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Winter Field Pea as a Leguminous Cover Crop in Corn Production

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Abstract

Leguminous cover crops, which fix nitrogen (N) from the atmosphere and add to the N content of the soil, have the potential to replace or partially replace commercial nitrogen fertilizers. In this experiment, field pea (*Pisum arvense*) was used as the leguminous cover crop in a conventional tilled corn (Zea *mays*) production system. In a 2-yr experiment (2008 and 2009), conducted at two locations in Arkansas, field pea was planted on half the field in the fall and allowed to grow until late April to early May. Field pea biomass was recorded, N content of biomass determined and then the pea plants were plowed into the soil followed by corn planting. Six nitrogen fertilizer rates were applied at 0, 56, 112, 168, 224, and 280 kg N ha^{-1} to plots with and without the pea cover crop. The field pea cover crop provided a significant amount of the N needs of the corn. The N fertilizer equivalent of the field pea cover crop to the following corn crop averaged 79 kg N ha^{-1}. Consequently, corn grown following the field pea cover crop was able to maximize grain yield on a lower rate of N fertilizer compared to corn following no pea cover crop. This has useful implications to increase producer profitability, decrease N fertilizer use, and improve the environment.

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I. Literature Review

A. Corn

Corn (*Zea mays*) is one of the oldest and most important crops known to the world. Corn originated in southern Mexico and Central America. Its oldest findings date back to 5000 B.C. And even then, corn had been domesticated to the point where it would not reproduce unless managed by humans (Hoeft et al., 2000). The reason for this domestication is its ability to store energy through large amounts of grain replication in each plant. In a relatively short time, a single corn grain can multiply into as many as 600 to1000 grains. In contrast, other grains, such as wheat, only multiply by a little more than 50 times (Hoeft et al., 2000).

In recent history, corn accounted for almost half of the 71% increase in world grain production between 1970 and 2006 (Westhoff, 2009). World grain production increase is not due to an increase in the amount of cropland in production, because almost the same amount of land is in production today as it was in the 1970s. However, corn area harvested has increased in this time by 27% (Westhoff, 2009). The increase in world grain yield is due to grain yield per area increasing by 64%. Corn grain yield per area surpassed world grain yield per area by increasing 72%, while world corn consumption increased 42% over this period (Westhoff, 2009).

Corn grows best at temperatures between 10º and 30º C with more growth occurring at the higher end of that range. Corn requires about 120 growing degree days to emerge from the soil and will reach physiological maturity at about 2,700 growing degree days (Hoeft et al., 2000).

B. Nitrogen Needs of Corn

Nitrogen (N) fertilizer is a fundamental input for production of corn and other grains in the grass family (Scharf et al., 2006). Nitrogen is the nutrient required in the greatest quantity by cereal crops and is often the most limiting nutrient for plant growth, development, and achievement of yield potential (Heichel and Barnes, 1984; Ma and Dwyer, 1998; Nyiraneza et al., 2009). The omission of N will result in a greater decline in yield than any other mineral element (Fleming et al., 1981). This requires effective management of N, creating a greater challenge to the farm operator than other fertilizer nutrients (Olson and Kurtz, 1982).

Crop N requirement is a physiological function of the genetic potential of the crop and plant growth conditions, which affect the fertilizer uptake efficiency (Zotarelli et al., 2009). The fertilizer uptake efficiency for a specific production system is dependent on environmental conditions, management, rate, timing, and source of N (Zotarelli et al., 2009). Nitrogen uptake efficiency rarely exceeds 70% of applied N and averages 50% or less (Hallberg, 1989; Bergstrom and Kirchmann, 2004). Fertilizer N recommendations for corn generally range from 1 kg to 1.5 kg of N for every 56 kg (1lb to 1.5 lb of N for every bushel) of expected corn yield. Fertilizer recovery typically decreases with an increase in N application rate, and economic loss occurs by applying more N than is required to obtain a positive yield response. (McDonald et al., 1989). High application rates of N fertilizer ensure production of near-maximum yields, but can result in unused N that can leach into groundwater and be very costly and harmful to human health (Scharf et al., 2006).

Nitrogen fertilizers are applied to make up the difference between what is believed the soil can supply and the needs of the plants (Magdoff, 1991). Nitrogen needs to be supplied either in an organic or inorganic form or a combination of both to obtain maximum production (Fleming et al., 1981). There are a variety of N fertilizers applied to soils. Most ammonium or ammonium-forming sources are quickly converted to nitrate (Magdoff, 1991). Corn will take up most of its N as nitrate either from fertilizer or from the decomposing soil organic matter (Magdoff, 1991).

C. Environmental and Economic Costs of Corn Production

Nitrogen fertilizer is one of the most energy-consuming inputs of corn production, considering economic and environmental cost (Ma and Dwyer, 1998). Economically, the increased cost of N fertilization is a great concern for sustainable crop production (Sainju and Singh, 2008). Today, the largest single input for crop nutrition is synthetic N fertilizer, mainly manufactured by means of the Haber-Bosch process from natural gas (Boddey et al., 2009). In 2006, N represented 39% of the operation cost of corn in the US and 18% of production value (Westhoff, 2009). It has been estimated that 40% of the protein consumed globally by humans originates from N supplied as synthetic fertilizer (Sinclair and Cassman, 1999; Smil, 2001). Also, synthetic N fertilizer use has grown 150% from 1970-2006 (Westhoff, 2009). Along with the increase in use, fuel and N fertilizer prices have increased considerably and have been very volatile in recent years. The US price of urea increased from \$332 ton^{-1} in 2005 to \$552 ton^{-1} in

2008, and \$486 ton^{-1} in 2009 (NASS, USDA). Average US bulk delivery fuel prices in 2005 were \$2.225 gal^{-1} and \$1.968 gal^{-1} for gasoline and diesel, respectively (NASS, USDA). In 2008, bulk delivery gasoline and diesel prices averaged \$3.331 gal^{-1} and \$3.619 gal^{-1}, respectively, and in 2009 bulk delivery gasoline and diesel prices averaged \$1.972 gal^{-1} and \$1.688 gal^{-1}, respectively. Production decisions and profitability rely on these prices. To minimize the effects of the increasing and volatile prices producers must adjust their production practices (Skalsky et al., 2008).

Another great concern of the intense use of N fertilizers is the environmental cost of producing them. Emissions of carbon dioxide as a result of N fertilizer production represents approximately 60 million Mg, or about 1% of the total global carbon dioxide released by industry (Peoples et al., 2009). It takes approximately $4.3m^3$ of natural gas to produce 1kg of ammonium-N (Olson, 1977). Although Smil (2001) showed that N fertilizer production has greatly improved in energy efficiency throughout the past 50 years from >80 GJ Mg^{-1} ammonium before 1955 to 27 GJ/Mg^{-1} ammonium in the most efficient plants in operation in the late 1990s. Laegreid et al. (1999) estimated the mean value of N fertilizer plants operating in 1999 to be 54 MJ kg^{-1} of N. The energy consumed by these plants has been translated into greenhouse gas emissions and estimated to be 1.4 kg of carbon dioxide per 1 kg of urea-N manufactured (Kongshaug, 1998; Schlesinger, 2000; West and Marland, 2002).

To combat the increasing economical and environmental costs of production, producers need a highly productive and sustainable alternative. It is becoming necessary for producers to maintain or increase productivity while trying to increase sustainability. For farming systems to accomplish this long term, it is necessary to replenish the reserves of nutrients which are removed or lost from the soil (Peoples et al., 1995). To provide soil with enough N to maintain high crop yields and to cope with increasing cost of N fertilizers, the N contribution of leguminous crops to subsequent crops may be very valuable (Hargrove, 1986; Frankenberger and Abdelmajid, 1995).

One way of incorporating leguminous crops into a production system is through using a winter cover crop. Cover crops grow between the harvest of one crop and the planting of another crop during periods when the soil might otherwise be fallow (Dabney et al., 2001; Griffin et al., 2000). Winter cover crops generally have a period of fall growth followed by a winter period when growth slows or stops, followed by an abundance of growth in the spring (Dabney et al., 2001; Sainju and Singh, 2008).

D. Benefits of Cover Crops

Increased yield of a marketable crop is the overall benefit that can be derived from growing cover crops (Snapp et al., 2005). Leguminous cover crops are known to enhance the growth and increase the yield of the succeeding crop (Hargrove, 1986; Meisinger et al., 1991). The most immediate response of succeeding crops is due to the conversion of atmospheric N into plant proteins and other components containing N. The decomposing plant material releases the converted N to be used by the succeeding crop (Martin and Touchton et al., 1983). Cover crops also increase yield stability (Snapp et al., 2005). Lotter et al. (2003) concluded from a field study in Pennsylvania that organic corn and soybean yields grown in a cover crop systems were higher than conventionally produced field crop systems grown without cover crops during drought years.

Use of leguminous cover crops can provide numerous benefits to crop growth and culture. For example, leguminous cover crops can be very effective in production of ground cover, which in turn protects the soil against water runoff and erosion (Johnson et al., 1998; Kaspar et al., 2001; Frankenberger and Abdelmajid, 1995; Torbert et al., 1996; Martin and Touchton et al., 1983; Mahler and Auld, 1989; Power and Doran, 1988; Kuo and Jellum, 2002). Leguminous cover crops also conserve residual fertilizers that might otherwise be lost through leaching (Shipley et al., 1992; Ditsch et al., 1993; McCracken et al., 1994; Owens et al., 2000; Frankenberger and Abdelmajid, 1995; Mahler and Auld, 1989; Power and Doran, 1988). In addition to conserving residual fertilizers, leguminous cover crops can reduce the need for N fertilizer through the conversion of unavailable organic N to an available inorganic N source (Bruulsema and Christie, 1987; Hesterman et al., 1992; Stute and Posner, 1995a; Frankenberger and Abdelmajid, 1995; Mahler and Auld, 1989; Kuo and Jellum, 2002). Improving or maintaining soil properties such as organic matter content is another benefit of leguminous cover crops. Organic matter content affects soil structure, buffering capacity, cation exchange capacity, water holding capacity, infiltration, microbial diversity and soil porosity (Frankenberger and Abdelmajid, 1995; Raimbault and Vyn, 1991; Martin and Touchton, 1983; Dabney et al., 2001; McVay et al., 1989; Reeves and Wood, 1994; Ebelhar et al., 1984; Martin and Touchton, 1983). Additional benefits include increased weed suppression through reduced light transmission and decreased soil temperature fluctuations (Teasdale and Mohler, 1993).

The benefits of legumes to subsequent crops have been documented across the World since ancient times (Bin, 1983; Pieters, 1927; Wedderbuan and Collingwood, 1976). Throughout history, except for the past 50-60 years, leguminous N fixation has sustained and replenished soil N removed by crops (Smith et al., 1987). The value of leguminous crops was recognized in the southern US by the turn of the 20th century. By the 1930s, it had been accepted and understood that legumes improved soil through improved N availability (Smith et al., 1987). Between the 1930s and 1940s leguminous cover cropping increased dramatically, with a peak of about 5-6 million hectares in 1940 (Rogers and Giddens, 1957; Martin and Touchton et al., 1983). The use steadily decreased after this time because of the availability of synthetic N fertilizers (Smith et al., 1987; Fleming et al., 1981). The improved availability of these synthetic fertilizers was due to the discovery of a new method of synthetic N production, the Haber-Bosch process, which provided a dependable and economical source of N fertilizer (Martin and Touchton et al., 1983).

Before the widespread use of N fertilizers, rotational farming practices with legumes supplied the majority of N used in crop production from 1900 to 1950 (Auld et al., 1982). Corn was usually grown following a N-fixing legume, especially forage legumes such as alfalfa or clover, in order to meet the N needs of the crop (Hoeft et al., 2000). This meant that 25-50% of the farm had to be maintained in a legume-rich pasture or cover crop. It has been estimated that as much as 50% of the N in farming systems was derived directly from symbiotic N fixation up to the 1950s (Smil, 2001). Presently, N is entering the earth’s ecosystem at twice the rate as it did in pre-industrial times, through synthetic N fertilizers (Vitousek et al., 1997; Smil, 1999).

Natural gas shortages and the resulting higher N fertilizer prices created a renewed interest in legume cover crops in the US (Auld et al., 1982; Hargrove, 1986). In the 1970s and 1980s, interest grew in the use of winter legume cover crops to supply a portion of the N required by nonlegume crops (Auld et al., 1982; Hargrove, 1986; Smith et al., 1987; Varco et al., 1989). This renewed interest was because of the increases and instability of fossil fuel prices and the concerns of agricultural practices affecting environmental quality (Smith et al., 1987; Varco et al., 1989). These are the same situations agriculture is facing today.

The primary pollutant in agriculture is sediment (National Research Council, 1993). On irrigated, sandy soils where bare soil is readily erodible, if left unprotected during the colder months, winter cover crops can reduce erosion (Snapp et al., 2005). Even in the relatively flat land of the Mississippi Delta, runoff often exceeds tolerable sediment levels (Murphree and McGregor, 1991). Cover crops can reduce runoff potential better than volunteer vegetation because cover crops produce more biomass, therefore, they transpire more water and allow more rainfall to infiltrate into the soil (Dabney, 1998).

Erosion reductions lead to improved soil quality and productivity. Cover crops reduce soil detachment and aggregate breakdown by intercepting the energy of rainfall, and reducing the amount and velocity of runoff (Dabney et al., 2001). The duration and surface-area coverage of the cover crop are the primary determinants of reduced soil erosion (Snapp et al., 2005).

Cover crops also have the ability to reduce leaching, which is a major agri-environmental pollution concern of surface and groundwater (Ma and Dwyer, 1998). Improvement in soil and crop management practices that optimize soil mineral N content, N cycling, N storage, and crop N uptake are needed to reduce nitrate accumulation in the soil, thus reducing N leaching (Sainju et al., 2007; Sainju and Singh, 2008). Small grain cover crops have been shown to reduce N leaching by 29% to 94% (Sainju and Singh, 1997). They are able to scavenge residual N during the fall and winter before it is able to move below the rooting zone. However, legumes have been shown to be less effective in reducing nitrate leaching, with a 6% to 48% reduction in a study by Sainju and Singh (1997). The reduction in effectiveness is attributed to the legumes' less active growth in the fall and winter allowing the residual N to move below the rooting zone before active growth in the spring (Shipley et al., 1992). In warmer climates, early fall plantings of leguminous cover crops may allow for more fall growth and more N scavenging.

E. Cover Crop Selection

Selection of appropriate cover crops for a given region requires an adequate knowledge of their growth potential (Kuo et al., 1997). Temperature and rainfall are the primary climatic variables that affect cover crop selection. Cover crops fit best in warm regions with abundant precipitation (Unger and Vigil, 1998). The warmer and wetter the climate, the greater the potential benefits of cover crops and the greater number of options are available (Dabney et al., 2001). The water that cover crops use may reduce yields of succeeding crops in dry regions (Unger and Vigil, 1998). Shorter growing seasons, which provide limited opportunity for cover crop establishment, and less potential for abundant cover crop biomass accumulation, and severe winter kill restrict their use in northern climates (Smith et al., 1987; Griffin et al., 2000). The southeastern US has historically been the area where they are most beneficial (Smith et al., 1987). The warm temperatures and abundant precipitation make this region very adequate to grow annual winter cover crops. The weathered low organic matter soils of the southeast also make annual winter cover crops advantageous (Smith et al., 1987). Using annual winter leguminous cover crops in the southern US may be a viable option to conserve soil and replace all or part of the N needed for crop production (Fleming et al., 1981).

Cover crop systems that are not costly and are agronomically feasible, will increase cover crop utilization and improve soil and water quality (Dabney et al., 2001). Legume winter cover crops are attractive to agronomists. However, their appeal to producers is determined mostly by economics (Smith et al., 1987). The economic feasibility of using legumes as cover crops varies widely with fluctuations in energy and other input cost (Allison and Ott, 1987). To further complicate the profitability of legume cover crops, it is impossible to precisely assign a cost for soil erosion, environmental degradation, or a value for long-term increases in soil productivity. If legume cover crops are considered to be only a replacement for N fertilizer, then the analysis is greatly simplified to a question of managing the legume cover crop verses the cost of applying an equivalent fertilizer (Smith et al., 1987).

Producers will absorb the initial cost of using leguminous cover crops, however, society will benefit from the ecological services provided by widespread adoption of cover crops (Snapp et al., 2005; Ogg, 1999). Internal costs of cover crops take two forms: direct and indirect. Cover crop establishment is a large part of the direct cost and establishment costs are particularly high for legumes; up to 10 times higher for legumes than for grasses (Roberts and Swinton, 1996). The increased cost is mostly due to seed cost. The indirect on-farm costs of cover crops fall into two categories: impeding the establishment of the succeeding cash crop, and cover crop management problems that hinder the realization of the expected benefits (Snapp et al., 2005).

The fact that only a very small percentage of US crop land is currently planted with cover crops suggests that most producers find the disadvantages outweigh the advantages, or have become accustomed to the ease of using industrial N (Dabney et al., 2001). Producers understand the benefits of using cover crops but are also concerned about the risk, such as residue management and N dynamics (Singer et al., 2007). Some of the drawbacks are the lack of equipment or time and unpredictable N compared with inorganic fertilizers (Snapp et al., 2005).

In a study by Singer et al. (2007), an estimated 18% of farmers in Illinois, Indiana, Iowa, and Minnesota who were farming in 2006 had ever used cover crops. Of these, 11% used them in the last 5 years, and 8% planted cover crops in the fall of 2005. Corn Belt farmers responded that cover crops are most effective at reducing soil erosion (96%), increasing soil organic matter (74%), and they preferred cover crops that fix N (64%). Despite the wealth of knowledge it is obvious that the use of cover crops is limited in production systems dominated by summer annual crops (Singer et al., 2007).

F. Field Pea

Field pea (*Pisum sativum*) as a winter cover crop may be part of the solution to environmental and economic concerns. Field pea require a cool and relatively humid climate with temperatures of - 7ºC to 30ºC (Muehlbauer and Tullu, 1997). Optimum growing temperature is 13ºC to 19ºC (Oelke et al., 1991). Power and Zachariassen (1993) reported that field pea fixed more N at 10ºC than at 20ºC and 30ºC. Field pea is not tolerant of wet soil environments during pre-reproductive and reproductive growth (Houlderbaum et al.,1990). In Kou et al. (1997), total N accumulation of the field pea was considerably lower in 1993 than in 1992. During the active growth of the cover crops in March and April, the mean temperature was similar between 1992 and 1993 (10.3ºC); however, nearly twice as much rainfall was received in 1993 (257mm) as in 1992 (136mm). The large amounts of rainfall reduced the growth and N accumulation of the field pea.

Field pea can tolerate frost down to -2ºC in the seedling stage. Once established it can tolerate much colder temperatures; however, top growth may be affected at or below -6ºC. If the main shoot is killed nodes below the soil surface will form new shoots (Oelke et al., 1991). Field pea can be grown on many types of soil, but good drainage is critical and a pH of 5.5-6.5 is ideal (Oelke et al., 1991). Field pea has a potential biomass yield of 10 Mg ha (Auld et al., 1982). This large biomass potential gives field pea great ability to fix large amounts of atmospheric N through the symbiotic relationship with the bacterium *Rhizobium leguminosarium* (Oelke et al.,1991). The amount of N fixed varies from 71 kg N ha^{-1} in

Alabama to 119 kg N ha^{-1} in Wisconsin (Mahler et al., 1988). The concentration of N in pea leaf tissue ranges from 1.8% to 2.3% (Mahler et al., 1988). Mahler and Auld, (1989), concluded that field pea gave 94 kg N ha^{-1} to a subsequent wheat crop in Idaho.

In Germany, Karpenstien-Mach and Stuelpnagel (2000) studied combinations of rye, crimson clover, and field pea cover crops in combination with a corn summer crop. The corn crop following the field pea was the highest yielding. This system was found to be highly productive because of the large amount of N release from the pea residue to support the large N demand of the corn crop. These results suggest that there is a possibility to obtain high yielding corn crops in a sustainable cropping system (Karpenstein-Machan and Stuelpnagel, 2000). The high yields are attributed to the rapid decomposition of the field pea. More than half of the N contained in the field pea biomass becomes available to the succeeding crop (Lohnis, 1926). Field peas have also been documented to increase the yields of subsequent crops of cotton, corn, and rice (Nelson, 1944).

In a study by Kuo et al. (1997), soil inorganic N levels increased rapidly after the incorporation of field pea in 1992 reaching a maximum in mid-June. The biomass N concentration in the aboveground biomass correlated significantly with inorganic N levels in the soil. Soil inorganic N concentrations following cover crop incorporation in 1993 also reached the highest level near mid-June. However, the peak levels for the soil were lower than those in 1992. Excess rainfall in April, prior to cover crop incorporation, and in May, after incorporation, along with cool temperatures in May, could have created soil conditions favorable for N leaching and denitrification. The short-term effect on the inorganic N concentration in the soil was determined mostly by the biomass N concentration of the cover crop. These studies indicate that field pea and alfalfa materials used as N sources can significantly increase cereal crop yield and soil inorganic N. Also, Tanaka et al. (1997) reported field pea provided adequate surface cover to control soil erosion effectively.

G. Legume Nitrogen Contributions

Crop residues that remain in the field represent a potential source of available N for succeeding crops (Wilson and Hargrove, 1986). Legume residues represent an even greater potential source of additional N with little undesirable effects, through symbiotic N fixation (Groya and Sheaffer,1985; Ladd et al.,1983; Groffman et al.,1987; Eblhar et al.,1984; Hargrove,1986; Mitchell and Teel,1977; Touchton et al.,1982). N fixation is one of the most studied benefits of legume winter cover crops to the subsequent summer crops (Smith et al., 1987).

Fixation, as described by Strodman and Emerich, (2009), is a function of plant root nodules fixing atmospheric dinitrogen into ammonium where it can be used by the plant to produce proteins, nucleic acids, and other nitrogenous compounds. The nodules are made up of infected and uninfected rhizobia cells. The uninfected cells provide metabolic support to the N fixation process, which occurs in the infected cells. The infected cells contain nitrogenase which is the enzyme that catalyzes the reduction of atmospheric dinitrogen to ammonium. The unique physiology and metabolism of the nodule allows for the precise oxygen concentrations that allow symbiotic N fixation to occur. The oxygen concentration is important because of the short half-life of nitrogenase in the presence of oxygen. The nodule receives the photosynthetically produced carbohydrates, sucrose and glucose, from the plant and metabolizes them to malate. The malate is provided to the bacteroids, the bacteria living in the infected cells, for deriving the energy and low potential electrons needed by nitrogenase. Nitrogenase then catalyzes the MgATP-dependent reduction of N_2 to ammonia in the equation:

$$N_2 + 8e^- + 16MgATP + 8H^+ \rightarrow 2NH_3 + H_2 + 16MgADP + 16P$$

Legume cover crops have the ability to supply sufficient N for production of a subsequent grain crop with little or no supplemental N fertilizer. To do this, the legume biomass quantity and N mineralization must synchronize with crop demand (Griffin et al., 2000). Yields and N uptake of summer crops, which follow leguminous crops, tend to be higher (Decker et al., 1994; Kuo et al.,1996). Several researchers have reported that monocot crops following a leguminous cover crops can have their N fertilizer rate reduced and in a few instances eliminated and produce optimum yields (Smith et al.,1987; Torbert et al.,1996; Sainju et al., 2007; McVay et al., 1989; Sainju et al., 2000; Boquet et al., 2004).

Zotarelli et al. (2009) reported cover crop based systems achieved higher initial growth rates, greater N accumulation, and ear yield in sweet corn systems without large quantities of supplemental N fertilizer compared with a no cover crop system. The use of leguminous cover crops to maintain the N status of soil provides a means of reducing our dependence solely on commercial N fertilizer in crop production (Frankenberger and Abdelmajid, 1995). Also, the accumulation of soil organic matter and the enhancement of soil physical properties could eventually provide more agronomic benefit than just the first year N contribution alone. This could offer an even more convincing justification for the adoption of legume cover cropping (Smith et al., 1987).

To realize the full benefits of leguminous cover crops, the supplemental N requirement following them needs to be accurate (Vyn et al., 1999). A fundamental goal of leguminous cover cropping is to reduce fertilizer cost and provide enough total or supplemental N for the next crop to optimize economic yield (Mahller and Hemamda, 1993). To evaluate the economics of using leguminous cover crops, dependable estimates of the N availability for the succeeding crops under specific environmental and soil conditions must be known (Hargrove, 1986; Mahler and Hemamda, 1993).

Estimations of legume N contributions can be calculated by the “N balance technique.” This technique compares total N uptake by a non-legume crop following a legume to total N uptake by a nonlegume crop following a non-legume crop or fallow (Varco et al., 1989). Smith et al. (1987) suggested this as a more sensitive estimate indicator of N supply than the “N fertilizer equivalence technique.” However, the “N fertilizer equivalence technique” is useful for a management perspective due to the ease of pricing crop yield and N fertilizer. This technique calculates the quantity of N fertilizer that must be applied to a crop following a non-legume crop or fallow to achieve the same yield as a crop following a legume cover crop with no N fertilizer applied (Ebelhar et al.,1984; Mitchell and Teel, 1977; Varco et al.,1989; Fox and Piekielek,1988; Pare et al.,1992; Reeves and Wood,1994; Smith et al.,1987). This simple and straightforward approach, however, does not take into account other factors that may contribute to yield.

Most experiments using the “N fertilizer equivalence technique” quantify the N contribution of legumes in a range of between 50 and 100 kg N ha^{-1} (Reeves and Wood, 1994; Smith et al.,1987). The most common legumes used in these studies are pea, vetch, and clover. Mahler and Auld (1989) determined pea can provide between 64 and 94 kg N ha^{-1} for the succeeding winter wheat crop. In Kentucky, Ebelhar et al. (1984) found that hairy vetch can supply N equivalent to approximately 90-100 kg N ha^{-1} in no-tillage corn. In Georgia, Touchton et al. (1982) reported N produced by crimson clover was sufficient for optimum grain sorghum yields without supplemental fertilizer N. Hargrove (1986) quantified the average amount of N replaced by the crimson clover to be 72 kg N ha^{-1}. Hargrove et al. (1984b) also reported winter legumes can provide the N needs for no-tillage cotton. Also, in Georgia, McVay et al. (1989) found that an adapted winter legume cover crop can replace up to two-thirds of the N required for corn production. Burket et al. (1997) compared sweet corn yield following clover, rye, and rye plus pea cover crops and reported that both legume cover crops replaced approximately 150 kg fertilizer N ha^{-1}. It is clear that in a favorable climate with proper management winter legumes can accumulate well over 100 kg N ha^{-1} without significantly interfering with the scheduling of a summer grain crop (Smith et al., 1987).

For legume cover crops to be considered an effective N source for corn they must supply sufficient N and there must be synchrony between legume N release and corn demand (Stute and Posner, 1995b). A N containing material must produce a large pool of mineral N before the period of rapid N uptake by a crop (Magdoff, 1991). If the mineral N pool in soil is produced too early it can potentially be lost via leaching and/or denitrification. If released too late it will not benefit the crop and poses a potential threat to groundwater quality via leaching (Stute and Posner, 1995a).

Adding legume N into farming systems needs to be balanced when using cover crops as nutrient management tools (Dabney et al., 2001). There is a risk of reduced yields or post-harvest soil nitrate leaching if cover crop N release is not synchronized with succeeding crop demand (Meisinger et al., 1991; Torbert and Reeves, 1991). Not adjusting N fertilization after leguminous cover crops or untimely synchrony between cover crop N mineralization may lead to an increase in the risk of nitrate contamination of surface and/or groundwater (Vyn et al., 1999). For this reason, not all reports suggest that leguminous cover crops are a good source of N. In Kentucky, Huntington et al., (1985), determined that the majority of cover crop N became available after corn silking, resulting in high levels of mineral N late in the season. Continued mineralization late in the season may represent a source of potentially leachable nitrate. Groffman et al. (1987), reported late-season mineral N levels were higher following a cover crop than following N fertilizer. Despite higher levels of mineral N late in the season, they reported that leaching losses were insignificant. Sarrantonio and Scott (1988), reported the accumulation of nitrate below 22 cm late in the growing season following a hairy vetch cover crop that was soil incorporated. In contrast, Ebelhar et al. (1984), reported that mineral N levels following hairy vetch declined over the growing season due to crop uptake and by September the corn had N-deficiency symptoms which suggested poor late-season availability. Huntington et al. (1985) estimated the recovery of N by a subsequent corn crop from a hairy vetch cover crop to be 29% of the initial vetch N with the majority of the N available after the period of corn silking. In contrast, Wilson and Hargrove (1986) found the release of N from crimson clover residue at 4 weeks to be 40% and 63% for no-tillage and conventional tillage conditions, respectively.

In order to effectively manage residue N it is necessary to know the pattern of N release from residues (Wilson and Hargrove, 1986). Synchronization of residue N release with crop N demand is important for maximum efficiency of residue N (Wilson and Hargrove, 1986). This can only be accomplished by gaining an understanding of the N release patterns for specific residues under a particular set of environmental and crop-soil management conditions (Wilson and Hargrove, 1986).

H. Nitrogen Cycle

Nitrogen exists in many different forms in the soil and its availability to plants is affected by several physical, chemical and biological processes. These processes are collectively called the N cycle (Hoeft et al., 2000). The major reactions include mineralization, nitrification, leaching, denitrification, immobilization, and volatilization (Hoeft et al., 2000). The amount of N that is made available to crops during the season includes any residual mineral N, plus the net amount of mineralized N that is not subsequently lost from the available N pool by volatilization, denitrification, leaching below the root zone, and immobilization (Magdoff,1991).

Soils contain approximately 1,000 lb N acre^{-1}N for each percent of organic matter in the top seven inches of soil (Hoeft et al., 2000). Most of this is unavailable to plants because it is tied up in stable organic matter which decomposes very slowly (Hoeft et al., 2000). The process of organic matter decomposition by microorganisms, mineralization, releases organic N as ammonium ions, which is a plant available form (Hoeft et al., 2000). To utilize legume N to the fullest extent and properly manage cover crops, a better understanding of legume N mineralization is needed. An improved understanding could lead to management strategies to better synchronize legume N release with crop N uptake (Wagger, 1989).

Nitrogen from legume biomass becomes available to plants slower than inorganic N fertilizers such as urea (Groffman et al.,1987). Urea [$CO(NH_2)_2$], a synthetic N fertilizer, is rapidly hydrolyzed to ammonium by the enzyme urease after being applied to soil (Agehara and Warncke, 2005). Unlike urea, natural organic materials, such as animal manures and plant residues are mineralized slowly to ammonium (Agehara and Warncke,2005). Because urea is readily soluble in water, urea hydrolysis is largely dependent on diffusion of dissolved urea in soil (Sadeghi et al., 1989). Urease activity is generally highest near field capacity and declines as soil moisture decreases (Vlek and Carter, 1983; Sahrawat, 1984). Urea hydrolysis is also accelerated with increasing temperature because the urea diffusion rate in soil is positively correlated with temperature (Sadeghi et al., 1988). MacLean and McRae (1987) reported that 52%, 67%, 80%, and 93% of urea was hydrolyzed at 4ºC, 9ºC, 13ºC, and 18ºC, respectively, after 3 days.

Mineralization of soil organic matter and crop residue is a complex process that depends on many different elements (Rice and Havlin, 1994; Trinsoutrot et al., 2000). The main elements that control the mineralization of soil organic matter and crop residue include: soil organic matter and crop residue characteristics and quantity, soil environmental factors (moisture and temperature), soil chemical and physical characteristics (pH and aggregate structure), and management.

As soil organic matter decomposes, available N is released (Magdoff, 1991). During the decomposition process N in organic molecules is converted into mineral forms (Magdoff, 1991). Recently formed organic N materials mineralize two to three times faster than older organic N materials (Hoeft et al., 2000). Wilson and Hargrove (1986), Wagger (1989), and Varco et al. (1989) reported recently formed cover crops decompose rapidly (about 50% loss of biomass within one month) in warm southern soils and can be a significant source of N to the following corn crop.

The release of mineral N from residues is dependent on residue composition (Frankenberger and Abdelmajid, 1995; Fox et al., 1990; Ajwa et al., 1998; Rowell et al., 2001; Kumar and Goh, 2003). The most important factor affecting mineralization is the carbon to N ratio of the residues, especially the carbon constituents lignin and cellulose (Wilson and Hargrove, 1986; Wagger, 1989; Varco et al., 1989; Muller et al., 1988; Bowen et al., 1993; Quemada and Cabrera, 1995; Frankenberger and Abdelmajid, 1995; Ranells and Wagger, 1996; Smith et al., 1987; Kuo et al., 1997). Legumes with similar carbon to N ratios are not expected to have greatly different decomposition rates (Wilson and Hargrove, 1986).

Most cereal grain cover crops have high carbon to N ratios > 30, which immobilize soil N and consequently increases the amount of fertilizer N required for optimum economic yield of subsequent non-leguminous crops (Mitchell and Teel, 1977; Frye et al., 1985; Bowen et al., 1993; Hargrove, 1986; Wagger, 1989b; Holderbaum et al., 1990; Sullivan et al., 1991; Decker et al., 1994). This immobilization is due to plant carbohydrates stimulating microbial growth which can lead to net N immobilization with residues that are low in available N but high in available carbon (Allison,1973). In contrast to cereal grain cover crops, legume cover crops usually have carbon to N ratios < 20 which mineralizes soil N and reduces the amount of fertilizer N required to obtain optimum economic yield (Touchton et al., 1982; Ebelhar, 1990)

The release of mineral N from residues is dependent on climate (Frankenberger and Abdelmajid, 1995; Muller et al., 1988; Bowen et al., 1993; Quemada and Cabrera, 1995). More specifically mineral N release is dependent on soil environment (Sims, 1986; Wilson and Hargrove, 1986; Vigil and Kissel, 1995; Seneviratne et al., 1998; Whalen et al., 2001; Cookson et al., 2002). Soil moisture and temperature are the major environmental factors affecting N availability from inorganic sources (Agehara and Warncke, 2005). Mineralization of natural organic materials is mediated by heterotrophic bacteria and fungi (Agehara and Warncke, 2005). Soil moisture regulates oxygen diffusion in the soil with maximum aerobic microbial activity occurring at soil moisture levels between 50% and 70% of water holding capacity (Linn and Doran, 1984; Franzluebber, 1999). Low soil moisture inhibits microbial activity by reducing diffusion of soluble substrates (Griffin, 1981; Schjonning et al., 2003), microbial mobility (Killham et al., 1993), and intercellular water potential (Stark and Firestone, 1995). Environmental factors that promote good plant growth and also favor high rates of N mineralization include soil temperatures between 10ºC and 29ºC, pH of 5-8, good soil aeration, and moist but not saturated soils (Hoeft et al., 2000).

I. Managing Cover Crops

Cover crop management relative to planting the principle crop may be potentially important to subsequent N availability (Wagger, 1989). Killing cover crops before they reach their full biomass potential reduces the N content that can be achieved (Groffman et al., 1987). In the southeastern US, cover crop dry matter accumulation is changing rapidly during what is usually considered optimum corn planting dates (Wagger, 1989). Allowing cover crops to grow later in the spring delays corn planting and late corn planting may (Bollero and Bullock, 1994) or may not (Nafziger, 1994) adversely affect corn production. However, allowing legumes to grow beyond flowering usually does not increase the amount of N available to subsequent crops because of the slower mineralization of cover crop biomass and because a fraction of the cover crop N may be tied up in hard seed (Wagger, 1989a; Wagger, 1989b; Ranells and Wagger, 1992). In North Carolina, Waggner, (1989) found the early and late desiccation timings did not affect the legume N content significantly. The early desiccation had a lower dry weight but higher N concentrations than the late desiccation timing. Clark et al., (1995), reported delaying the spring kill date of vetch and rye increased the dry matter yield and N content, however, the carbon to N ratio increased as well.

Tillage systems affect the dynamics of decomposition and N mineralization (Wilson and Hargrove, 1986; Wagger, 1989; Varco et al., 1989). Cover crop residues release N more slowly if left on the soil surface than when incorporated with tillage (Wilson and Hargrove, 1986). The residue N release is even slower in dry years, especially during the first 4 to 8 weeks. After 16 weeks there are usually no differences between tillage and no-tillage systems (Varco et al., 1989).

Most studies conducted in the Southeast have shown that, regardless of tillage system, decomposing legumes release a large amount of available mineral N at 2 to 5 weeks after killing off the cover crop in the spring (herbicide or tillage). This is followed by a gradual decline over the growing season (Utomo et al., 1990; Groffman et al., 1978; Sarrantonio andScott, 1988; Huntington et al., 1985). The magnitude of the N release has been shown to be greater in conventional tillage systems than in no-tillage systems, suggesting greater mineralization by the incorporated residues.

In Georgia, Wilson and Hargrove (1984) used nylon mesh bags with crimson clover plant residues to determine the pattern of N release under Georgia conditions. The bags were placed in no-tillage and conventional tillage conditions. The study showed that N mineralization variation from year to year was much greater in the no-tillage system compared to the conventional tillage system. This might be expected since residue on the surface is subject to greater environmental influence than residue buried in the soil. This variation is quite large at the 1-, 2- and 4-week samplings, but was negligible by the 16-week sampling. For example, after 2 weeks in the field the residue contained only 48% of the original N under conventional tillage, whereas 78% of the residue N was still present under no-tillage conditions. By 16 weeks, the percentage of N remaining in the residue had declined to 31% and 36% for conventional tillage and no-tillage conditions, respectively. This pattern suggests that these residues contain organic N compounds that have varying degrees or resistance to microbial decomposition. The compounds remaining in the residue at 16 weeks seem to be resistant to further rapid decay and may represent the organic fraction that contributes to the formation of soil humus. The portion of the original residue N that ends up in the resistant fraction after 16 weeks was 31% and 36% for conventional tillage and no-tillage, respectively (Wilson and Hargrove, 1986).

Varco et al. (1989) examined the differences of conventional tillage and no-tillage systems of a vetch cover crop with regard to corn yield, total N uptake, extractable soil N, and labeled N recovery. In 1984, final total N uptake by corn was 31 kg ha^{-1} greater with conventional tillage than with no-tillage; however, no difference in grain yield occurred. This year was characterized by limited precipitation during grain fill. In 1985, early season N uptake was greater with conventional tillage than no-tillage but there was no difference in final total N accumulation between tillage systems and no-tillage treatments averaged more grain yield. The higher yield was likely due to higher soil water content. In 1986, corn yield and N uptake were both significantly higher in corn grown under conventional tillage. Labeled vetch recovery averaged over years was 32% with conventional tillage and 20% with no-tillage. The extractable soil N levels suggest that N mineralization occurs near the soil surface with no-tillage, however, N mineralization occurs throughout the plow depth with conventional tillage. The concentration of mineral N at the soil surface allows the potential for gaseous losses, especially when conditions are favorable for denitrification. In dry conditions, the concentration of mineral N at the soil surface may not allow plant uptake.

Apparently, the buffering effect of the soil environment minimized the effect of different climatic conditions, resulting in similar N release patterns for the incorporated legume residues. Wilson and Hargrove (1986) also observed this buffering effect under contrasting environmental conditions, and also reported N release to be highly variable when residues were left on the soil surface.

J. Recommendations for Further Study

To gain a better understanding of leguminous N fixation future research needs to focus on adaptation and practical use (Bantilan et al, 1995). Legume selection must be considered within the context of the farming system and geographical region in which the legumes are grown. Proper integration of legumes requires a good understanding of the role of the legume within the system and a better understanding of the relative contributions of N sources and the fates of fixed N (Giller et al, 1995).

Using cover crops in the summer annual dominated farming systems could have significant conservation benefits to soil, water and air. However, the adoption of cover crops remains low (Singer, 2008). Information gaps need to be filled in cover crop cost, selection, and management (Snapp et al., 2005; Singer et al., 2007). Residue decomposition studies are only applicable in a narrow range of climatic conditions. Studies in specific climates are needed to determine the N release from winter legumes residues (Wilson and Hargrove, 1986).

K. Objectives of Current Study

The objectives in this study are: i) To determine if all or some of the N requirements of a corn crop can be met with the N from a field pea winter cover crop, ii) To quantify the amount of N the field pea winter cover crop can contribute to a following corn crop, and iii) To determine if the cost of N requirements replaced by the field pea winter cover crop is greater than the cost of implementing the field pea winter cover crop into corn production.

II. Materials and Methods

A field study was conducted on a Captina (fine-silty, siliceous, active, mesic, Typic Fragiudults) silt loam soil at the University of Arkansas Division of Agriculture Research Station, Fayetteville, AR, and on a Bosket (fine-loamy, mixed, active, thermic, Mollic Hapludalfs) fine sandy loam soil at the Eddie Rushing Farm, McCrory, AR. The experimental design was a split plot where the whole plot portion was a randomized complete block with three replications and pea cover crop as a factor and the split plot factor was N rate. Nitrogen fertilizer treatment rates were (0, 56, 112, 168, 224, and 280 kg N ha^{-1}) applied as urea. Each plot consisted of four rows spaced 1 m apart and the plots were 6 m in length. Analysis of variance techniques were used to determine P values for comparisons and mean separations were determined using Fisher's protected least significant difference at the $P<0.05$ level. Also, yield was fit as a quadratic function of N rates, allowing the coefficients to differ by cover crop. Analysis of covariance techniques were used to determine whether the cover crop and no cover crop coefficients were different.

A. Pea Management

Field pea (*Pisum sativum* L.), variety 'Austrian winter pea', were seeded in mid-October of 2007 and 2008 on the same half of the fields in the same plots each year. Seed bed preparation was conventional tillage at each location and each year. Tillage consisted of double disking at a 10 cm depth followed by a rolling cultipacker. The field pea were seeded with a grain drill at 32 kg ha^{-1} with a row spacing of 15 cm. No fertilizers, herbicides, or insecticides were applied to the field pea.

In May of 2008, field pea biomass yield was determined by hand harvesting plant samples from 5-1 m^2 random areas of the field at each location. The field pea had begun flowering when the samples were taken, indicating most vegetative growth had occurred and plant N levels were optimum (Wagger, 1989a). In May of 2009, at McCrory, 18-1 m^2 biomass samples were taken from the no or 0 kg N ha^{-1} treatments. This was an attempt to correlate field pea biomass yield to other data from these plots. In May 2009, at Fayetteville, no biomass yield was recorded because of a *Sclerotina sclerotiorum* (white mold) infection had caused most plants to die.

The field pea biomass samples were dried at 60^{o}C to a constant weight in a forced air dryer and weighed to determine dry matter yield. A subsample of the biomass was collected and the remainder of the plant samples were returned to the harvested area and spread uniformly by hand. The subsamples were ground to pass a 1 mm screen then analyzed for N content by combustion (LECO FP-248, St. Joseph, MI; Campbell, 1992) at the Agricultural Diagnostic Laboratory, University of Arkansas, Fayetteville, AR. The N content was multiplied by the total dry matter production to acquire total N of the field pea above ground dry matter. After sampling, field pea were cut with a rotary mower. The mowed field pea were then disked into the soil at a depth of 10 cm.

B. Corn Management

In Fayetteville, the field was plowed to 1 m raised rows following the disking of the pea, then planted on May 25, 2008, and May 21, 2009, with Pioneer corn hybrids 31G96 and 33M57, respectively, at 81,000 seeds ha^{-1}. In McCrory, the field was prepared using a CASE IH 568 8-row pull type cultivator, set to a 5 cm depth, following the disking in of the pea, and then planted on May 29, 2008, and May 19, 2009, with Dekalb corn hybrids DKC 64-82 and DKC 63-84, respectively, at 81,000 seeds ha^{-1}. All stands were acceptable as a visual observation. These planting dates are beyond the optimum planting dates for Arkansas. The hybrids selected for the experiment were based on seed availability. The four hybrids represent high yielding technologically advanced products that are commercially marketed. All contained the Roundup Ready2 trait for glyphosate herbicide resistance. The Pioneer hybrids, 31G96 and 33M57, also contain the Herculex I insect protection trait and the Liberty tolerant gene. The Dekalb hybrid, DKC 63-84, contained the insect protection traits of YieldGard VT3.

In Fayetteville 2008, one application of Roundup Power Max (Glyphosate 48.7%) at a rate of 1.75 l ha^{-1} was applied 2 weeks after emergence for weed control. In Fayetteville 2009, Dual Magnum (S. metolachlor 83.7%) at a rate of 1.55 l ha^{-1} and Aatrex (Atrazine 42.6%) at a rate of 2.34 l ha^{-1} were applied pre-emergence, and Roundup Power Max (Glyphosate 48.7%) at a rate of 1.75 l ha^{-1} was applied 3 weeks after emergence. In McCrory 2008 and 2009, the corn was row cultivated at a 10 cm depth 2 weeks after emergence, followed by an application of Roundup Power Max (Glyphosate 48.7%) at a rate of 1.75 l ha^{-1} 3 weeks after emergence for weed control. Weed pressure was minimal at both locations.

Furrow irrigation was used at both locations when needed at the farm manager's discretion. However, irrigation was limited because of high amounts of rainfall in both years. Weather data is located in Tables 1 and 2.

Two weeks after planting, N fertilizer was applied to plots as single and split applications by hand broadcasting urea (46-0-0) to each plot. The 56 and 112 kg N ha^{-1} rates were applied in a single application. The 168, 224, and 280 kg N ha^{-1} rates were split applied with half the total N applied at approximately 2 weeks after planting and the second half of the total Nat the five-leaf corn stage. The plots were in the same location each year.

C. Soil Sampling

Soil samples were taken to make sure there were no deficient nutrient patterns influencing the N response. The samples were taken in February and November of 2008. Five samples from four quadrants of each field were taken with a 2.5-cm core soil sampler at a depth of 15 cm. Each sample was composed of four cores collected in a 1 m^2 area. The samples were analyzed at the Agricultural Diagnostic Laboratory, University of Arkansas, Fayetteville, AR, using the Mehlich 3 analysis method (Helmke and Sparks, 1996). Fertilizer was applied according to the University of Arkansas Cooperative Extension Service recommendations. The McCrory location did not require any preplant fertilizer in 2008 or 2009. At Fayetteville, preplant fertilizer of 225 kg ha^{-1} (0-0-60) and 225 kg ha^{-1} (0-46-0) was required in 2008 and 225 kg ha^{-1} (0-46-0), 170 kg ha^{-1} (0-0-60), and 33 kg ha^{-1} zinc sulfate in 2009. These fertilizers were applied between the mowing and disking of the field pea in both years.

Soil samples were also analyzed for alkaline hydrolyzable-N (AHN) by the direct steam distillation procedure in 2009 only because the method was not available in 2008 (Roberts et al., 2009). These samples were taken 1 week after planting in 2009. The samples were taken from the no or 0 kg N ha^{-1} treatments at both locations. Samples were taken with a 2.5-cm core soil sampler to a depth of 30 cm. Five cores were taken from each plot area and combined into one sample.

D. Corn Nitrogen Sampling

Entire aboveground corn biomass was measured from 1.5 m of row in each plot at physiological maturity, in 2009 at both locations. The samples were weighed in the field, a subsample was taken and dried at 60^{o}C to a constant weight in a forced air dryer, and then ground in a mill to pass a 1-mm screen.

Stover and cobs were combined, but grain was ground separately. The ground samples were then analyzed for N concentration by the combustion method (LECO FP-248, St. Joseph, MI; Campbell, 1992) at the Agricultural Diagnostic Laboratory, University of Arkansas, Fayetteville, AR. The N concentration was multiplied by the aboveground corn biomass to determine total N uptake in kg N ha^{-1}.

E. Corn Harvest

Grain yield was determined by hand harvesting ears from a 3-m portion of the middle two rows of each plot once corn had reached physiological maturity. Corn ears were bagged and dried at 60^{o}C in a forced air dyer. After drying, the corn was shelled by using an electric sheller. The grain was weighed and yields were adjusted to 13.5% moisture.

F. Economics

Economic analyses were based on budgets Tables 3 and 4 generated by the Mississippi State Budget Generator (MSBG; Spurlock and Laughlin, 1992). The field pea expense budgets only included operations differing from the no cover crop treatments as a partial budgeting approach was employed to evaluate the effect of N fixation on profitability. These budgets were to analyze the cost of including a field pea cover crop into corn production as added cost to be offset by N fertilizer savings.

Budgets were generated for the 2008 and 2009 crops; also a 2-year average budget Table 5 was generated using 2008 and 2009 input prices for purposes of sensitivity analysis and reducing the effect of unexpectedly high or low input prices as a function of volatile energy prices reflected in fertilizer prices. The budgets were divided into direct operating expenses and total specified expenses (operating and ownership costs). Direct operating expenses include, fuel, lube, labor, operating interest, equipment repair, and maintenance. These operating costs simulate cash costs a grower would face and allows determination of a breakeven price at which inclusion of field pea would offset N fertilizer prices in the short run (ownership charges for equipment employed would not be covered). Ownership expenses include depreciation and interest charges on equipment investment. Excluded in ownership cost are insurance, property taxes, and equipment housing charges as those are expected to both vary widely across producers and are minor in comparison to depreciation and capital costs. Land charges are also not assessed as they would be incurred whether field pea are included or not. Also, these budgets do not include the cost of the field pea seed since one of the purposes of the economic analysis was to identify a breakeven price for seed given non-seed costs of pea production and the price of N fertilizer. The following equation was used to calculate the breakeven price of pea seed.

(Urea fertilizer cost savings ha^{-1} – Non-seed related field pea cost ha^{-1}) / kg of field pea seed needed ha^{-1} = breakeven price of field pea seed

The non-seed related field pea costs can be either including or excluding ownership charges and urea N fertilizer cost savings are a function of observed prices and actual N supplied by the field peas. Depending on N prices, a producer would then plant field pea if the seed price was below the breakeven price to increase profitability.

Alternatively the breakeven price of urea could be calculated using the following formula. Field pea expenses including seed per hectare divided by the kilogram of urea fertilizer saved per hectare equals the breakeven price of urea.

The kilogram of urea fertilizer saved per acre was a function of the experimental field trials conducted. The amount was estimated on the basis of how much commercial N fertilizer applied in the form of urea was saved to obtain similar yields with using field pea as opposed to commercial fertilizer alone. While this would vary with the level of urea applied, this experiment based the urea savings on 172 kg urea ha^{-1}. The breakeven price of urea than would tell producers at what price level of urea they should employ field pea. That is, if the current market price of urea was lower than the calculated breakeven price, they should forgo planting field pea and vise versa.

III. Results

A. Field Pea Biomass and N Accumulation

Total field pea biomass accumulation, field pea N concentration, and total N accumulation (a product of the biomass accumulation and N concentration) are shown in Table 6. These accumulations only measure top growth. Mitchell and Teel, (1977), concluded that two-thirds of total winter legume biomass is in the top growth. Biomass accumulations and N percentages varied widely, but were within ranges reported in the literature (McVay et al., 1989). In 2008, field pea biomass, N percentage, and N contribution were respectively 2597 kg, 1.87 %, and 48.7 kg N ha^{-1} at Fayetteville and respectively, 3160 kg, 3.32 %, and 104.9 kg N ha^{-1} at McCrory. In 2009, field pea biomass, N percentage, and N contribution at McCrory were 4187 kg, 2.36 %, and 98.8 kg N ha^{-1}, respectively. The variations in biomass and percent N of the field pea between locations and years were likely due to environmental differences between years and locations. The late hard freeze in April 2008 at the Fayetteville location we believe hindered field pea biomass accumulation. Also, large amounts of rainfall during periods of rapid growth can hinder biomass accumulation and increase the incidence of disease. A *Sclerotina sclerotiorum* (white mold or stem rot) infection hindered biomass accumulation in Fayetteville in 2008 and the infection was so severe in 2009 it prevented an accurate measurement of biomass. The infection withered the leaves and stems, leaving little to be collected. *Sclerotina sclerotiorum* is a soil born pathogen which thrives in humid environments (Coker et al., 2010). Field peas are susceptible, and adversely affected by *Sclerotina sclerotiorum* (Muehlbauer and Tullu, 1997). The higher biomass production in McCrory was likely due to a warmer climate and no apparent *Sclerotina sclerotiorum* infection. The Fayetteville location had accumulated more biomass in past experiments (Marsh et al., 2008).

B. Corn N Uptake and Alkaline Hydrolyzable-N Soil Test

Corn N uptake was greater after the field pea cover crop than after no cover crop in both locations, but not statistically significant in McCrory. In McCrory, the mean corn N uptake following the pea cover crop was 93 kg N ha^{-1} and the mean corn N uptake following no cover crop was 77 kg N ha^{-1}. Though these means were numerically different, they were not statistically different (P=0.12). In Fayetteville, the mean corn N uptake following the pea cover crop was 50 kg N ha^{-1} and following the no cover crop the mean corn N uptake was 38 kg N ha^{-1}. These means were statistically different (P=0.02) and the greater corn N uptake following the pea cover crop suggests that more N was available for uptake by the corn compared to when corn followed no cover crop.

The AHN test is a soil test method to quantify the pool of potentially mineralizable N. Higher values indicate that more soil N is potentially available to the crop during the growing season (Roberts et al., 2010). Alkaline hydrolyzable-N values were higher following the pea cover crop than following no cover crop at both locations. At the McCrory location, the mean soil AHN value following the pea cover crop was 128 mg N kg $soil^{-1}$ and the mean soil AHN value following no cover crop was 101 mg N kg $soil^{-1}$ which were statistically different (P=0.01). At the Fayetteville location, the mean soil AHN value following the pea cover crop was 90 mg N kg $soil^{-1}$ and the mean soil AHN value following no cover crop was 83 mg N kg $soil^{-1}$. Although the means for the Fayetteville location are numerically different, they are not statistically different (P=0.14). Over the two locations, the mean soil AHN value following the pea cover crop was 114 mg N kg $soil^{-1}$ and the mean soil AHN value following no cover crop was 86 mg N kg $soil^{-1}$. These soil AHN means for the field pea cover crop and no cover crop were statistically different (P=0.003) with the soil following the pea cover crop having a higher AHN value and thus a greater amount of plant available N compared to the soil with no cover crop.

C. Corn Yield and Nitrogen Fertilizer Replacement Value of Field Peas

Quadratic equations were generated for corn yield response to N fertilizer rate in the presence and absence of a field pea cover crop to determine the N fertilizer equivalence of the pea cover crop (Figures 1- 4). Placing the y-intercept corn yield of the pea cover crop into the equation of the corn following the no cover crop and solving for x calculates a "N fertilizer equivalence" value. The "N fertilizer equivalence" values are estimates of the N contributed by the field pea cover crop when 0 N was applied (Ebelhar et al.,1984; Mitchell and Teel, 1977; Varco et al.,1989; Fox and Piekielek,1988; Pare et al.,1992; Reeves and Wood,1994; Smith et al.,1987). The average over years and locations indicates a field pea cover crop provided the equivalent of 79 kg N ha^{-1}.

At Fayetteville in 2008, the yield of corn following the pea cover crop was greater than the corn following no cover crop at low N fertilizer rates (Figure 1). The yields of corn become similar as N rates increase to 150 kg N ha^{1} or more. Corn following the pea cover crop reached 95% of its maximum yield

(8273 kg ha^{-1}) when 101 kg N ha^{-1} of fertilizer was applied. Corn following no cover crop did not achieve an equivalent yield to the corn following the pea cover crop until 159 kg N ha^{-1} of fertilizer was applied.

At Fayetteville in 2009, the *Sclerotina sclerotiorum* (white mold) infection had caused most plants to die and even though because of this disease no pea biomass samples were taken, there was a substantial amount of dead field pea biomass. Corn following the pea cover crop had greater yields compared to corn following no cover crop at all N fertilizer rates applied (Figure 2). Corn following the pea cover crop yielded 95% of its maximum yield (9554 kg ha^{-1}) when 184 kg N ha^{-1} was applied while corn following no cover crop never achieved an equivalent yield. The field where this study was conducted had been in a continuous corn rotation for 5 years. We believe the continuous corn rotation may have limited the yield potential of the corn crop and did not allow the corn following no cover crop to attain an equivalent yield to the corn following field pea.

At McCrory in 2008, corn following the pea cover crop did not increase in yield with an increase in N fertilizer rate (Figure 3). Corn following no cover crop increased in yield as N rate increased until 180 kg N ha^{-1} was applied and then declined as N rates increased beyond 180 kg N ha^{-1}. Yields of corn following the pea cover crop were greater than corn following no cover crop until reaching the 80 kg N ha^{-1} rate. Corn yields following the pea cover crop reached 95% of its maximum yield when 0 kg N ha^{-1} was applied. Corn following no cover crop did not reach an equivalent yield to the corn following the pea cover crop until 64 kg N ha^{-1} was applied. The low response to applied fertilizer N at the McCrory location in 2008 indicates there was ample plant available soil N. This McCrory location had been in a wheat-soybean rotation for many years before this test was conducted and we believe that the contribution to soil N by the soybean residue and the N fertilization of the wheat may have resulted in the high native soil N content and the low to no response to N fertilizer of the corn following the no cover crop and pea cover crop, respectively.

Corn responded better to N fertilizer the second year (2009) of the study indicating the previous corn crop in 2008 lowered the native soil N availability at the McCrory location. Corn yields in 2009 at McCrory were greater following the pea cover crop compared to corn following no cover crop at the low N fertilizer rates (Figure 4). Corn yields following the pea cover crop reached 95% of maximum yield (9915 kg ha^{-1}) when 130 kg N ha^{-1} was applied. Corn yields following the no cover crop did not reach an equivalent yield (9915 kg ha^{-1}) until 165 kg N ha^{-1} were applied.

D. Economics

For a producer to consider the use of field peas as a substitute or partial substitute for urea fertilizer, the added cost of field peas must be offset by fertilizer cost savings. The added expenses, ones incurred over the no cover crop, are in Tables 3, 4 and 5. Direct operating expenses for planting field peas (excluding seed) in 2008 and 2009 were \$67.03 ha^{-1} and \$54.12 ha^{-1}, respectively (Table 5). Total specified expenses (operating and ownership costs) in 2008 and 2009 totaled \$115.44 ha^{-1} (Table 3) and \$100.53 ha^{-1} (Table 4), respectively. The 2-year average (2008 and 2009) direct operating expense was \$60.58 ha^{-1}, and the 2-year average total specified expense was \$107.99 ha^{-1} (Table 5).

The cost of the field pea seed was estimated at \$55.36 ha^{-1} at a seeding rate of 32 kg ha^{-1} and a seed price of \$1.73 kg^{-1}. The urea fertilizer savings per hectare for using the field pea cover crop, averaged across years and locations, was 172 kg urea ha^{-1}. Urea would need to be priced at \$611.40 ton^{-1} to breakeven with the 2-year average direct operating expenses (Table 5) plus the cost of seed, and urea would need to be priced at \$861.41 ton^{-1} to breakeven with the 2-year average total specified expenses plus the cost of seed. This compares to a 2-year average (2008 and 2009) US retail price of \$519 ton^{-1} urea. As such, it appears that the current price of urea per ton must increase for corn following a pea cover crop to be economically feasible. Alternatively, the price of field pea seed given urea savings (\$98.42 ha^{-1}) using the 2-year average direct operating expenses (\$60.58 ha^{-1}) and the 2-year average US retail price of urea (\$519 ton^{-1}), field pea seed would need to be priced at \$1.18 kg^{-1}. Even in the case of trying to just meet non-seed related field pea direct operating expenses, the urea costs savings were insufficient to allow paying for field pea seed in this analysis. For this to be a profitable practice there must be a decrease in operational expenses, a decrease in field pea seed price, or an increase in urea price.

IV. Conclusions

The use of field peas as a winter cover crop in Arkansas has potential benefits if a successful cover crop can be grown and urea fertilizer prices increase in the future. In both years and in both locations, corn yield was greater following the field pea cover crop when low N rates were applied. These results support the conclusion that a field pea cover crop benefits corn yield in low N fertilizer input production. The corn yield increase at low N fertilizer rates following the field pea cover crop was likely due to larger amounts of available N. This is evident from the results of the AHN soil test. This supports the conclusion that N is the major factor responsible for the increased corn yield.

The "N fertilizer equivalence" of the field pea cover crop in this experiment ranged from 38 kg N ha^{-1} to 108 kg N ha^{-1} and averaged 79 kg N ha^{-1}. Though the range is relatively wide, the average represents a large portion of the N fertilizer requirement of a corn crop. Replacing such a portion of the N fertilization requirement with a field pea cover crop N source could have a positive impact on the environment and not just from N fertilizer savings.

About 1% of total global carbon dioxide emissions by industry come from fertilizer production (Peoples, 2009). Also, fertilizer production constitutes 1-2% of world energy use (Smil, 2001; Hauggaard-Nielsen et al., 2003). By reducing our dependency on commercial fossil fuel based N fixation, we can reduce carbon dioxide emission and decrease energy consumption. An increase in cover crop usage could also increase carbon sequestration from the atmosphere since much of the carbon would be bound in cellular material. The other perceived benefits of the field pea cover crop include decreased erosion, decreased N runoff, decreased N leaching, and increased soil organic matter which enhances other soil properties.

Although the increased use of winter cover crops may be beneficial to the environment, it was not economically justified in this study. This may not be the outcome in every application, and justifies further studies to obtain a broader range of contributing factors and outcomes. Modifications in production practices such as reduced tillage could lower the production cost of using a field pea cover crop. Also, if the cost of N fertilizer rises, the use of a field pea cover crop could become a more acceptable source of N and a profitable production practice.

The use of field peas as a winter cover crop has some varying additional constraints. Biomass growth is unpredictable due to environmental conditions. Field peas are susceptible to *Sclerotina sclerotiorum* (white mold or stem rot) which can inhibit biomass accumulation. To combat the *Sclerotina sclerotiorum* infection, field peas need to be planted on well drained soils and implement crop rotations if an infection does occur or use a different legume cover crop. The unpredictability of estimating the potential N contributions to a succeeding crop will require more N management by the producer when using a field pea cover crop. Not knowing how much N is contributed by the field peas may lead producers to over apply or under apply N fertilizer. With the recent advances made toward an in-season soil N test, and the use of in-season N monitoring tools, the risk of over or under applying N fertilizer may be reduced because of an increased knowledge of the N status during the season.

Additional supporting studies should include testing additional cover crops and cover crop mixtures. Also, supporting studies should include differing production practices to decrease the cost of cover crop implementation and enhance cover crop benefits. Some other cover crops such as clovers, vetches, brassicas, rye, and varying combinations of cover crops may be better suited for an Arkansas environment and the many drainage classes of soils in Arkansas and may be more beneficial. Differing production practices such as reduced tillage and different cover crop desiccation practices may be more beneficial and cost less than the practices used in this study.

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VI. Tables and Figures

Table 1. Mean monthly minimum and maximum air temperatures and total monthly rainfall from 2007 to 2009 in Fayetteville, AR.

Month	2007		2008		2009		30 Year Average	
			Temperature, °C					
	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
Jan.	6.1	-3.9	7.2	-3.3	7.2	-3.9	6.7	-4.4
Feb.	7.8	-1.7	9.4	-0.6	12.2	0.6	10.6	-1.7
Mar.	19.4	8.3	15.6	3.3	15.6	4.4	15.0	3.3
Apr.	17.8	6.7	18.9	5.6	19.4	7.8	20.6	7.8
May	30.6	15.0	23.9	13.3	22.2	12.8	24.4	12.8
June	27.8	18.9	27.8	18.9	30.0	19.4	28.9	17.8
July	30.0	20.0	31.1	20.6	31.7	19.4	31.7	20.6
Aug.	33.3	22.2	29.4	19.4	30.0	18.9	31.7	19.4
Sept.	27.2	16.7	26.1	14.4	24.4	15.0	27.2	15.0
Oct.	22.2	11.7	21.1	8.9	16.7	7.8	21.1	8.3
Nov.	16.1	4.4	14.4	2.2	17.8	6.1	13.9	2.8
Dec.	10.0	-1.7	9.4	-3.3	5.6	-3.3	8.9	-2.2
			Precipitation cm					
Jan.	9.3		3.3		4.2		5.4	
Feb.	5.5		12.4		6.6		6.1	
Mar.	7.0		26.6		9.7		10.6	
Apr.	7.6		26.6		10.0		11.0	
May	8.3		13.6		16.6		12.8	
June	12.4		13.4		11.7		13.4	
July	11.3		19.4		11.9		8.0	
Aug.	6.5		12.1		3.1		7.6	
Sept.	11.7		20.9		11.7		12.3	
Oct.	11.7		9.1		30.0		9.5	
Nov.	14.0		2.9		3.9		12.0	
Dec.	8.2		5.7		3.0		8.1	

Table 2. Mean monthly minimum and maximum air temperatures and total monthly rainfall from 2007 to 2009 in McCrory, AR.

Month	2007		2008		2009		30 Year Average	
	Temperature ºC							
	Max.	Min.	Max.	Min.	Max.	Min.	Max	Min.
Jan.	15	-7.2	18.9	-5.6	16.7	-10.0	7.8	-1.7
Feb.	16.1	-5.0	18.9	-3.9	17.8	-3.3	11.7	0.6
Mar.	22.8	3.3	20.6	-1.1	20.0	-1.7	16.1	5.0
Apr.	23.3	1.7	21.1	5.0	23.3	5.6	21.7	10.0
May	26.7	14.4	26.7	13.3	26.1	13.3	26.1	15.0
June	27.8	22.2	30.6	22.2	32.2	18.9	30.6	20.0
July	28.9	22.2	31.1	23.3	28.9	21.1	32.8	21.7
Aug.	32.2	25	32.2	21.1	29.4	17.8	32.2	20.6
Sept.	27.8	15.6	27.8	16.1	25.0	16.1	28.9	16.7
Oct.	25.6	8.3	23.9	5.6	22.2	8.9	23.3	10.0
Nov.	21.1	0.0	16.7	-1.1	17.8	6.1	16.1	4.4
Dec.	13.3	-1.1	13.3	-9.4	10.0	-3.9	10.6	0.6
	Precipitation cm							
Jan.	13.7		3.5		1.9		9.7	
Feb.	2.7		11.0		7.2		9.7	
Mar.	4.2		24.2		11.2		12.1	
Apr.	8.4		18.3		17.8		13.2	
May	5.2		3.0		18.1		14.5	
June	13.4		3.0		13.3		10.3	
July	4.6		11.9		24.1		7.9	
Aug.	9.0		1.9		10.3		6.4	
Sept.	16.8		3.7		24.6		7.7	
Oct.	11.7		2.3		33.6		9.1	
Nov.	6.9		1.9		3.4		12.1	
Dec.	15.3		8.1		2.5		11.5	

Table 3. Field pea operational expense budget per hectare in 2008.

ITEM	UNIT	PRICE	QUANTITY	AMOUNT
		dollars		dollars
DIRECT EXPENSES				
OPERATOR LABOR				
Tractors	hour	10.91	1.16	12.66
HAND LABOR				
Implements	hour	8.19	0.42	3.44
DIESEL FUEL				
Tractors	liter	0.93	38.80	36.08
REPAIR & MAINTENANCE				
Implements		9.07	1.00	9.07
Tractors		3.95	1.00	3.95
INTEREST ON OPERATING CAPITAL		1.83	1.00	1.83
TOTAL DIRECT EXPENSES				67.03
FIXED EXPENSES				
Implements		18.26	1.00	18.26
Tractors		30.15	1.00	30.15
TOTAL FIXED EXPENSES				48.41
TOTAL SPECIFIED EXPENSES				115.44

Table 4. Field pea operational expense budget per hectare in 2009.

ITEM	UNIT	PRICE	QUANTITY	AMOUNT
		dollars		dollars
DIRECT EXPENSES				
OPERATOR LABOR				
Tractors	hour	11.23	1.16	12.39
HAND LABOR				
Implements	hour	9.06	0.42	3.81
DIESEL FUEL				
Tractors	liter	0.59	38.80	22.89
REPAIR & MAINTENANCE				
Implements		10.01	1.00	10.01
Tractors		4.23	1.00	4.23
INTEREST ON OPERATING CAPITAL		0.79	1.00	0.79
TOTAL DIRECT EXPENSES				54.12
FIXED EXPENSES				
Implements		17.52	1.00	17.52
Tractors		28.89	1.00	28.89
TOTAL FIXED EXPENSES				46.41
TOTAL SPECIFIED EXPENSES				100.53

Table 5. Direct operating expenses and total specified expenses of the field pea cost in 2008, 2009, and an average of 2008, and 2009.

Expenses Included	Dollars ha^{-1}		
	2008	2009	Average (2008,09)
Direct	67.03	54.12	60.58
Total	115.44	100.53	107.99

Table 6. Field pea biomass accumulation, N percentage, and N contribution.

	2008						2009					
Location	kg ha^{-1}	STD[†]	% N	STD	kg N ha^{-1}	STD	kg ha^{-1}	STD	% N	STD	kg N ha^{-1}	STD
Fayetteville	2597	797	1.87	0.27	48.7	13.2	---- [‡]	----	----	----	----	----
McCrory	3160	522	3.32	0.20	104.9	14.5	4187	661	2.36	0.37	98.8	26.3

[†]STD means standard deviation.
[‡]Dashes indicate that no measurement was taken.

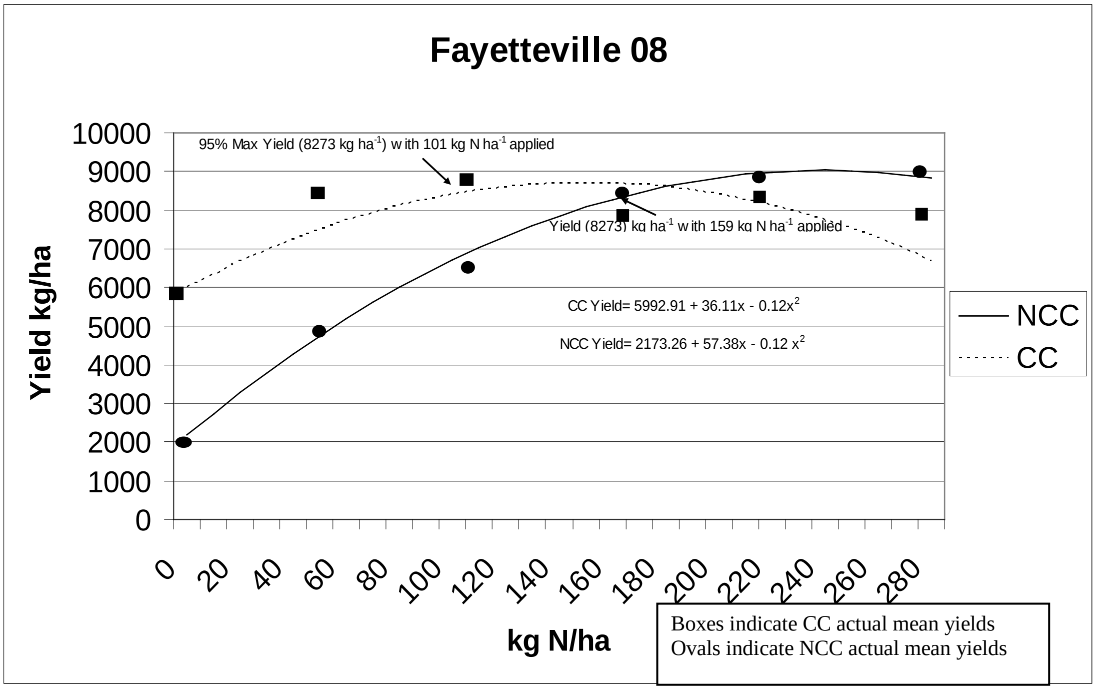

Figure 1. Quadratic equations for yield response to N fertilizer in the presence (CC) and absence (NCC) of a field pea cover crop, Fayetteville 2008.

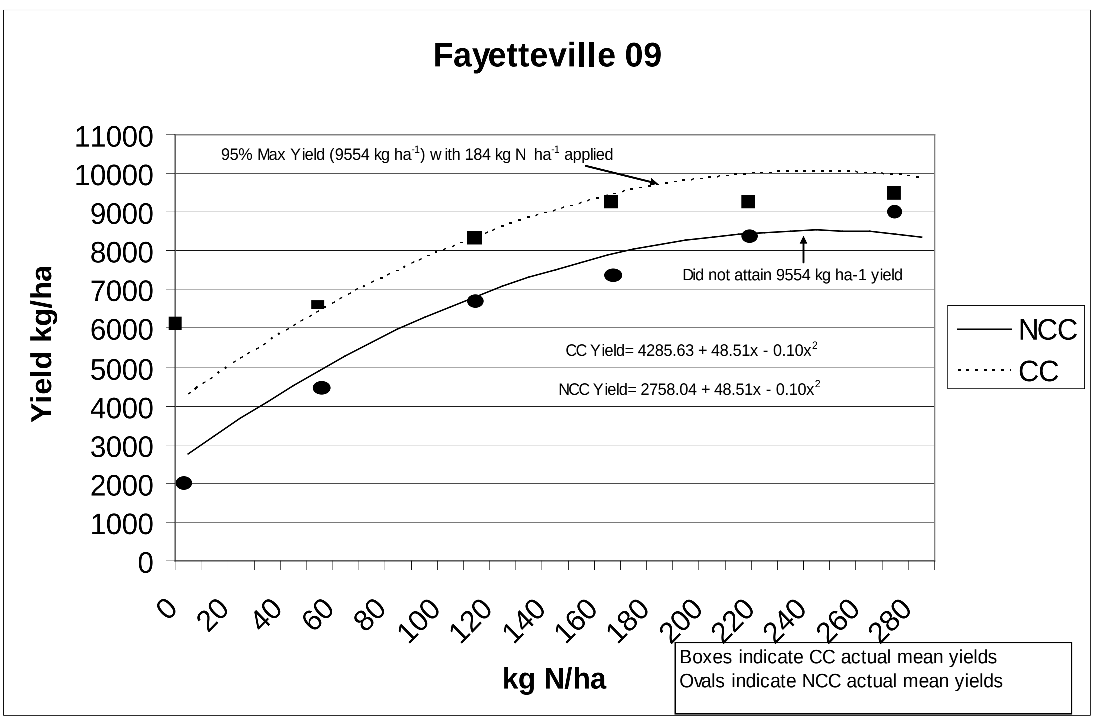

Figure 2. Quadratic equations for yield response to N fertilizer in the presence (CC) and absence (NCC) of a field pea cover crop, Fayetteville 2009.

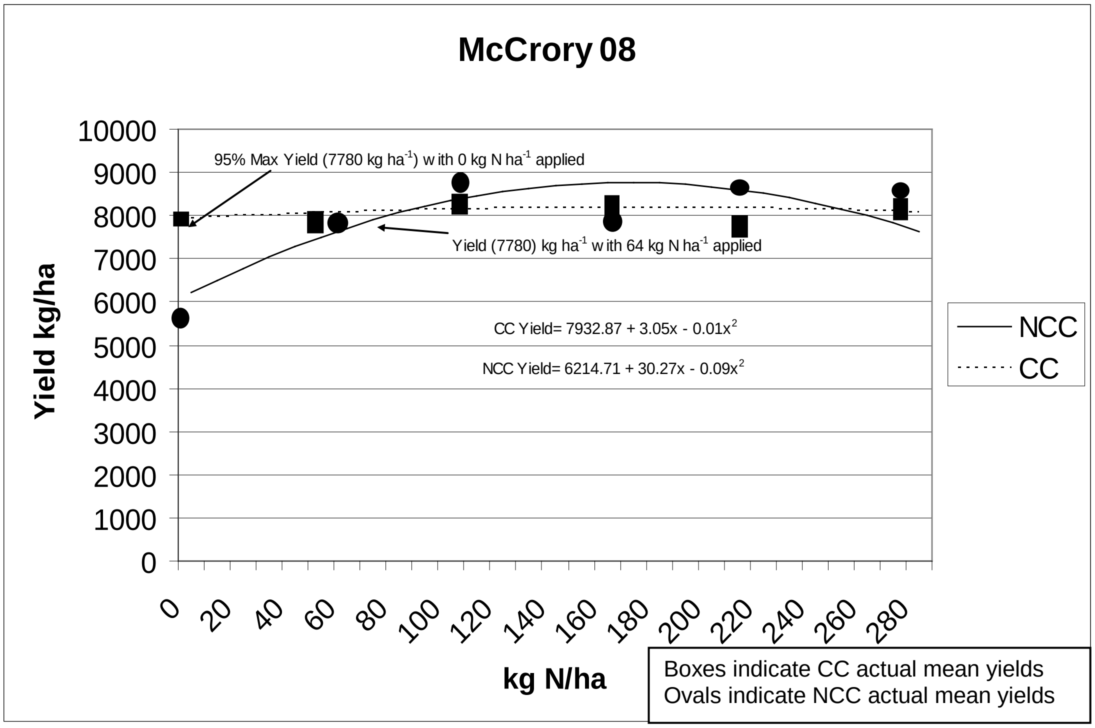

Figure 3. Quadratic equations for yield response to N fertilizer in the presence (CC) and absence (NCC) of a field pea cover crop, McCrory 2008.

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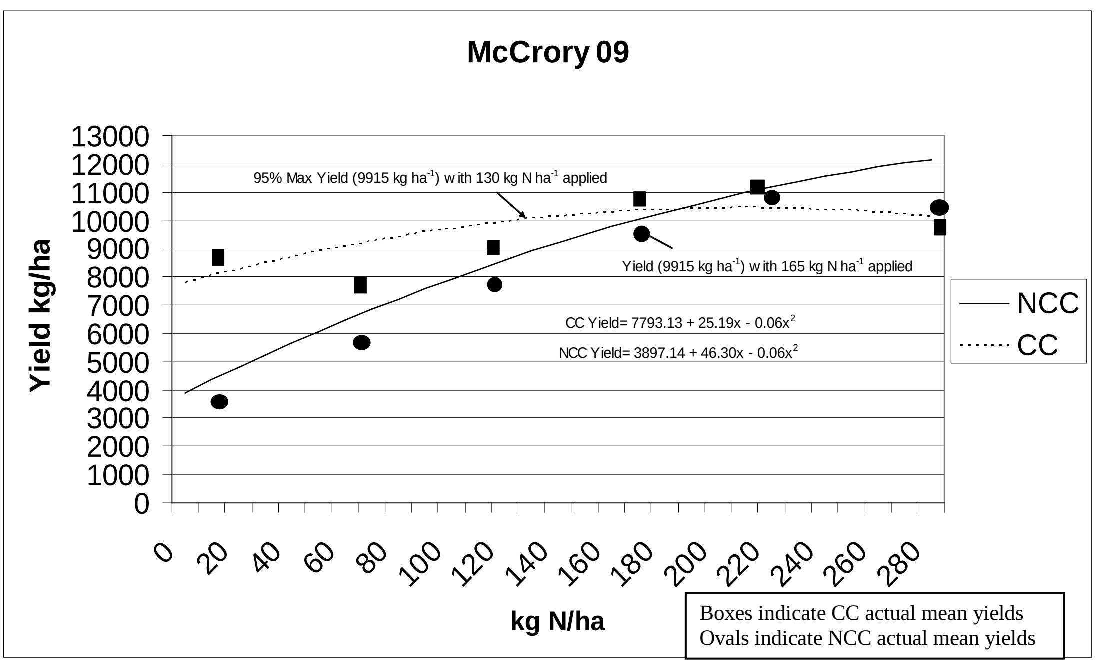

Figure 4. Quadratic equations for yield response to N fertilizer in the presence (CC) and absence (NCC) of a field pea cover crop, McCrory 2009.