters (Figure **3-4a**). The May $31^{st}$ treatment had significantly lower quantities of N available, compared to the May $4^{th}$ and May $15^{th}$ treatments, on one date, but the overall N availability over time was not significantly different for the three vetch treatments.

The deepest sampling depth, 30 to 60 centimeters, showed a different pattern of inorganic N content compared to the other depths, and the N content in the soil was not affected by treatment. The three treatments did not different in the quantity of N available on any given date or in the pattern of release (Figure **3-4b**). There were, however, significantly higher quantities of inorganic N present in early September compared to the preceding months.

Table 3-1: Summary of statistical significance for 2007 soil inorganic N content at three depths.

| Source | d.f. | Soil depth | | |
|---|---|---|---|---|
| | | 0-15 cm | 15-30 cm | 30-60 cm |
| | | | p-value | |
| Planting date (PD) | 2 | 0.9769 | 0.0023 | 0.8547 |
| Sampling date (SD) | 13 | <0.0001 | <0.0001 | <0.0001 |
| PD x SD | 22 | 0.0033 | 0.3017 | 0.9970 |
| Residual | | 151.22 | 11.85 | 3.62 |

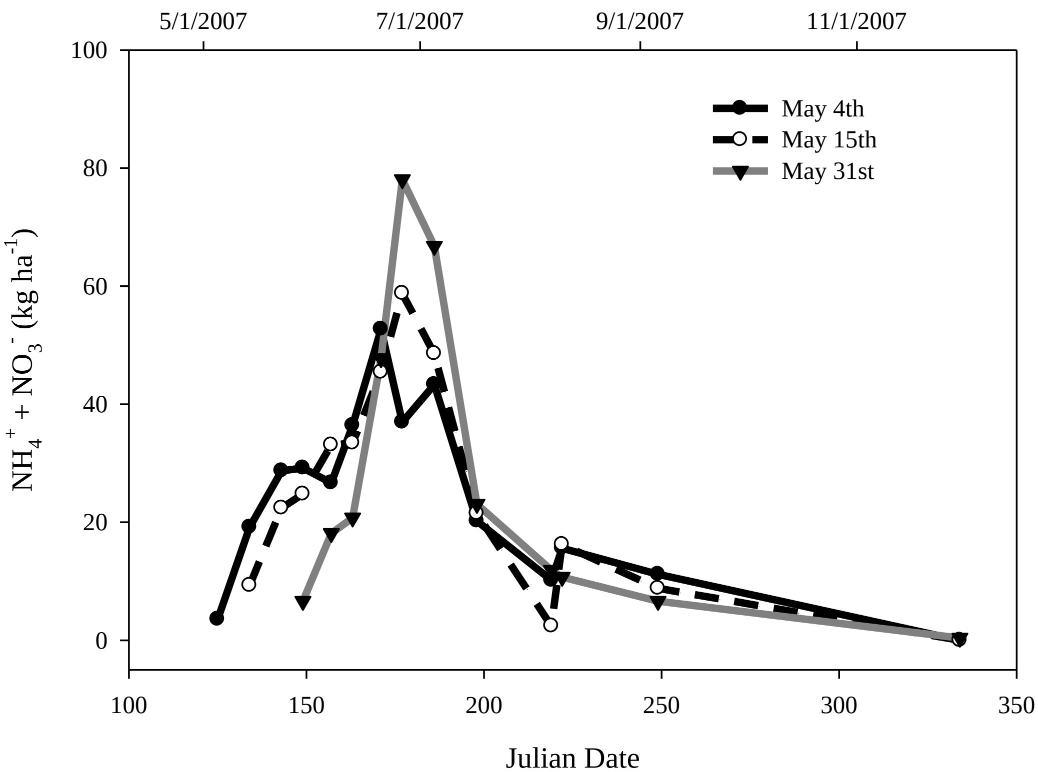


Figure 3-2: Average soil inorganic N content of the top 15 cm, pre-planting to post-harvest, for the three vetch treatments (May 4$^{th}$, May 15$^{th}$, May 31$^{st}$).

Table 3-2: Summary of statistical significance for 2007 average soil inorganic N content of the three vetch treatments at three sampling dates from 0-15cm.

| Planting date | Sample Date | | |
|---|---|---|---|
| | May 29th | July 5th | November 30th |
| | ----------------------- kg ha$^{-1}$ ----------------------- | | |
| May 4th | 29 | 43 | 0 |
| May 15th | 25 | 49 | 0 |
| May 31st | 7 | 67 | 0 |
| | LSD or level of significance | | |
| **May 4th x May 15th** | NS | NS | NS |
| **May 4th x May 31st** | * | * | NS |
| **May 15th x May 31st** | * | * | NS |

* Significant at the 0.05 level of probability

NS Not significant at the 0.05 level of probability

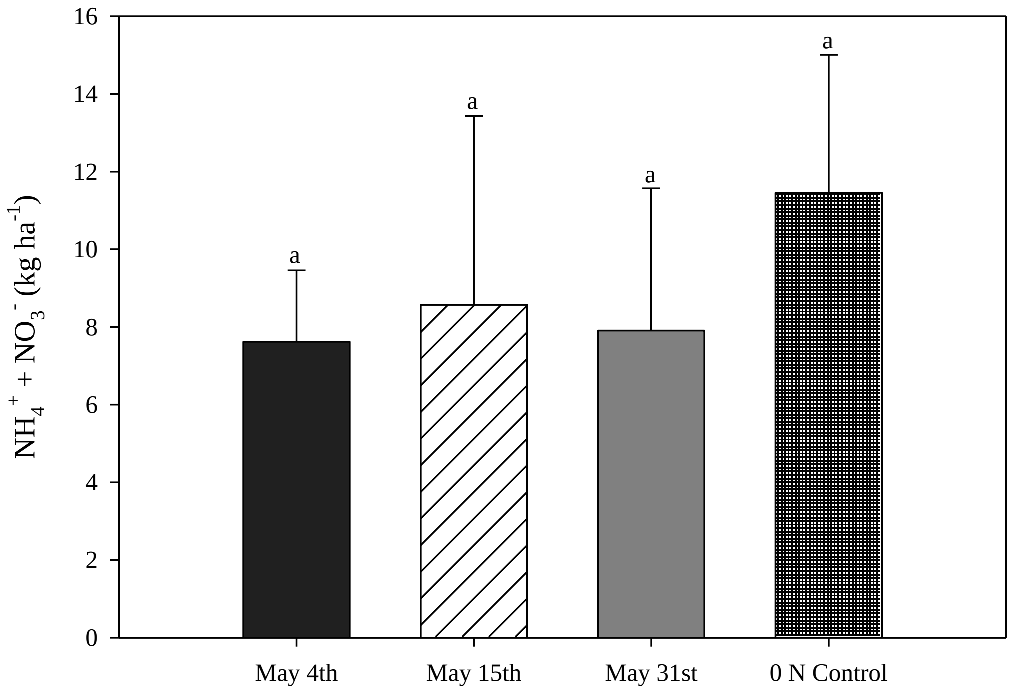


Figure 3-3: Average PMN for the three vetch treatments (May 4th, May 15th, May 31st) and the 0 N control.

Bars with different letter designation are significantly different at $P = 0.05$; bars with the same letter designation are not significantly different.

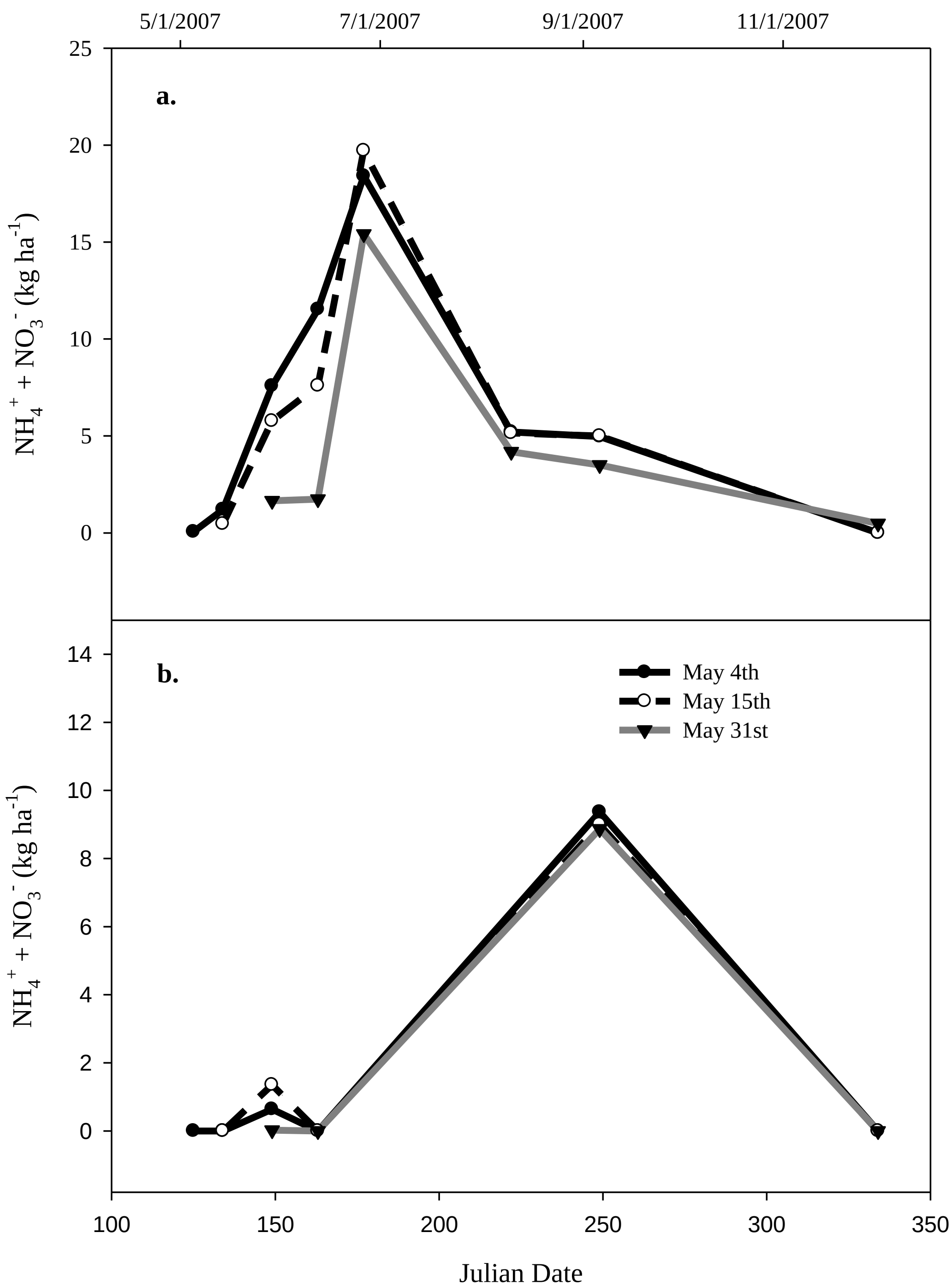


Figure 3-4: Average soil inorganic N content from (a) 15 to 30 cm and (b) 30 to 60 cm, pre-planting to post-harvest, for the three vetch treatments (May 4th, May 15th, May 31st).

**Corn Biomass and N Content**

The corn populations for the three planting dates were not significantly different, with the exception of the corn planted into live vetch on May 31$^{st}$, which had a significantly higher population than the other treatments (Figure **3-5**). Cumulative growing degree days (GDD) were 2800, 2600, and 2400 in the May 4$^{th}$, May 15$^{th}$, and May 31$^{st}$ planting date treatments, respectively (Figure **3-6**). Despite these differences in GDD accumulation, the corn biomass at harvest was similar between the treatments (Figure **3-7**).

The N content of the corn differed significantly between vetch treatments from the emergence to R6 (Table **3-3**). The general trend of N content, in the vetch treatments, was rapid accumulation that peaked mid-season and then dropped to a lower, fairly constant quantity (Figure **3-8**). The peak N content occurred in close timing with the corn's transition into the reproduction growth period, R1, for the three vetch treatments. The total N content at harvest, corn stover plus grain, did not differ between the vetch treatments (Figure **3-9**).

The rate of N uptake also differed significantly between vetch treatments over the course of the growing season (Table **3-4**). The May 15$^{th}$ planting date treatment had the highest initial N accumulation, on June 12$^{th}$, which was significantly greater than the rate of accumulation in the May 4$^{th}$ treatment, but not significantly greater than the May 31$^{st}$ treatment (Figure **3-10**). The average peak N accumulation rates of the three vetch treatments were 4.13, 3.71, and 5.07 kg N ha$^{-1}$ day$^{-1}$ for the May 4$^{th}$, May 15$^{th}$, and May 31$^{st}$ planting dates, respectively. The May 31$^{st}$ vetch treatment's peak N flux rate was significantly greater than the May 4$^{th}$ and May 15$^{th}$ treatments', and occurred one week later. The peaks occurred on July 2$^{nd}$, for the May 4$^{th}$ and May 31$^{st}$ treatments, and July 12$^{th}$, for the May 31$^{st}$ treatment. After the peak accumulation rate, which corresponded to one week after V6, the N flux rates decreased until post-R1 and then maintained a rate close to zero.

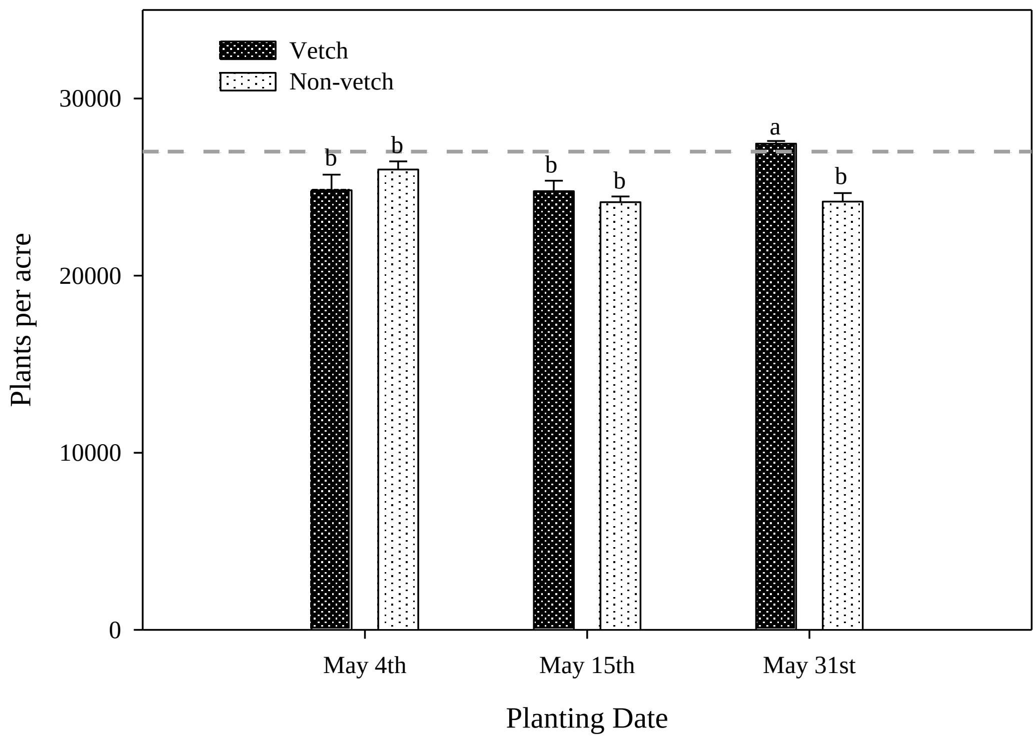


Figure 3-5: Average corn population for the three planting dates (May 4th, May 15th, May 31st) planted into either live vetch or fallow plots. Corn population goal reference line at 27,000 plants per acre.

Bars with different letter designation are significantly different at $P = 0.05$; bars with the same letter designation are not significantly different.

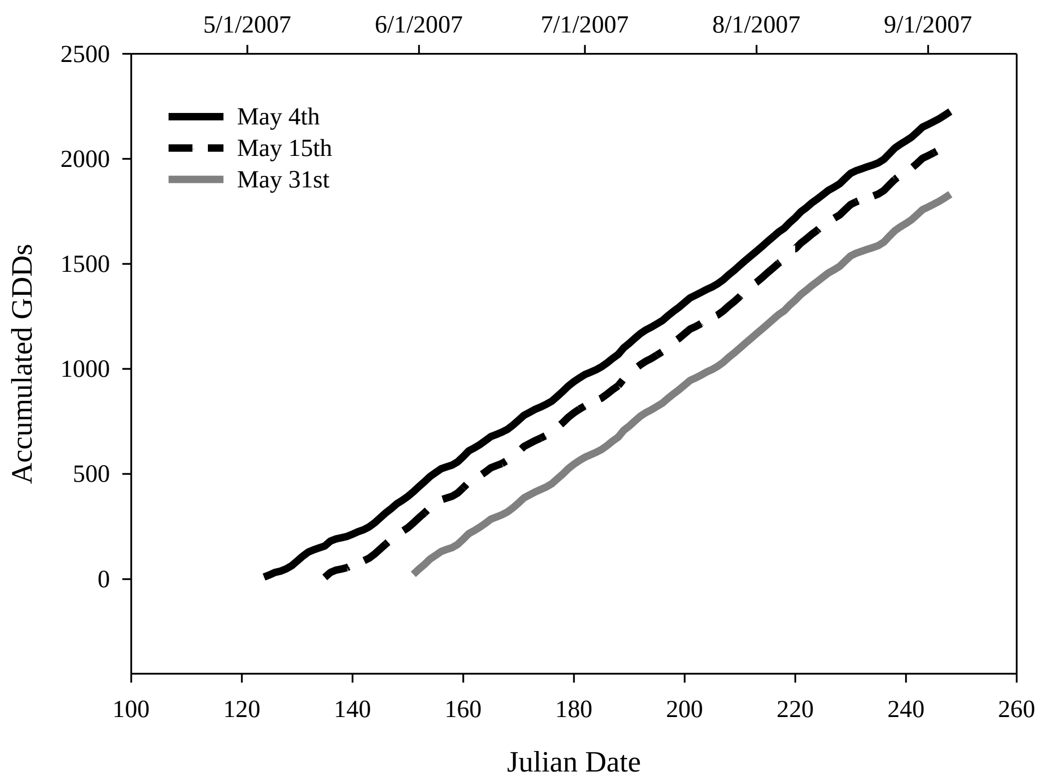


Figure **3-6**: Growing degree days (GDD) accumulated for the three planting dates (May 4$^{th}$, May 15$^{th}$, May 31$^{st}$) from their respective planting date to maturity.

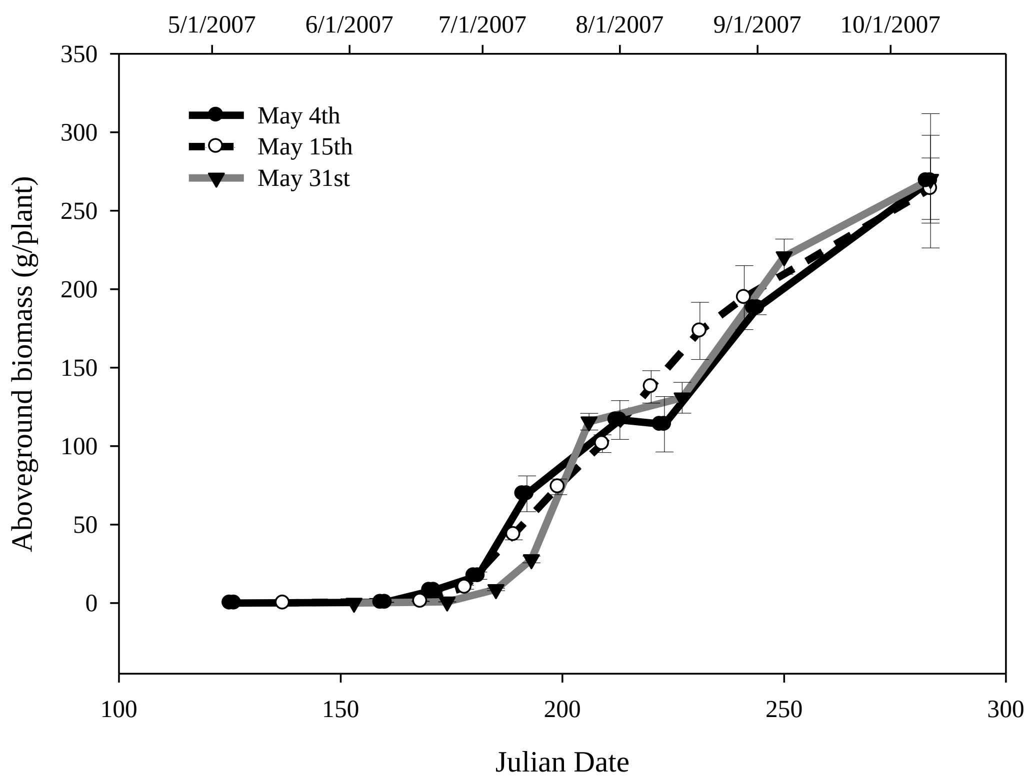


Figure 3-7: Average corn aboveground biomass per plant, from planting to harvest, for the three vetch fertilized treatments (May $4^{th}$, May $15^{th}$, May $31^{st}$).

Table 3-3: Summary of statistical significance for 2007 corn total N content in vetch treatments, from VE to R6.

| Source | d.f. | p-value |
|---|---|---|
| Planting date (PD) | 2 | <0.0001 |
| GDD Accumulation (GDD) | 5 | <0.0001 |
| PD x GDD | 10 | 0.0152 |
| Residual | | 0.9976 |

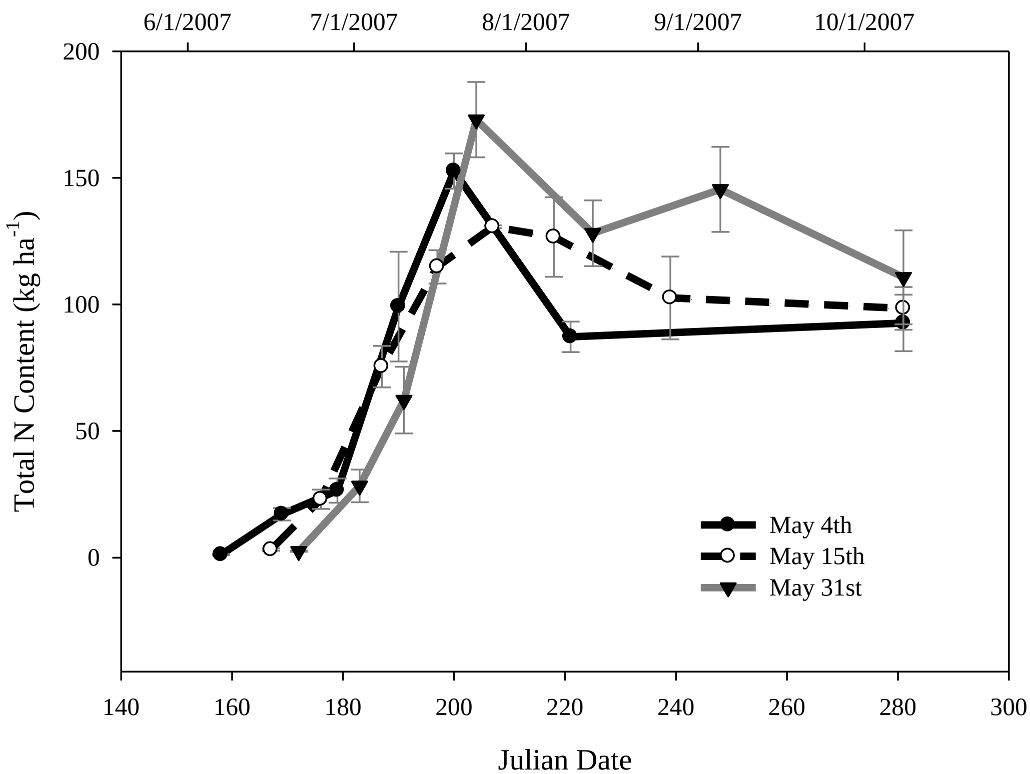


Figure 3-8: Average corn total N content for the three vetch treatments (May 4$^{th}$, May 15$^{th}$, May 31$^{st}$) throughout the growing season.

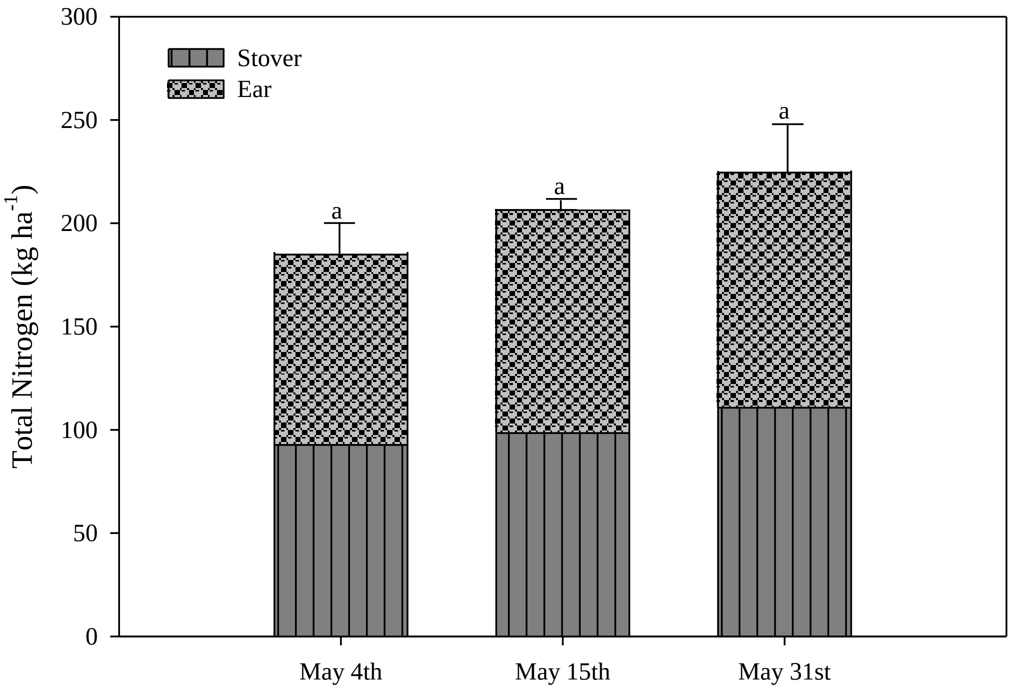


Figure **3-9**: Average total corn N content for the three vetch treatments (May 4th, May 15th, May 31st) at harvest (October 8, 2007). N content of ear calculated based on 1.29% N concentration, as found in a study by Karlen et al. (1988).

Bars with different letter designation are significantly different at $P = 0.05$; bars with the same letter designation are not significantly different.

Table 3-4: Summary of statistical significance for 2007 corn N flux in the vetch treatments.

| Source | d.f. | p-value |
|---|---|---|
| Planting date (PD) | 2 | 0.1088 |
| Time (T) | 12 | <0.0001 |
| PD x T | 24 | <0.0001 |
| Residual | | 0.4319 |

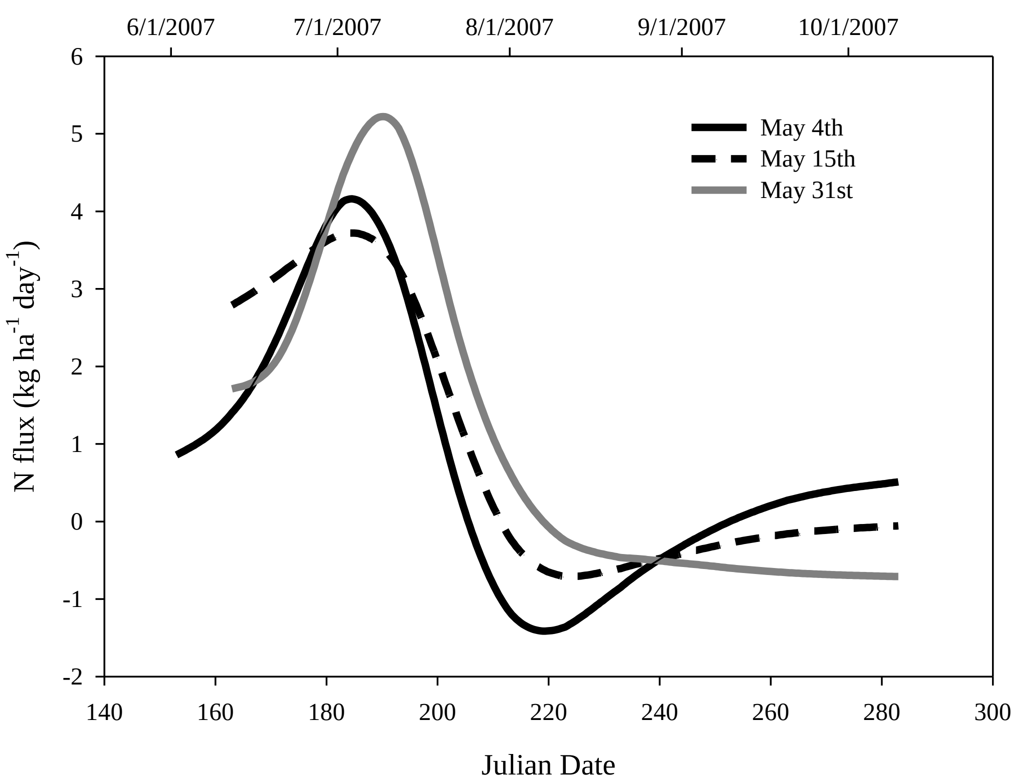


Figure 3-10: N flux in corn for the vetch treatments (May 4$^{th}$, May 15$^{th}$, May 31$^{st}$) from one month after their respective planting date to harvest.

**Grain Yield**

The corn yields for the vetch treatments and HBN-fertilized plots were compared separately due to differences in plot sizes and sampling techniques. The vetch treatments had similar yields, which were comparable to the 168 kg N $ha^{-1}$ and 84 kg N $ha^{-1}$ treatments' yields (Figure **3-12**). In general, the May 4$^{th}$ treatments had lower yields than the May 15$^{th}$ and May 31$^{st}$ treatments, although the difference was not always statistically significant.

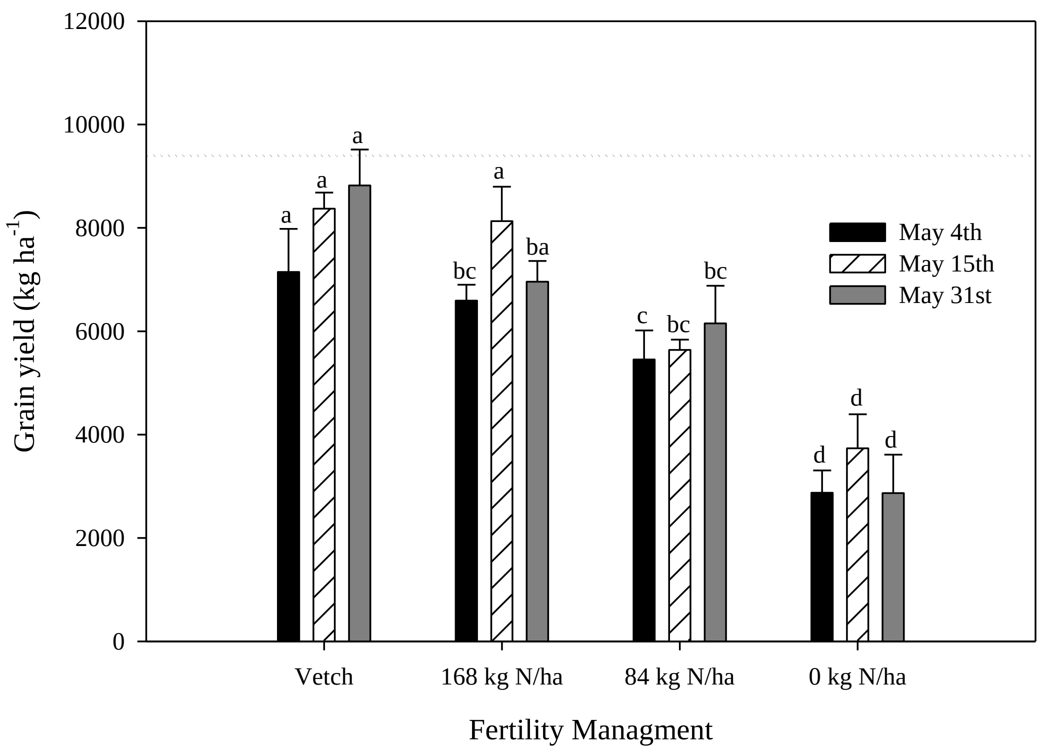


Figure **3-11**: Average corn grain yield for the three planting dates (May 4$^{th}$, May 15$^{th}$, May 31$^{st}$) under each N amendment level. Corn production capability reference line provided for Hagerstown soil type (Duiker 2007).

Bars with different letter designation are significantly different at $P = 0.05$; bars with the same letter designation are not significantly different. Vetch and HBN treatments yields were analyzed separately.

**Chapter 4**

## Discussion

The manipulation of vetch termination date and corn sowing date did affect the synchrony of vetch N release and corn N uptake. The vetch biomass and N content, soil N availability patterns, corn biomass accumulation, and corn N uptake differed significantly among the three planting dates. Corn yield, however, was not significantly different between planting dates. As such, treatments with the greatest quantity of N available in the soil, without subsequently higher yields, could be considered to have poor N uptake synchrony. The ideal treatment would have low levels of soil inorganic N, but high N concentrations in corn tissue and high yields (George et al. 1992).

The delay in vetch termination date had a significant effect on the potential N contribution of the vetch residues, with an increase in biomass of 200% when delayed two weeks and over 300% when delayed four weeks. The May 4$^{th}$ date's average vetch biomass (approximately 1600 kg ha$^{-1}$) was lower than values reported by Clark et al. 1995 and Wagger et al. 1989, who both found biomass levels ranging from 3000 to 4000 kg ha$^{-1}$ in Maryland and North Carolina. The May 4$^{th}$ biomass was also roughly half that of typical values cited in the Penn State Agronomy Guide (2007) for a late April/early May termination date. The vetch growth was initially poor in the early spring, but improved as time progressed, possibly due to increased GDD accumulation (Teasdale et al. 2004). The cooler conditions prevalent during March and April allowed only for slow biomass accumulation, but the later termination dates benefited from warmer May temperatures—leading to the large disparity in biomass between the termination dates. The May 15$^{th}$ termination date had vetch biomass levels that were comparable to the mid-May vetch biomass production found by Clark et al. (1995) and a study in Kentucky conducted by Ebelhar et al. (1984). The May 31$^{st}$ date's average vetch biomass was within the range of values (5,400 to 9,250 kg ha$^{-1}$) found for vetch terminated in the last week of May in a study at the Rodale Institute in Kutztown, PA over five years (Sarrantonio 2003). Based upon the large difference in vetch biomass that can result from a termination delay of even two weeks, it may be necessary to delay corn planting in order to meet its N requirements.

The four week delay between the May 4$^{th}$ and May 31$^{st}$ vetch termination dates also translated into greater potential N contribution, which was due to greater biomass as opposed to higher N concentration in the biomass residues, and consistent with trends reported by Holderbaum et al. 1990 and Wagger et al. 1989. In contrast, however, Clark et al. (1994) and Wagger et al. (1989), did find that the vetch N concentration varied significantly among their termination dates, with a general trend of increasing N concentration as termination was delayed. This discrepancy in N concentration results may be related to the differences in growing season between the study sites. The vetch growing season in Maryland is largely concentrated between April and early May (Clark et al. 1995) and Wagger et al. (1989) reported 25 percent flowering in the first week of May, but vetch growing in Pennsylvania typically flowers in late May or early June (Wilson 2007). In our study, the similarities between termination dates also extended to the C/N ratio and inorganic N content of the residue, which is a soluble fraction thought to be important in the early stages of decomposition (Kuo et al. 1997, Ruffo and Bollero 2003, Trinsoutrot et al. 2000). The lack of differences in C/N ratio and N content and solubility, three typical predictors of N mineralization, explain the similar soil inorganic N availability patterns under the three vetch residues.

There has been considerable variability in reported vetch N release to the soil. Some researchers have reported vetch N release within two to four weeks following termination (Stute and Posner 1995, Ebelhar et al. 1984), whereas others have reported delayed N availability from vetch residues, in some cases until R1 (Crews and Peoples 2005). Our study found peak soil N content coinciding closely with V6. The timing of the peak soil inorganic N content followed closely with the values found in the aforementioned study conducted by the Rodale Institute (Sarrantonio 2003). In general, the late June/early July timing of peak N availability was consistent among the three vetch treatments, regardless of differences in termination date.

Despite the consistency in the timing of peak soil N content and the pattern of its availability, the quantity of N available over the season was significantly different among the vetch treatments. The greater potential N contribution of the May 31$^{st}$ vetch was reflected in the larger quantity of inorganic N at the peak timing in those treatments. This was not true of the May 15$^{th}$ vetch treatments, which had an almost identical trend of inorganic soil N availability compared to the May 4$^{th}$ treatments, despite having a 245% greater total N contribution. The reduced initial inorganic N content could be due to low soil water content and precipitation in the first week following the May 15$^{th}$ vetch termination (George et al. 1992) (Figure **4-1**). This could have been coupled with corn N uptake coinciding closely with the N release, which would reduce the amount of inorganic N found in the soil. The corn N uptake and vetch N contribution, for all treatments, may have been inhibited due to dry conditions in the later summer months (Gastal and Lemaire 2002, Dou et al. 1994). Rock Springs, PA was considered abnormally dry from June 26$^{th}$ until July 17$^{th}$, at which point moderate drought conditions prevailed in until August 21$^{st}$ (National Drought Mitigation Center 2007). A pulse of rainfall in August, however, did not result in a significant release of nitrogen. This would lead one to believe that much of the N provided from mineralization of vetch residues had been previously released or was actively being utilized by the corn. Indeed, the post-harvest values of inorganic N approached zero and the PMN incubations showed that the vetch treatments contributed an average of 10 kg ha$^{-1}$ of inorganic N, which was not significantly different from soil that had not been amended by any N source.

The soil N content decreased rapidly after June 25$^{th}$, which was within a week of the corn V6 growth stage for the three planting dates. Reaching the V6 stage marked the transition into a period of increased corn N uptake, which continued until the corn N accumulation peaked at R1. Whether the soil N available before this period of rapid corn N uptake was susceptible to loss is a question worth asking. In a review on the subject of legume synchrony, Crews and Peoples (2005) identified the time between legume termination and considerable crop N uptake as being the most opportune window of N loss. The May 31$^{st}$ vetch treatments had the risk of losing the greatest quantity of N, with approximately 20 kg ha$^{-1}$ more available soil N compared to the May 4$^{th}$ and May 15$^{th}$ dates before the V6 stage was reached. The greater soil N availability in the May 31$^{st}$ treatments was reflected in the significantly greater N flux rates, but these were after V6 and did not result in greater total N content in the corn residue or significantly higher yields (Figure **4-2**).

In Central PA, producers do not generally delay corn planting due to yield loss concerns related to pest pressure and reduced pollination (Hoeft et al. 2000). These problems are tied to planting date due to its effect on anthesis timing. For example, some insects target late-planted corn because its silking period, typically in late July or August, coincides with feeding, in the case of corn rootworm, or egg-laying, for European corn borer. There is also a risk of silk desiccation if the weather is too hot and dry in those months, which can drastically reduce kernel fertilization. Planting delays do not have a fixed effect on corn development, however, due to the response of GDD to increases in temperature. There is also evidence that corn hybrids, with a varying degree of response, require less GDDs to reach certain critical stages, which may be due to the integrative effect of cooler night temperatures during grain fill and differences in photoperiod (Nielsen et al. 2002). These authors found that if corn planting is delayed into early June, the GDD requirements to reach key stages from planting to R6 decreased by 10%. Our study also found a reduction in required GDDs per stage. The corn planted on May 31$^{st}$ required

327 less GDDs to reach V6 and 127 less to reach R1, when compared to the corn planted on May 4th. The May 14th planting date also required less GDDs to reach the V6 and R1 stages compared to the May 4th planted corn: 220 and 41, respectively. The response is affected by corn hybrid choice, so a later-maturity hybrid may not have such a marked response, when compared to the short season variety used in this study.

The early-maturing variety in this study, chosen in order accommodate the latest planting date, may not be an attractive option to producers due to decreased yield potential. This was reflected in the yield results: the May 4th planted corn had decreased yields regardless of N source and rate. Despite the advantage of a longer growing season, the May 4th did not have greater yields when compared to the May 14th and May 31st yields at an equal N fertilization rate. Clark et al. (1995) found that the late-terminated vetch treatment had significantly greater yields than early-terminated, but concluded that the yield difference was a result of greater soil moisture content under greater vetch biomass rather than the greater N contribution. In addition, the Maryland study did not couple the late terminated vetch with late planted corn—meaning the late planted corn had the advantage of greater vetch N contribution without sacrificing any of the growing season.

In addition to the listed risks associated with a late planted corn crop, the late-terminated vetch had the largest pool of N susceptible to leaching and/or volatilization. When considering the vetch N as the soil N input and the corn stover and grain as the N outputs—the excess N values are -124, +4, and +80 kg N $ha^{-1}$ for the May 4th, May 15th, and May 31st vetch treatments, respectively. If the quantity of N stored in the soil (PMN) is also considered, then the only treatment with a pool of susceptible N is the May 31st vetch treatment—with approximately 70 kg N $ha^{-1}$ at risk. If the level of vetch residue present at the May 31st date was returned the soil consistently, in a long term no-till soil, the quantity of N stored in the soil would increase (Burke et al. 2002, Robertson et al. 2000), thereby increasing the risk of high N losses due to early spring or post-harvest organic matter mineralization (Groffman et al. 1987). This study was conducted on soil that had been tilled relatively recently and intermittently in the past, which could have reduced the size of the indigenous N pool (Drinkwater et al. 2000) and, therefore, early spring and fall N mineralization.

Our study showed that vetch termination date did affect the vetch biomass level and N content, as well as the quantity of inorganic N available in the soil. In addition, the corn planting date affected the corn development and corn N uptake dynamics. Taken together, the vetch termination date and corn planting date did not have an effect on yield, but they did affect the synchrony of the system. A comparison of inputs and outputs in the May 4$^{th}$ vetch treatment suggest that the corn growth relied heavily upon mineralization of soil OM for N uptake, which could have an adverse effect on soil quality in the future (Addiscott et al. 2005). The May 14$^{th}$ vetch treatment, however, had a large enough vetch N contribution to support the corn growth. The treatment had increased N uptake with a reduced quantity of susceptible N and similar yields when compared to the May 31$^{st}$ vetch treatment, which had 45% greater vetch N contribution. The two week vetch termination delay appeared to benefit the corn growth without threatening soil quality or yield potential.

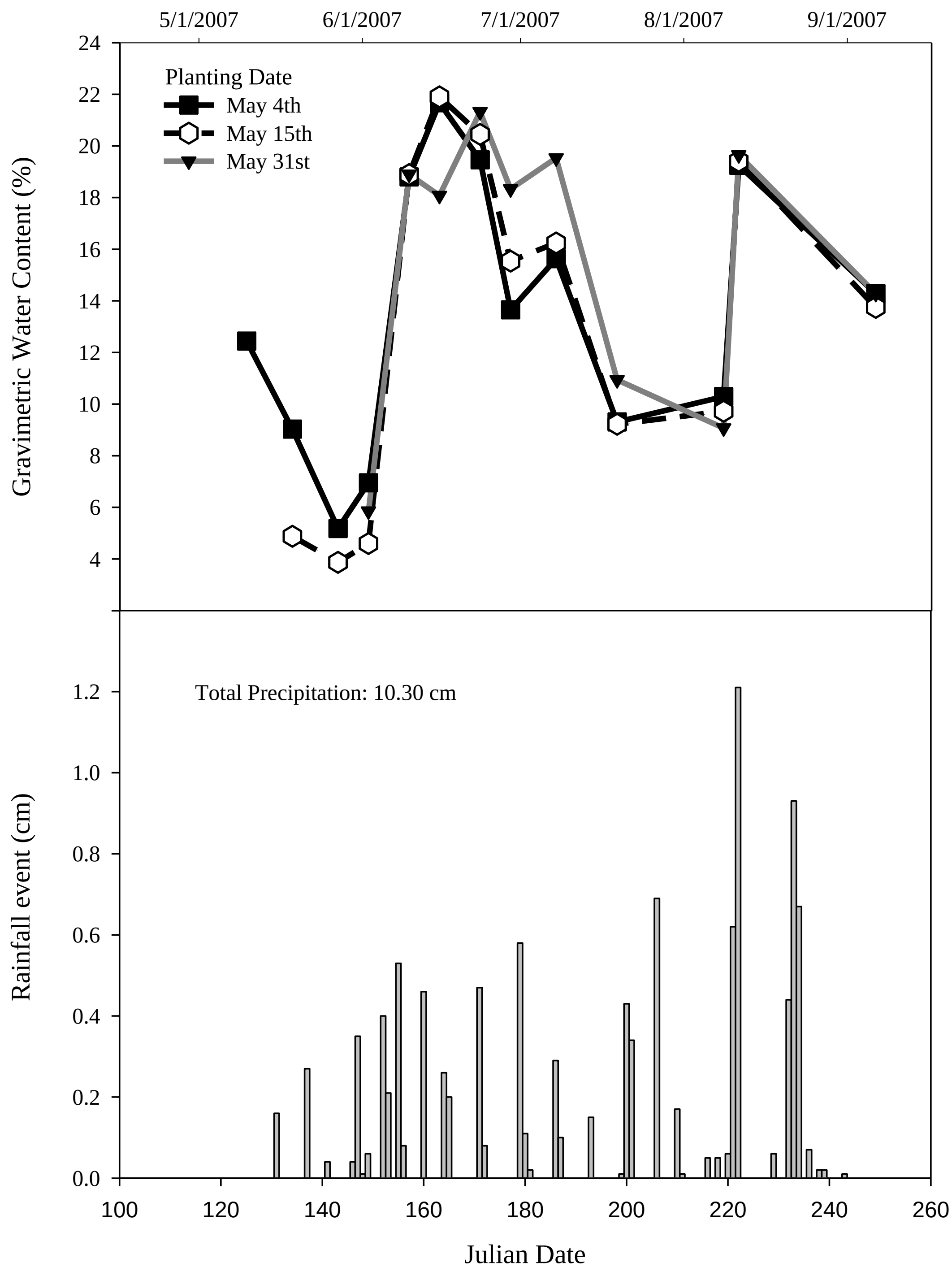


Figure **4-1**: Average gravimetric water content for the three vetch treatments (May $4^{th}$, May $15^{th}$, May $31^{st}$) and the precipitation throughout the growing season.

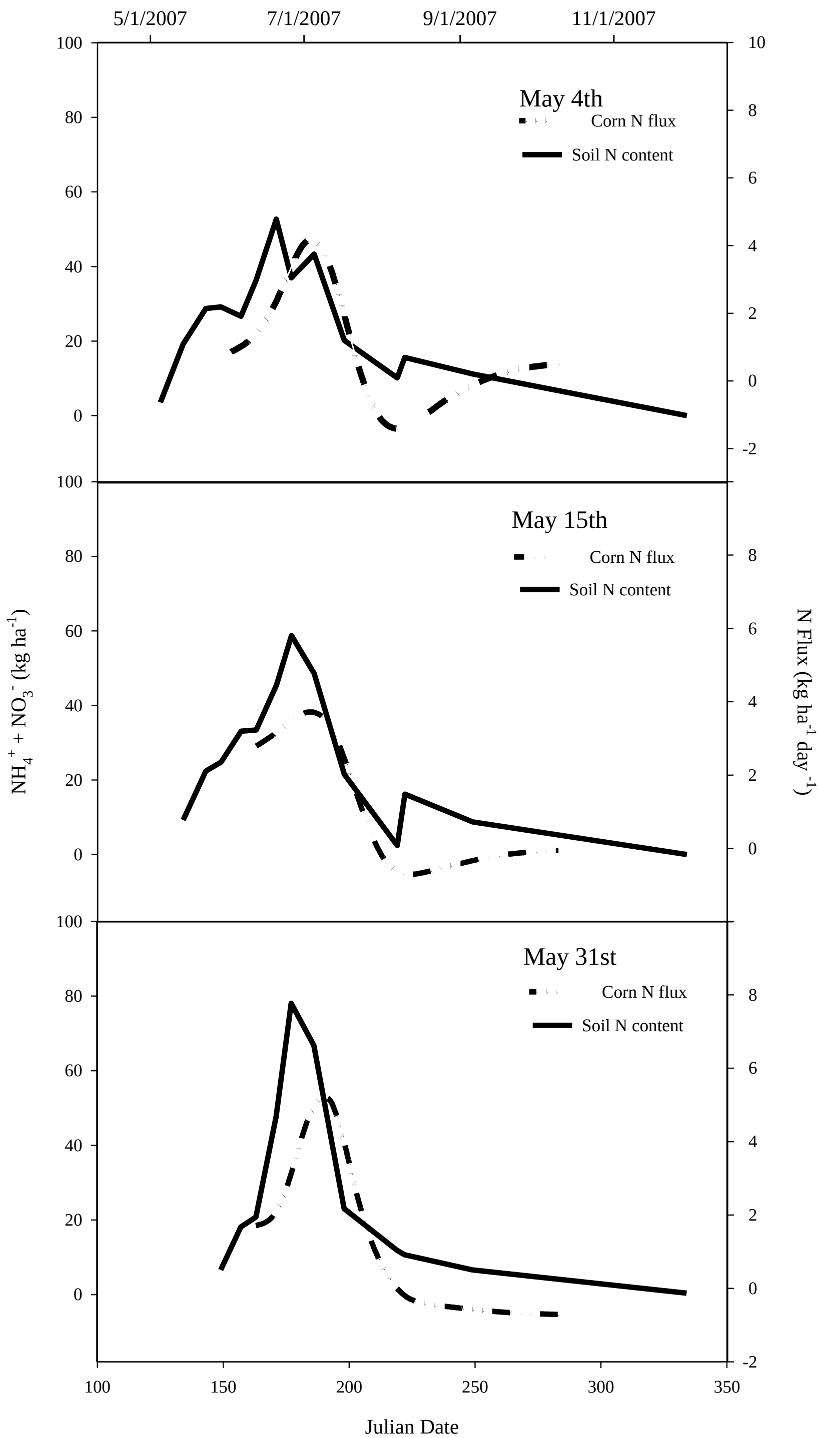


Figure 4-2: Inorganic soil N content in the top 15 cm and N flux rates for the three vetch treatments (May 4th, May 15th, May 31st).

## Chapter 5

# Conclusion

The alteration of hairy vetch termination date and corn planting date affected the vetch biomass, vetch N content, soil inorganic N content, and corn N uptake. The advantage of increased potential vetch N contribution could be enough to encourage a two week corn planting delay, but the risks associated with late planting probably outweigh any benefits past that time period. The May $15^{th}$ planting date is suspected to be the most ideal vetch treatment due to its adequate N supply from the legume, perhaps slightly repressed due to drought conditions, and yields that were comparable to treatments with higher soil inorganic N levels.

The synchrony of vetch N release and corn N uptake is an important topic that still requires further scrutiny. To complete this study, consistency in vetch biomass (in relation to weather), N content, and soil N dynamics under vetch needs to be established. It would be troublesome to a producer if they could not anticipate the legume N contribution year-to-year, and it can be variable due to its dependency on multiple environmental factors (Peoples and Craswell 1992). It would be immensely advantageous to be able to predict, fairly accurately, the vetch biomass based on April and May growing conditions—and, therefore, chose a termination date accordingly. A cool spring may call for a delayed termination, while a warmer spring could result in high biomass levels at an earlier time, encouraging an earlier termination.

It is common practice for a legume winter cover crop to be terminated weeks before corn establishment, as a means to allow for soil warming, decrease chances of moisture competition, and suppress weeds (Duiker and Curran 2007). This system leaves a wider window of N susceptibility and may not provide enough N to the succeeding crop (Crews and Peoples 2005). Our study did not find any emergence or disease problems associated with heavy residue. This could be due to the abnormally dry weather, which could have reduced the wetness of the residue and allowed soil warming.

In general, the viability and productivity of a hairy vetch fertilized system could be questioned in some climates (Cherr et al 2006b). An integrative approach to fertility management that is tailored to a specific cropping system and environment is preferable to absolutes in any form. Our study shows that vetch termination can be used as a tool to manipulate N availability and uptake, which could be used in conjunction with other fertility options. An early killed vetch, followed by a side-dress at V6, could benefit the soil, decrease fertilizer use, and improve expected yields. The productivity of an early planted corn variety and late killed vetch could be a very productive and N efficient system, provided that water stress is not an issue (Duiker and Hartwig 2003).

Hairy vetch can provide winter cover and provide enough N to support moderate corn yields. Future experiments that focus on the predictability of vetch growth and N content with weather conditions could standardize the practice of legume fertility. While vetch may not be the optimal fertilization method for every cropping system, it could be used in conjunction with other methods to improve soil biology and, in some cases, the N synchrony.

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