5-2008

A study of Irrigation, Fertigation and Plasticulture in Burley Tobacco, with a Focus on Yield, Quality and TSNA Reduction

Eric F. Caldwell
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To the Graduate Council:

I am submitting herewith a thesis written by Eric F. Caldwell entitled "A study of Irrigation, Fertigation and Plasticulture in Burley Tobacco, with a Focus on Yield, Quality and TSNA Reduction." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering Technology.

Brian Leib, Major Professor

We have read this thesis and recommend its acceptance:

Hugh Savoy, Paul Denton, John Tyner

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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A Study of Irrigation, Fertigation and Plasticulture in Burley Tobacco Production with a Focus on Yield, GRI and TSNA Concentration

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Eric Frank Caldwell

May 2008

Dedication

This thesis is dedicated to my brother

Brian Caldwell

who passed away at far too young an age while I was doing this research. It causes me great sorrow somehow to finish this project, but I am comforted in knowing that he'd be proud of me.

Acknowledgements

The author would like to express his appreciation to all members of his committee; to Dr. Brian Leib for his support, guidance, insights and patience and to Dr. Hugh Savoy, Dr. Paul Denton and Dr. John Tyner for their comments assistance and support.

The author would also like to thank the personel at the Highland Rim and Greeneville Experimental Stations and in particular Rob Ellis and Bill Pitt. A great deal of work went into this research, and all of it was carried out very professionally by the staff at these two facilities.

Lastly, the author would like to thank all of his family and friends and in particular, his wife Erica, for their continued support. Without their help and encouragement this moment would have never been possible.

Abstract

Nitrogen fertilization is important in attaining high yielding, quality tobacco. However, practices that use excessive N can be uneconomical, threaten the environment and produce leaves that are high in nitrates. Leaves high in nitrates have been positively correlated with leaves that are high in tobacco specific nitrosamines (TSNA), which are considered potent carcinogens. Competition from cheaper, foreign leaf, increasing costs of fertilizers and new market structures which show purchasers seeking low TSNA leaf demand that producers become more efficient in their N use. The objective of this study is an examination of burley (TN 90) and dark (KY 171) tobacco cultural practices with the hypothesis that optimizing growing conditions will enhance N efficiency.

This experiment took place during 2005 and 2006 in the traditional tobacco growing regions of Springfield (Dickson silt loam) and Greeneville, TN (Lindside silt loam). Experimental isolated growing condition variables. Irrigation treatments isolate the importance of soil moisture. Fertigation, while using irrigation practices, isolates the effects of synchronizing crop N demand with N supply. Plasticulture, using fertigation protocol, isolates the importance of soil temperature. Season long measurements of soil-water tension, soil temperature and leaf nitrates were used to evaluate the ability of each practice to keep plants in optimal N uptake and utilization growing conditions.

Results showed that the most dramatic and consistent treatment effects were found in the TSNA analysis. Even during a season characterized by precipitation being sufficient in volume and timing to meet plant water demands, irrigation was successfully able to decrease TSNA concentration by about 30%. During drier growing seasons, TSNA was reduced by 50% or more. Measurements of leaf nitrates taken with a Horiba

monitor were able to consistently detect treatment and N rate differences. The last sample taken around eight weeks after transplanting correlated strongly with TSNA content (0.81). This tool could prove effective in characterizing optimal N management.

Cultural practices that offer control over soil water tension, nitrate content in leaves and soil temperatures can be effective in increasing the ability of the plant to uptake and utilize N towards achieving high yielding, high GRI quality and low TSNA leaf.

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CHAPTER I

INTRODUCTION

Scientific research and grower's experience have determined that insufficient N can significantly reduce the yield and quality of tobacco. (Miner and Sims, 1983). Because tobacco is a high price crop relative to the cost of N, applications of N above recommended levels of 150-200 pounds per acre (Denton, 2006) are often made to insure that N is not limiting. Although applications of N beyond recommended rates can be profitable to a point, "The motivation for increasing N fertilizer applications is self protection: farmers find it profitable to reduce the probability that they might be 'caught short' of fertilizer" (Babcock, 1992). Growing conditions affect both the demand and the ability of the tobacco plant to uptake and utilize soil N towards growth. During good growing years (plentiful rain and sun), farmers need to apply larger amounts of N than during poor growing years. Without this additional N yield and quality will not be optimized. Because farmers do not know what the growing conditions will be before nitrogen is applied, the rewards offset the risk for them by planning for good years (Babcock, 1992).

Nitrogen is a difficult nutrient to manage and residual N from the previous season is difficult to quantify. In the soil, N exists in many transient forms, ranging from unavailable to highly soluble forms prone to leaching. N can also be lost through a gaseous stage resulting from denitrification and volatilization as it becomes involved in the soil microbe community. N can accumulate in soils under some conditions, however, the rate of accumulation and the length of availability is extremely unpredictable. As such soil N is not included in standard soil tests (Zublena, 1991). Nitrogen application rates that cannot account for the fate of soil N involve a level of uncertainty. This lack of control over the growing media contributes to the need to apply excess N as ‘insurance’.

When tobacco is transplanted into the field, only approximately 2.5% of its total growth will occur during the first three weeks when the plant is becoming established (Reed, et al., 1994). During this stage, while the plant is establishing roots, preplant nitrogen is susceptible to leaching and denitrification. An alternative management practice is to apply N as a split application: part of it as a preplant, with the remainder applied as a side dressing preceding the growth stage of ‘rapid growth’. During the three to eight weeks following establishment, the ‘rapid growth’ stage, will account for 80% of the plant’s total biomass (Reed et al., 1994). This is when plant available N in the soil will be of high demand. During a side-dress application, producers could compensate for estimated leaching losses due to precipitation with additional N being applied. But, there are logistical problems associated with side dressing. While the plants are growing rapidly during this stage, there is a narrow window of time in which machinery can enter the field before the plants become too tall, thus barring entry. If the field is too wet during this time, the opportunity for side dressing is lost and yield and quality will suffer. Experience and research has shown that high yielding, high quality (as measured by the government graded index) tobacco can be attained with high-preplant practices only (Denton et al., 2007). But, the traditional, high-preplant, dryland practice is decidedly inefficient as leaves entering harvest often have high nitrate concentrations. Application rates largely ignore the ability of the plant to utilize soil N towards growth. Growing conditions, including soil moisture and temperature affect the ability of the plant to uptake and utilize soil N. During dry periods, which need not be as severe as drought, nitrates which could have been used to support growth will accumulate in the plant.

There are many reasons that require producers to become more efficient with N practices. N fertilizer is increasingly expensive, meaning it is no longer an inexpensive insurance policy against N being limiting. Also, producers must take into consideration the potentials for environmental contamination of ground and surface waters resulting from N applications made beyond plant uptake potentials. This is increasingly important as the proximity between residential developments and production agriculture increases. Furthermore, current market structures desire a harvested tobacco leaf with lower leaf nitrate and TSNA content, as exemplified by the Philip Morris "Zero Nitrosamine Initiative" (Philip Morris, 2007). TSNA defines a group of highly potent carcinogens that form from free nitrates in leaves and petioles during periods of anaerobic curing.

Under the previous quota market structure, quality was defined by the graded leaf index that used leaf characteristics to determine price per pound. Part of the dissatisfaction exhibit by purchasers under this program involved the large gulf that existed between leaves that were still of a high grade index but contained undesirable levels of nitrates. As nitrate and nitrite in tobacco leaves are the precursors of TSNA, leaf nitrates at harvest have been positively correlated to TSNA content (Xu, et al., 2006). Under the old market structure, purchasers were forced to pay a premium for leaves that contained this undesirable characteristic. With the demise of the quota system, and the emergence of the marketing contract structure, purchasers have more control over the leaf that they buy. Marketing contracts are relationships established between producers and purchasers, beginning before planting even occurs. The producers receive preplant security on a buyer and price for a crop, while the purchaser is able to communicate management practices that will promote the growth of leaves with desirable qualities (Cousineau, 2003).

American tobacco, largely regarded as the highest quality in the world, has not only lost its market share to cheaper foreign leaf, but has also been shown to consistently have significantly higher TSNA content than foreign leaf (Ashley et al., 2003). TSNA also exist in many food products, and history has shown federal regulation to be swift and uncompromising with products such as cured meats and flue-cured tobacco. Government regulation demanded reductions in cured meat TSNA content without providing alternative processing technology. TSNA content in cured meat is in the parts per billion range while air cured tobacco is consistently in the parts per million range. Flue cured curing innovations that lowered TSNA content became a costly, mandatory production procedure often requiring new barn construction (Cousineau, 2003). Considering these USDA actions, and a proclivity for governmental tobacco regulation, buyers are wise to position themselves with growers that will allow them to produce a less carcinogenic product.

The University of Kentucky, while assessing the environmental impact of burley tobacco production in the eight state burley belt, concluded that the average amount of N applied to be 270 lbs/acre (Palmer and Goode, 2003). While these rates may attain a high yielding, high GRI quality harvest, they also contribute to the production of cured leaves with undesirable levels of nitrates, (MacKown et al., 1984) and could lead to detrimental effects on quality of soil and water resources. Tobacco fields that are heavily fertilized with N often have soil acidity-induced Mn toxicity problems (Hiatt, 1963), and could have concentrations of soil nitrate that can potentially lower the quality of ground and surface waters. Even when recommended rates are used, harvested tobacco can be high in unutilized leaf nitrates and substantial residual soil nitrates can still be found in the soil (Zartman and Leggett, 1976).

What is required is a greater understanding into management practices as they affect yield, quality and TSNA concentration. Uptake of soil N is only part of the nutrient equation for the plant. Growing conditions can be optimized which will enhance the plants ability to use N towards growth. This involves the monitoring for and establishment of optimal growing condition parameters as they relate to N use efficiency. These observable parameters should diminish uncertainty and instill confidence in N management that will reduce the need for "insurance'. Future management practices should afford the producer greater flexibility to either control or adapt to growing conditions in a way that can optimize profits.

In this study, four management practices were implemented; dryland, irrigation, fertigation and plasticulture. Dryland is considered the traditional practice and will be used as the basis of comparison. This study will define dryland as using all N as preplant without irrigation. Each additional management practice is designed to isolate the variables of soil water tension, soil temperature and N application rates and timing. At harvest, comparisons were made based upon yield, graded index quality (GRI) and TSNA. During the season, soil water tension, soil temperature and petiole leaf nitrate content were evaluated and related to harvest data.

CHAPTER II

REVIEW OF LITERATURE

The objective of this research is to provide growers with information regarding cultural and management practices that aid profitable tobacco production in new market structures. The air-cured tobacco market underwent a radical transformation in 2004 when the quota system, initiated in 1939 was eliminated. "We have just witnessed the most dramatic change in tobacco policy in more than 65 years, perhaps even the most dramatic change in any agricultural policy in the last half century with tobacco's new distinction as the only government supported crop moving to a totally free market." (Tiller, 2004). A review of the literature will help identify qualities of leaf that are demanded in the increasingly important contract market, along with cultural practices that can most cost effectively achieve these qualities.

The now defunct, legislatively created quota system was representative of an era when tobacco was so profitable that quotas were allotted to control entry into tobacco growing. This structure was successful at creating market stability, protecting small growers and profits while still dominating the world-wide market share. During the 1950-1960 era, tobacco farmers accounted for 77 percent of the total global production (Kuegel and Myers, 2001). Currently U.S. exports have declined to about 18% of the global market, with cigarettes manufactured in the U.S. now containing 48% foreign leaf. A cursory look at the current market would conclude that American tobacco was no longer able to compete against cheaper, foreign leaf. Furthermore, it is implied that a market that protected small growers neither provided the impetus for innovation nor the economies of scale that could support innovation (Tiller, 2004).

Tobacco represents well the term, “traditional growing practice”, as cultural practices have remained relatively the same for many generations. This growing practice is referred to as dryland. It consists of nitrogen being applied preplant without the use of irrigation. The quota system of an allotment of tobacco growing acreage or poundage has historically kept farms small and unable to support the infrastructure and development associated with an irrigation system. This is a reasonable growing practice as tobacco is considered to be somewhat tolerant to drought and intolerant to flooded soils (Denton 2003). Average to good precipitation in a humid region such as Tennessee is also, on average, sufficient to meet seasonal plant water needs (Akehurst, 1981).

The quota system limits the poundage that each allotment owner can produce. These quota levels were established based upon previous years sales and expected demand. Decreasing demand consistently saw the allotment lowered in the final years of the system. From 1997 – 2000, burley tobacco had experienced a 65 percent decline in allotment. As quota levels continually declined, buyers would be able to receive adequate supply, but would be forced to accept as a portion of that supply an unacceptable portion of tobacco that is not of the appropriate quality to meet their needs (Cousineau, 2001). The government grade index (GRI) was used to determine the price per pound in the quota market. This system used qualities such as color as they are “strongly correlated with desired qualities that cannot be measured by visual inspection” (Abdullah, 1970). Nitrate content of the leaf after curing was not considered in price determination. Under the previous quota system, cured leaf high in nitrates could still earn a high price. This has resulted in nitrate levels in cigarette tobacco rising from 0.3-0.5% in 1950 to 0.6-1.35% in 1995 (Hoffman and Hoffman, 1997). The increased nitrate concentration in the cigarettes equates enhanced formation of TSNA. Buyers were forced to pay a premium for tobacco receiving a high quality grade index value, but this tobacco did not provide qualities that matched corporate mission goals of achieving healthier products (Philip Morris, 2007).

Perhaps in response to declining domestic quality and increased production costs, foreign leaf quality has also increased due to substantial investments in technology, training, seeds and money form major US cigarette companies and leaf dealers over recent decades (Cousineau, 2003). Concurrently, technological processing improvements enabled cigarette companies to maintain adequate taste and flavor levels while using a higher proportion of lower quality leaf. Also, many foreign smokers of American blend cigarettes are attracted more by the status of the cigarettes than by their taste. Simply having a U.S. brand name or some other link to the U.S. is often enough to sell American blend cigarettes overseas, even if they contain no U.S. tobacco. (Kuegel and Myers, 2001).

The literature suggests that each of these factors contributed to decreasing demand in the more expensive domestic leaf and ultimately the demise of the quota system even before it was legislatively ended at the end of the 2004 growing season. But, the market would not be accurately categorized as simply demanding a cheaper product. For U.S. growers to remain profitable, they must produce a leaf with fewer input costs while meeting the buyers desired quality characteristics.

Increasingly, Philip Morris has been relying on contracting for it's domestic burley supply. It created the Tobacco Farmer Partnering Program in the year 2000 with over 10,000 burley producers (Philip Morris, 2007). Because of Philip Morris' dominant position in the domestic market, the contracting program was quickly followed by others in the industry. In 2002, 75% of TN burley production was marketed through direct sales (Tiller, 2004). Desired quality characteristics can be better understood by looking at these contract arrangements.

According to Philip Morris representatives, the principal reason for establishing contract relationships was a need for supply security. Specifically, Philip Morris expressed concern that it was having increasing difficulty purchasing sufficient quantities of the specific grades of tobacco it requires. The system for grading and auctioning tobacco does not meet the differential values of the quality grades it desires. Another primary buyer benefit of contracting for the buyer is the "increased rate of technological innovations necessary to address specific quality or regulatory concerns (e.g., reduced TSNA/nicotine levels) (Snell and Green, 2001). The buyer/seller agreements are marketing contracts meaning that the growers retain ownership of the leaf and the right to refuse the price at sale if they think it will do better at auction, but they do contain elements of production contracts. The contract specifies that, "Contracted tobacco must be produced and cured using recommended agronomic and cultural practices, using only seed varieties that meet minimum standards" (Snell and Green, 2001). One of the approved agronomical practices is the limitation of total N applied (Barron, 2007).

In exchange for the predictability of a contracted price, the buyer is given some control over the quantity and quality of tobacco that will be available to them while being able to avoid the auction system.

This contract allows for communication between buyer and producer regarding specific qualities outside of government grades. Product traceability allows for a mechanism to monitor and recommend specific agricultural practices. As a mission goal, Philip Morris lists creating a “less harmful product”. With increased control over supply, Philip Morris hopes to launch a “Zero Nitrosamine Initiative” that works toward achieving this goal (Philip Morris, 2007). Nitrosamines are considered to be potent carcinogens in cigarettes. A strong correlation between nitrate levels in the plant at harvest and TSNA levels after curing (Burneman and Hoffman, 1991).

Marketing contracts have been present in flue-cured tobacco since 1999. In 1999, Star tobacco began marketing ‘StarCure tobacco’, produced using a proprietary process that reduced the formation of carcinogenic toxins present in flue-cured tobacco smoke, primarily TSNA. Flue-cured tobacco contracts began as buyers expressed an interest in this low TSNA tobacco (Hull, 2001). The USDA moved to have all flue-cured tobacco cured in this manner by June 2001 (Cousineau, 2003). This is evidence of technology reshaping markets and management practices overnight. In the instance of flue-cured tobacco, these technologies were costly in that they often required retrofitting barns.

Decreasing nitrosamines has become an industry priority. Using the example of flue-cured tobacco, where the USDA acted swiftly and uncompromisingly to reduce nitrosamines, purchasers are wise to position themselves with practices and growers that can provide leaves low in nitrosamines.

Nitrosamines are found not only in tobacco but also in food products. For centuries, nitrite was used to preserve meats, fish and poultry. Nitrites cured meat against many food-borne bacterium including botulism. In the late 1970's there was concern about a potential cancer risk when nitrites bonded with alkaloids forming nitrosamines. In the 1980's the USDA established maximum nitrosamine levels forcing the meat industry to find a substitute for nitrite curing while still providing protection from bacteria. The nitrosamine levels found in meats are in the range of parts per billion. For instance, bacon must contain below 5 ppb nitrosamines. The amounts of tobacco specific nitrosamines of a single cigarette are often 250 times higher than the nitrosamine levels of 1 gram of cooked bacon (USDA, 1978). Air-cured tobacco, as of yet, is not regulated even though nitrosamine levels are typically found in the parts per million range. This does not mean that regulatory legislation should not be expected. Nor should nitrosamine regulation be expected to be enacted any slower than it has been with flue cured tobacco and the food industry.

TSNA is formed during tobacco curing by nitrosation of tobacco alkaloids. The nitrosating agent is nitrite. The source of nitrite during the air-curing process is microbial. The time for microorganisms to produce nitrite from nitrate is by the end of yellowing when the cells in tobacco leaves loose their integrity and the cellular content is leaking into the intercellular space. Nutrition is then made accessible to microorganisms and the water content in the tobacco is high enough for bacteria to grow. Nitrite may accumulate as a result of nitrate reduction by bacteria and TSNA are formed by chemical reactions between nitrite (source of nitrosating species) and alkaloids. At the end of the curing process the water content in tobacco is too low, <40% for bacteria to grow and contribute to further production of nitirite (Parsons et al., 1986). Thus the amount of nitrates in tobacco at harvest has an important effect on the level of TSNA. The final level of TSNA in tobacco is dependent on these factors: tobacco variety and agronomic conditions which affect the initial alkaloid and nitrate concentrations; curing conditions during which nitrosation of the alkaloids occurs (Davis and Nielsen, 1990).

Since 1950, the makeup of cigarettes and the composition of cigarette smoke have gradually changed. In the 1970's the particulates in cigarettes were thought to be the casual agent of cancer (Hoffman and Hoffman, 1997). In the United States, the sales-weighted average "tar" and nicotine yields have declined from a high of 38 mg "tar" and 2.7 mg nicotine in 1954 to 12 mg and 0.95 mg in 1992, respectively. In the United Kingdom, the decline was from about 32 mg "tar" and 2.2 mg nicotine to less than 12 mg "tar" and 1.0 mg nicotine per cigarette. During the same time, other smoke constituents changed correspondingly. In most countries where tobacco blends with air-cured (burley) tobacco are used, the nitrate content of the cigarette tobacco increased. In the United States nitrate levels in cigarette tobacco rose from 0.3-0.5% to 0.6-1.35% in 1995, thereby enhancing the combustion of the tobacco. More complete combustion decreases the carcinogenic polycyclic aromatic hydrocarbon, yet the increased nitrate content in uncured leaf has corresponded with higher TSNA content after curing (Hecht and Hoffman, 1988). "While the complexity of tobacco smoke prevents establishment of a cause and effect relationship to any specific carcinogen, TSNA certainly plays a significant role in cancer induction" (Gray and Boyle, 2001).

Under optimal growing conditions, increases in total N concentrations found in tobacco can be attributed to the use of nitrogen fertilizers. Nitrate nitrogen only forms a small proportion (5-15%) of the total nitrogen content of tobacco. Protein N constitutes about 75% total nitrogen while alkaloids contain about 15%. Because the protein N and alkaloid N concentration is fairly constant, any variation in total N can be reasonably attributed to the variation in the nitrate portion of total N (Axford, 1998). These results, found under environmental constants of laboratory conditions are not always reflected in field grown tobacco. A three year series of experiments showed little relationship between rate of nitrogen fertilizer and leaf content of nitrogen (Askew et al., 1947). The authors concluded, in agreement with a previous study by Darkis et al. (1936), that weather conditions, primarily precipitation but also temperature were a much more important factor than fertilizer rates in determining nitrate concentrations in tobacco. The increased concentration of nitrates could be due to the plants inability to utilize N towards growth in less than optimal soil water conditions, but there are likely other contributing factors. In a comprehensive book titled, 'Tobacco', Akehurst concluded that the increased nitrate concentration is due in some part to the increased concentration of soluble N in diminished soil water found during dry periods. It is also likely that the plant is accumulating nitrate ions to increase the osmotic tension by which water is attracted to and held by the plant during dry periods (Akehurst, 1981).

In summation, under ideal growing conditions, nitrate concentrations in the plant can be reasonably attributed to N fertilizer rates. Environmental conditions, primarily precipitation and to a lesser degree temperature, will more directly effect the total N concentration of the plant by increasing the nitrate concentration.

Nitrogen fertilizer is of great concern as it is considered to be the most important of the inputs that a tobacco farmer has control over, as it effects the development of the leaf and its properties after it has been cured (McEvoy, 1945). Optimal nitrogen levels markedly increase leaf size with a tendency for a relatively greater width expansion (Garner et al., 1934). As the pricing of foreign leaf becomes more competitive, and as marketing contracts are increasingly limiting the amount of N fertilizer that a grower can use (Baron, 2007), management practices must be reconsidered in ways that will more efficiently use N. Typical burley tobacco yields can produce between 2.5 to 3 tons of dry matter per acre, while dark can be expected to produce even slightly higher yields of 3 to 3.5 tons per acre. This is achieved during a growing period that only lasts about 85-95 days in the field. Such intensive production can be expected to remove about 200 lb nitrogen, 35 lb phosphate, and 240 lb potash per acre from the soil (Peedin, 2004). Of these, Nitrogen is the single most important nutrient required for attaining high yielding, high quality tobacco (Miner and Sims, 1983). Nitrogen is an integral component of many essential plant compounds. It is a major part of all amino acids, which are the building blocks of all proteins-including the enzymes, which control virtually all biological processes. Other critical nitrogen components include the nucleic acids, and chlorophyll, which is at the heart of photosynthesis. Nitrogen is also essential for carbohydrate use within plants. A good supply of nitrogen stimulates root growth and development, as well as the uptake of other nutrients (Brady, 2002)

With rising fuel costs, ammonium nitrate costs about .183 $/lb in 2006 while it cost approximately 0.098 $/lb only five years earlier in 2001. By the ton, ammonia prices increased from $227 per ton in 2000 to $521 per ton in 2006, an increase of 130%. (Huand, 2007). Ammonium nitrate has a 34% N analysis meaning an additional 50 lbs of N will cost $26.91. But, this is assuming all things remain equal, which they are not in fertilizer production. Ammonium nitrate has been the dominant source of fertilizer N for tobacco in recent years. It is relatively easy to transport, store and apply with equipment common on most tobacco farms. The mix of ammonical-N (AN) and nitrate-N helps to balance N availability through the growing season and matches well with growth stage demands. However, there have been increasingly stringent regulations being placed on transport, storage, and sale of AN as a result of homeland security concerns. Some manufacturers have stopped or limited production of AN and some dealers are reluctant to store large quantities. These factors suggest that the price per pound may rise at rates that are not proportional simply to energy costs. The alternative to paying more for AN is to switch fertilizers. Urea has been used in the past by tobacco growers and historically has had a lower cost per pound of N than AN. The urea analysis is 46% N compared to 34% N for AN. Before N in urea can be used by tobacco plants, it must first be converted to ammonium and then to nitrate. This conversion is readily carried out by enzymes and microorganisms that are common in the soil. However, some of the N in urea may be lost into the air during this conversion if the fertilizer is left exposed on the soil surface. To reduce these losses, urea can be applied as a liquid where it will be watered into the soil during an irrigation cycle. This could best be achieved through irrigation after application of N, or through fertigation. A cover such as a plastic mulch will further limit gaseous losses of N. Timing of application must be monitored as urea can take between 2 and 3 weeks to be fully converted into nitrate from the ammonium stage. (Pearce et al., 2006) The cost per ton of Urea is about the same as ammonium nitrate (0.181$/lb in 2006 and 0.095$/lb in 2001) according to the USDA, but the analysis of urea is 46% N. This equates $19.67 for every 50 lbs of N. In addition to the reduced cost of urea, if there is a drip tape irrigation system in place, applications are not limited by size of the plant or condition of the field.

Extension agents and researchers have expressed concern over the amount of N that farmers consistently apply to fields. Extension agent Ronald Barron of Cheatham county, TN reports that, "Recently, many tobacco farmers have reduced their nitrogen rates and altered their application timing. Much of this is due to the buyers concerns over TSNA levels, and also requirements from buyers to limit N use. Even though he believes N rates have been reduced, he still has yet to see a true nitrogen deficiency in a field (other than those caused by lack of moisture, soil compaction, etc) (Barron, 2007).

Aside from increasing fertilizer costs, there are long-term field implications involved with excessive N application. Growing high yielding, high quality tobacco requires an understanding of the short term and long term consequences of management practices. Unless some other factor is limiting, growth rates and N uptake are usually increased as concentration of available soil N increases from deficient to adequate. Increased N uptake will correspond to increased plant growth. Yet, when relatively large amounts of N fertilizer are applied to the soil, as commonly are applied in burley tobacco production (200-300 lb/acre), soil acidity is increased and problems generally attributed to manganese toxicity may occur (Reneau et al., 1968). Soil pH values within the range of 5.5-6.0 are best for most tobacco varieties, particularly when considering diseases (Valleau et al., 1954). Addition of high rates of P,K, and N fertilizes to silt loam soils can result in soil pH values of 0.5-1 pH unit lower than initial values for most of the growing season (Reneau et al., 1968). Lowered pH results in solubilizing Mn and Al that may be toxic to tobacco plants and in rendering soil Mo, Ca, and Mg less available to plants. Additionally, low soil pH may decrease rates of nitirification of ammonium N. Burley tobacco fields that are heavily fertilized with N often have soil acidity-induced Mn toxicity problems (Miner and Sims, 1983).

Under such conditions growth of tobacco may be retarded during approximately the first half of the growing season. In a study performed by Sims and Atkinson, at 40 days after transplanting, the dry weight of plants treated with 400 lb N/acre was about half that of plants receiving zero N fertilizer. Thereafter, dry matter accumulation in plants treated with high rates of N equaled or exceeded that in plants treated with no N. This retarded growth is attributed to nutritional problems due to increased soil acidity and Mn toxicity (Sims and Atkinson, 1973). Although the high N treatments caught up to and exceeded zero N treatments in the second half of the growing season, there were consequences to this delayed growth particularly evident in accumulated leaf nitrates. Higher leaf nitrates in the high N treatments resulted in slower protein synthesis during early growth. During early growth stages nitrate reduction to amine forms also was slower than in the zero N treatments.

Soil microbes perform important functions in making N available to plants. Soil organisms are able to mineralize organic matter into plant available ammonium and nitrate. This is done most efficiently when conditions are warm and moist. Although plants can take up ammonium, soil microbes effectively out-compete plants for much of the available ammonium. Plants rely largely on the nitrifying bacteria nitrosomonas and nitrobacter to convert ammonium into plant available nitrate. These are considered to be one of the most sensitive groups of soil organisms to soil acidity. Even though these nitrifiers produce acid during oxidation, optimal pH is 8 and optimal temperature is 80^{o}C.

If a large source of nitrogen is dumped into the environment, these organisms can potentially kill themselves by metabolizing it to nitric acid, unless pH is buffered (Edwards, 1988). Perhaps what makes dryland a viable practice is that the acidity and cooler soil temperatures in the Spring, effectively act to encourage a slow release of N. But it would seem more desirable to control the rate of this reaction by feeding the microbes ammonium in proportion to the amount of nitrate desired instead of overwhelming the system which is sure to have unpredictable consequences.

One example of such an unpredictable consequence resulting from overwhelming a soil system comes from an examination of the symbiotic mychorrhizae. Mycorrhizal fungi are known to extend uptake capability particularly for immobile ions but also for water and nitrogen. The mutualistic relationships that result from mychorrizhal inoculation are not as stable as the word symbiotic infers. There is a cost in carbohydrates to the plant that send out the complex chemical signal allowing for inoculation. If the plant is provided with nutrients that are readily available in the soil, not only is rooting limited, but also the cost of mutualism is avoided. When the mutualistic relationship is denied, the fungi may turn to parasitism for survival. (Hendrix et al, 1995).

Research regarding split N applications attempts to improve upon N efficiency in preplant practices by synchronizing applications of N more closely to plant demand of N. The premise is that applications of N split over two events limits the amount of time that the total amount of N is in the field reducing the time that it may be lost. Split applications allow the grower to account for perceived losses due to leaching during periods of heavy rains. Greater control over the amount of N in the field reduces uncertainty and thus the need to apply N in excess to insure that it is not limiting.

University researchers in Tennessee, Virginia and Kentucky conducted a two year series of nitrogen fertilization experiments on burley tobacco within their states (Denton, 2007). This study used nine combinations of preplant and sidedressed N, with a total N ranging from 80 to 340 pounds per acre. The three preplant N rates were 80, 160 and 240 pounds. The three sidedressed rates were 0, 50 and 100 pounds/acre. Often, traditional management practices apply all nitrogen preplant and this is representative of the protocol for dryland treatments. There are additional labor and equipment charges associated with sidedressing. There is also the potential of damaging plants as applications are made three weeks after the plant is established. There is also the risk of not being able to enter a field that may be too wet from precipitation, thus missing the window of time for application before the plant enters the stage of rapid growth. This study justifies the use of large N preplant practices with regards to yield. The highest yielding plot had applied 240 pounds of N preplant and 0 pounds sidedressed, averaged 2,707 pounds per acre.

When TSNA was measured in this study, increased N applied equated increased TSNA. It didn't seem to matter whether the N was applied preplant or sidedressed. The only TSNA treatment affect resulted from total rate differences. With regards to TSNA, the preplant application of N seems no less or more effective in achieving low TSNA than split application practices. The split rate applications were limited by plant size to three weeks after transplanting. Split applications did not achieve higher yields, but achieved statistically similar yields with slightly less total N and are therefore considered to be more efficient. This study determined the more efficient management practice consisted of using 80 pounds N preplant and 100 pounds sidedressed. This practice attained yields comparable to the high N preplant yields with an average yield of 2,622 pounds per acre.

The drip tape used in irrigation can be used to apply liquid or dissolved forms of N (Keller and Karmeli, 1973). Part of the total N is applied preplant, as sufficient levels of plant available N are required for the transplants to effectively root during plant establishment. The other fractions of the total N are applied over split applications that can easily allow the producer to apply N when growth stages demand it or compensate for N lost due to leaching. The literature does not show experimentation with the use of fertigation in air-cured tobacco. Fertigation provides the capabilities of applying N whenever the plant requires it without regard to accessibility to the field by a tractor. The use of split applications achieved a small efficiency in the Denton et al. study. It is possible that these results may be enhanced by splitting the applications up further, and further along in the growing season, effectively, 'spoon-feeding' the plant N. Multiple, small applications of N result in decreased N losses by decreasing the N residency time in the soil, while increasing the certainty of the soil N concentration.

Growers, faced with increasing fertilizer costs, marketing contracts that limit the amount of N that can be applied to a field and purchasers desire for attaining tobacco leaves with lower TSNA, must effectively develop management practices that will utilize N efficiently. Management practices should consider application timing and rates so as to limit losses to the environment. There should be consideration given for plant growth stages as the demand for N changes. Furthermore, it is a premise of this research that cultural practices that keep plants in optimal growing conditions with respect to soil moisture, soil N and soil temperature will enhance uptake and utilization of N for use towards growth.

Nitrate is considered highly mobile in the plant as it is able to be transported through the phloem (Nye and Tinker, 1969). For this reason, the seedlings (up to one week after transplanting) will accumulate nitrate at rates to support optimal growth while maintaining a constant N internal concentration rate. If the soil nutrient concentration falls below a critical level in seedlings, the internal concentration will remain the same, but shoot weight will be reduced (Clarkson, 1974). This supports the positive correlation widely accepted between soil N concentration and plant biomass, and supports yield results that correlate N rates applied and yield attained. But this N availability and plant N uptake relationship changes as the plant becomes established in the field. Correlating this change in N uptake, the literature supports a possible explanation found in plant physiology. Seedlings are said to prefer ammonium uptake while more established plants prefer nitrate (Yoshida, 1963). It is also reported that plants utilize nitrate more efficiently in soils that are slightly acidic whereas ammonium ions were most readily used in the pH ranges of 7-9. The change in uptake of N from ammonium to nitrate may be due to physiological changes in the plant as it approaches establishment, or it may be in part due to the change in pH from seedling beds to increasing acidic soils as ammonium is converted (McEvoy, 1957).

Nitrate uptake is only part of the picture for the plant. Equally important is an understanding of nitrate utilization by the plant and growing conditions and practices that can enhance N use efficiency. Once nitrate has been taken up by the plant, it must be reduced from nitrate to ammonium for it to be in a form that the plant is able to use.

Nitrate reduction comes with a high energy cost of NADH or NADPH to the plant. Eight electrons are required to reduce one nitrate to ammonium, whereas only four are required to reduce CO_2 to the carbohydrate level. Accordingly, a C/N ratio of 10:1 in the plant biomass indicates that about 20% of the photosynthetically produced electrons are consumed for nitrate reduction. Thus, “luxury” reduction should be avoided (Kaiser, 1994). It would not be efficient for the plant to reduce any more nitrate than is required to support growth.

In tobacco, more than 80% of this reduction occurs in the leaves. The maximum nitrate reductace activity (NRA) occurs when the leaves are at 27% of their final weight and 33% of their final area. Thereafter, the NRA activity declines as the leaf continues to expand and age (Wakhloo and Staudt, 1998). Nitrates first reduction stage is to nitrite which is toxic to plants when present in concentrations of only a few parts per million, and then ammonium, which if accumulated in the leaf will have adverse affects on plant physiology. Tobacco fertilized only with ammonium will have lower biomass than nitrate and ammonium nitrate fed plants (Yoshida, 1966). They show reduced transpiration rates, poor stomatal conduction and decreased potassium uptake and translocation (Lu et al., 2005), symptoms commonly referred to as ammonium toxicity. It would than be considered beneficial for healthy plant growth to have nitrate reductase activity coordinated with the plants demand for ammonium. The tobacco plant uses its control over reductase activity to limit the amount of nitrate being reduced. An adverse consequence of this synchronization is that plants that have delayed development will have increasing difficulty reducing nitrate towards growth during later growth stages.

The NRA enzyme has a half life of only a few hours which allows for the plant to control reduction rates. (Li and Oaks, 1993) NRA activity rates are reflective of environmental conditions and therefore attention to management practices should create conditions where NRA potential is optimized when growth stages demand ammonium. During the night, reduction has been shown to drop by as much as 50-85% (Huber et al., 1999). NRA is also limited by the absence of CO_2. As CO_2 is required for photosynthesis, the plant will regulate reduction during period of low N demand. Closure of stomates during periods of drought stress results in decreased water loss but also results in a decrease of CO_2 supply to photosynthesis. This is of particular interest as stomates are very sensitive to water stress and will close when changes in the plant water status are not yet even measurable (Schulze, 1986). From day 1 through day 5 of drought stress induced in pot grown tobacco, NRA will drop in a linear fashion to only 10% of its original capacity (Foyer et al, 1988). This is not to say that the enzyme requires CO_2. The exact reasons for this correlation have not been determined. It is only certain that there are some combinations of factors contributing to the inhibition of NRA as a regulatory mechanism enacted by the plant during periods of low ammonium demand. One study concluded that low CO_2 concentrations inhibit the transport of nitrate across the plasmalemma or the tonoplast (Werner et al., 1989). It is also possible that cyanide or a related compound formed in leaves at low CO_2 concentrations is also involved in deactivation of NR in plants (Lorimer and Gewitz, 1974). During periods of drought stress, the plant will continue to uptake nitrate. The result of drought stress is a high concentration of nitrate with impaired ability of the plant to reduce it towards growth.

High concentrations of nitrates in the leaf have also been shown to correlate strongly with a long-term decrease in the growth rate of plants roots (Scheible et al, 1997). As mentioned earlier, decreased root growth rate is correlated with decreased nitrate uptake, that in part, accounts for the delay of restoring normal nitrate uptake and reduction even after soil moisture has been restored.

Tobacco is considered to be somewhat tolerant to drought, and intolerant to flooded soils. Average to good precipitation in a humid region such as Tennessee is considered to be sufficient to meet tobacco plants water needs. Therefore, farmers do not extensively rely on irrigation systems (USDA, 1997). Also, the quota system of allotment of tobacco growing acreage has historically kept farms small and therefore less likely to be able to support the infrastructure and developmental costs associated with supporting an irrigation system. Tobacco does best in deep, fertile soils of Kentucky and Tennessee with reddish-brown silt loams of limestone origin with subsoils of well structured silty clays. The water holding capacity of these soils is 'good' and able to help maintain growth through periods of erratic precipitation (Akehurst, 1981).

In Tennessee, rainfall can be expected to contribute a little more than four inches of rain in May, close to four and a half in June, which is when the plant is requiring the most water to support 'rapid growth', and a little less than four inches in July, and close to three and a half in August, which is when decreased rain is desirable as the plant is yellowing in the field (NOAH, 2007). If these rain events are well distributed, these amounts should be sufficient to achieve high yielding, high quality tobacco.

It is difficult to assess the value of an irrigation system in tobacco as irrigation retains value as insurance against dry periods in a growing season. Many cultural practices develop from producers experience, and experience would tell them that normal, well distributed precipitation will be sufficient to provide high yielding, high quality tobacco. Yet, what makes precipitation sufficiency difficult to quantify is the specific importance of distribution. Either excess or too little at critical growth stages often affects growth and quality of tobacco as much or more than total rainfall during the growing season (Mulchi, 1985). Tobacco quality is heavily influenced by the moisture regime of its environment (Akehurst, 1981). The importance of rainfall timing is evident in the tobacco crop of 1999. Early summer precipitation was good, and projections for yields were high. Those that planted in early May, while precipitation was good, reported average to excellent yields, while those that planted late and faced drought conditions near the end of the season, reported between average yields and yields that were considered to be a total loss (Danekas, 2000).

There are many studies in the literature citing the effects of water stress on total uptake of N and concentration of N in tobacco. These studies support the importance of soil moisture, not only during drought conditions, but also in optimizing soil moisture levels as a way to enhance the quality of tobacco leaves as demanded by new market structures.

Van Bavel (1953) found that total N concentration found in the plant after curing was significantly higher in flue-cured tobacco when water tensions increased past -100 kPa water pressure for a total of 33 days during the growing season in non-irrigated plots. Yield and quality were found to be significantly higher in irrigated plots. These days occurred primarily between weeks 3-10 after transplanting. Irrigated plots received water when tensions approached -30 kPa in one treatment and -80 kPa of tension in the other.

It is noted that yield, quality and total N concentration were similar between these two irrigated rates. This confirms a previous study that found total N concentration was up to 30% lower in wet years as compared to dry years (Darkis et al., 1937). Atkinson (1981) found that irrigation increased N uptake of burley tobacco in 100 lb N and 300 lb N acre plots while lowering the total N found in the plant after curing. Plant size was increased more by irrigation than by N fertilization in this experiment. Acre yields of cured leaf were increased by both irrigation and N fertilization and the response to nitrogen was much greater on irrigated treatments. Total N, total alkaloids and nitrate concentrations in cured leaf increased as N fertlization was increased but irrigation reduced concentrations of N constituents in the leaf when compared to non irrigated treatments.

Recently, there has been experimentation with the use of drip tape irrigation that applies water directly and slowly to the plant allowing for infiltration and efficient use of water. In a five year study, which is expected to more fairly represent expected precipitation amounts, Dr. John Buchanan from the University of Tennessee, showed the use of drip tape irrigation can be expected to be profitable enough to pay for itself and insure the producer of steady revenue returns. Non-irrigated burley plots averaged 2824 lb/acre, while plots receiving one inch of water every ten days with rain being supported by irrigation, averaged 3165 lbs/acre. The average increase in irrigated plots was 341 lbs/acre per year (Buchanan et al., 2005).

What may be of more interest are the level of TSNA found in irrigated as compared to non-irrigated crops. Experiments with irrigation have shown a reduction in leaf nitrate beginning with early flowering. The reasons for this are not certain, but are believed to be in part, due to nitrates being converted into amino acids and other compounds more readily utilized during leaf ripening in plants with optimal soil moisture. A plant can undergo up to five days of drought conditions with little visible sign of stress, but nitrate reductase activity will decline almost immediately at the onset of drought stress (Sifola and Postiglione, 2003). As nitrosamines form from residual nitrates in the leaf at harvest during curing, reduced leaf nitrate contents at harvest are expected to achieve reduced TSNA concentration after curing.

The growth stages of particular concern regarding N demand are; ‘establishment’, ‘rapid growth’ and ‘flowering’. During ‘establishment’, nitrate is taken up by the plant in response to the growth rate of the plant. As the plant develops and increases biomass, the concentration of nitrate within the plant remains the same. Plant development during this stage is correlated to external N supply (Rideout and Raper, 1993). Once ‘established’, the plant is ready to enter the ‘rapid growth’ stage, which occurs approximately four weeks after transplanting. ‘Rapid growth’ is also referred to as ‘exponential growth’ meaning the plant will grow exponentially related to the size of the plant entering this stage. There is going to be a compounding of the existent dry matter with the differential in absolute dry weights becoming greater between the well established plants and the slow to acclimate, stressed (Osmond and Raper, 1981).

The N availability and plant N uptake relationship changes as the plant becomes established in the field. Generally, N concentration in the plant will diminish as the plant ages in the field during establishment (Rideout and Raper, 1993) Considering the equilibrium uptake of the seedlings, this was thought to be due to the fact that N concentrations were decreasing in the field due to uptake and loss and thus N becomes limiting. Such thinking would warrant the use of excess N to ensure that growth was being supported with sufficient N. The study conducted by Rideout and Raper concluded that sufficient N concentration is important during the seedling stage and the first two weeks in the field, but from week three to week five, there is no correlation between N media concentration and the relative growth rate of the plant. Nor was the external concentration correlated to the N accumulation rate of the plant (Rideout and Raper, 1993).

During rapid growth, the N uptake relationship changes. It is no longer correlated to soil N concentrations. Instead, uptake rates become correlated to root growth rates. In this growth stage, soluble carbohydrate is not accumulated in a storage pool but is committed to respiration and materials for new tissues at rates equal to it transport from the shoot. There is interdependence between the carbon supplying function of the shoot and nitrogen supplying function of the roots. In this relationship, nitrogen uptake rate is not dependent on root extension, but rather that both root extension and nitrogen uptake depend upon carbohydrate flow from the shoot for continuing re-supply of the root pool. This is based upon the concentration of soluble carbohydrates being maintained at 5-9% over a wide range of environmental conditions (sunlight and temperature) (Raper et al., 1978). Extensive rooting from establishment into rapid growth, will allow for high nitrate uptake rates that ensure that N is not limiting.

Entering the ‘flowering’ period, the cells of the tobacco leaf are no longer multiplying but they are elongating. This is the period occurring approximately eight weeks after transplanting and immediately prior to flower initiation when topping should occur. Topping stimulates root growth that improves drought tolerance and nutrient absorption. Although nitrogen is still required to maximize quality and yield, this is a period in which excess nitrogen can have adverse affects. Too much nitrogen will increase sucker growth, delay optimum harvest time and increase the severity of some foliar diseases, along with potentially lowering quality, and yields. A study conducted by Clemson Extension revealed that sucker problems increase with excessive nitrogen. With an additional 20lb/A of nitrogen past the recommended rate of 120 lbs per acre, increased sucker count by 15 percent, while 40 lb/A of additional nitrogen increased sucker number over 50%. Yet, it has been reported that leaf nitrates at topping are important to help develop color and balance of nitrogenous and carbohydrate constituents in the cured leaf, while not adversely affecting the rate of ripening (Tobacco Research Board, 1994).

There has also been interest in the affects of ambient temperatures on plant development. Increasing temperatures showed a positive correlation with increased root growth and whole plant biomass although there were no significant relationships found between ambient temperatures and the relative growth rate of the plants from week two to week five, there were final biomass measurements that favored warmer temperatures (Raper et al, 1978). What was concluded from this study was that increased N concentration in the media and increased temperatures allowed the plants to establish rapidly. Thus they were able to achieve higher N accumulation rates associated with established plants more rapidly, accounting for the differences in final plant biomass. The decreasing N accumulation rates during this period were not attributable to decreasing N soil concentration, but instead, were correlated to the root growth rate. Warm temperatures encourage rooting which allows the plant to maintain high N accumulation rates regardless of soil N concentration (Rideout and Raper, 1993).

The importance of soil temperature has led to experimentation with plastic mulch with pre-transplant, seedling growing practices in an outdoor, soil-based bed. In a study conducted by Davis and Dean (1965), the increased soil temperatures brought about by the use of plastic mulch resulted in accelerated plant growth reducing the time required to produce tobacco transplants by 18 days.

There is limited researching regarding the use of plastic mulch with tobacco. In 2004, the University of Kentucky conducted a one year study using plastic mulch. This study found yields to be about 300 lbs/acre less in mulched plots when compared to non-mulched plots. The lost yield was attributed to "the increase in soil moisture from plastic mulch which may have increased the damage from soil borne diseases like black shank" (University of Kentucky extension, 2004).

The convective heating resulting from plastic mulch is expected to not only keep plant roots in optimal temperatures longer, but it is also expected to allow roots to avoid temperatures which are detrimental to development. Kneivel (1973) reported that root temperatures influenced nutrient availability, uptake, and significantly affected plant growth. An experiment by Osmond and Raper, comparing the importance of root zone temperature, ambient air temperature and soil nitrate concentration, from weeks 2-5 after transplanting, determined that temperature of the root zone had the greatest effect on plant growth. This was true for both shoot and root growth. Plant biomass at week 5 was found to be half in the 61^{o} F root temperature treatment when compared to the closely grouped 75^{o} F and the slightly higher 90^{o} F. The immediate result of temperature 61^{o} F was water stress due to poorly acclimated root systems. After 2 weeks the plant began to establish new root systems that have a greater degree of membrane unsaturated fatty acids which make them more permeable to water flow. But, by week 2, the plants were already roughly half the size of the 75^{o} F and the 90^{o} F treatments (Osmond and Raper, 1981).

New techniques using image sequence analysis shows root growth to be much more reactive to temperatures than previously thought. Even when air temperatures are held constant, the velocity of root growth has been shown to almost double within a period of an hour when soil temperature was raised by 10^{o}F (Walter et al., 2002). As such, even cool night-time temperatures can have an affect on plant establishment which will have ramifications all the way through development into harvest. Studies have shown that early season green-up due to nitrogen applications do not have the affect on yield that early season soil temperatures have (Whitty et al., 1966).

Plastic mulch has been used with great success in the fruit and vegetable industry, so much so that its use is considered an industry standard. Plasticulture cropping showing increased yields of 3 to 4 times that of non-mulched cropping methods is common. For example, North Carolina State University Extension reports yield increases over state averages of muskmelons at 4x, tomatoes at 3x, cucumbers at 5x, watermelons at 4x and eggplant at 3x (Sanders, 2001). It is true that these results are obtained from a fruit crop, whereas tobacco is a leaf crop with its value in biomass, but because tobacco belongs to the same Solanacae family as tomato and eggplant, a comparison does seem appropriate. For an example of plant biomass as it relates to fruit yield we can look at the results of a muskmelon chemigation experiment where yields were compared between plastic mulch and non-mulched plots. It was reported that muskmelon yield increased 10 fold when under plastic mulch. A four-fold yield increase was related to plastic mulch alone. During the first biomass sampling there was a marked difference between the plastic mulch treatments with larger plants versus the bare soil treatments with smaller plants. This muskmelon experiment indicates that plant biomass increased due to plastic mulch cropping and this increased biomass was closely linked to fruit yield (Leib, 2003).

Such examples seem to warrant further research in plastic mulch with tobacco, particularly where tobacco favors warm soils associated with black mulch use.

Cultural practices that allow for greater control over the growing media are expected to allow producers the ability to keep plants in optimal growing conditions longer, with regards to N uptake and utilization. This is expected to allow growers to achieve high yielding, high quality tobacco while also potentially reducing the amount of N applied. The timing of nitrogen availability is of great importance to tobacco. (Akehurst, 1981) Aside from visible deficiency symptoms there may be non-apparant stresses which have physiological effects of importance to the product. Water culture work has shown that stopping the nutrient supply of nitrogen at various growth stages has a considerable effect on leaf chemisty (Raper and MCants, 1967). Raper and McCants performed a nutrient accumulation study for flue-cured tobacco. (A similar study for Burley could not be found in the literature.) This study was performed over 13 weeks and intended to capture current average production conditions. Table 1 presents the nitrogen accumulation in flue-cured tobacco during the growing season by weeks.

Table 1. Nitrogen accumulation in flue-cured tobacco by growing week

	Week 3	Week4	Week5	Week 7	Week 9	Week 11	Week 13
Nitrogen Accumulation	3%	21%	42%	83%	90%	95%	100%

In this instance, over 40% of the total N was taken up by the plant during weeks 5-7. Approximately 20% was taken up per week during weeks 3-7. Very little uptake occurred during the first three weeks that the plant was in the field. An efficient N management program would attempt to apply N as the plant demanded it. This would both limit the residency time of N in the soil, diminishing losses to the environment, and would also avoid unnatural conditions of high N concentrations in the soil.

Under natural conditions, plants are usually exposed to low nitrogen levels. However, in agricultural areas the nitrate levels in soil solutions can reach 20 mM due to fertilization (Andrews, 1986). High nitrate concentrations in the plant can become detrimental to the plant, if the concentration increases beyond 5mM, where it is usually maintained constant (Speer and Kaiser, 1991). Products of nitrate reduction such as nitrite or ammonium are even more toxic. Therefore nitrate assimilation has to be equilibrated with carbon availability (Kaiser, 1997). Results presented show that total nitrogen and also the organic nitrogen content of root and shoot tissue were significantly lower in plants with high soil nitrate supply, indicating that actually less nitrate was metabolized (Stohr, 1999). Nitrate is stored in the plant in the vacuole where it functions as an osmotic ion. At optimal soil nitrate concentrations of 5-10 mM, the plant is translocating larger amounts of carbohydrates from leaves to roots, which then grow faster and thus maintain the C/N ratio while metabolizing more nitrates. Plants growing in higher nitrate concentrated soils are limiting root growth and are thus limiting the total amount of nitrate assimilated to prevent internal concentration level from exceeding desired levels.

Other experiments have shown that the concentration of nitrogen in the soil has altered the physiology of the plant. In a hydroponic experiment, tobacco plants grown in a constant nitrate concentration between 5 -10 mM of nitrate was considered optimal for relative growth rate. Visual N deficiency (chlorosis) was evident at 2 mM while concentrations greater than 10 mM increasingly showed reduced leaf area with highly altered root morphology and root area reduction (Stohr, 1999). Moderate nitrogen deficiency (assumed to be within 5 – 10 mM range) has been shown to inhibit shoot growth while it stimulates root growth (Agren and Ingestad, 1987). If the deficiency becomes more extreme, there is a general inhibition of growth, but root growth is decreased less than shoot growth. This prioritizing of roots allows the plant to better forage for nitrogen during deficiencies, allowing for leaf production and plant photosynthesis to be increased when adequate nitrogen levels are restored (Bloom et al. 1985).

Extensive rooting by the tobacco plant has the additional benefit of being able to better forage for nitrate in the soil, thus increasing the likelihood of each unit of N applied being utilized towards plant growth. It has also been shown that photosynthetic energy dedicated towards root growth after the plant has become established is not detrimental to final yield and quality so long as soil nitrate concentrations are neither excessive nor limiting (Raper et al., 1978). Instead, well established plants are shown to enter rapid growth with a higher potential for nitrate uptake. The roots should not be thought of as a sink for carbohydrates as the roughly 10% total could not sustain respiration for more than a few hours (Raper et al., 1978). Instead, the demands of an increased root area attempting to maintain a carbohydrate balance will proportionately increase the potential for nitrate uptake for the plant. Once levels of nitrate in the soil become excessive, this natural balance is lost, resulting in a decreased root area attempting to inefficiently uptake nitrate. This inefficiency can result in the plant attempting to achieve its full growth potential later in its development while nitrate reductace activities are diminishing.

The once dominate, highly profitable American tobacco leaf has recently watched its market share continually decline. To retain profitability requires a thorough understanding of the product that is in demand in the new market place. The literature supports the premise that agronomical practices are an integral component in achieving this product. Research that has been conducted towards defining optimal growing conditions with regards to plant nitrogen uptake and utilization should be implemented with cultural and management practices that can best achieve them. These practices should allow themselves for adaptations during the growing season in association with monitoring. The literature supports the idea that nitrogen and precipitation cannot be thought of as final sum, seasonal requirements. In order to achieve high yielding, high quality tobacco, they need to be considered in the increments that growth stages demand them.

CHAPTER III

MATERIALS AND METHODS

The literature review supports the hypothesis that cultural and management practices can be used to enhance tobacco quality and yield by affecting the efficiency of nitrogen uptake and utilization by the plant. To test this hypothesis, we will measure yield, quality and TSNA content at harvest for eight separate treatments. These treatments were designed to isolate the affects of soil moisture and soil temperature as well nitrogen rates and timing of application. Season long monitoring of growing conditions including precipitation were used to assess the effectiveness of cultural and management practices as they related to the final leaf product. Data obtained from monitoring is to be considered useful in helping to define the parameters of optimal growing conditions.

Variety

Variety TN 90 burley tobacco was used for this study in Greeneville and Springfield Tennessee. As dark tobacco is traditionally grown in middle Tennessee, a variety KY 171 dark tobacco was added to the study at Springfield.

Soil

The NRCS web soil profile classifies Greeneville as an Ooltewah/Lindside Silt Loam (23% clay, 67% silt, 10% sand), Lindside fine-silty, mixed, active, mesic fluvaquentic eutrudepts (NRCS, 2007). The parent material is a loamy alluvium derived from interbedded sedimentary rock. There is generally more than 80 inches to the restrictive layer. In the top 24” of soil, the available water capacity is classified as moderate to high, with 0.21 inches of water per inch of soil. The drainage class is, moderately to well drained, with a pH naturally around 6.5. These soils respond well to good agricultural management practices, but flooding may be an issue. The ECEC is 14.4 milliequivalents per 100 grams of soil at neutral pH levels (NRCS, 2007). These soils were determined to have medium phosphorous and potassium by experiment station soil samples. UT extension recommended application rates for medium phosphorous is 75 lbs/acre of P_20 and 200 lbs/acre of K_20. The experimental plots were planted in Timothy orchard grass two years previous to being planted in burley tobacco.

At Springfield, the soil is Dickson Silt Loam (22% clay, 70% silt, 8% sand), Dickson fine-silty, siliceous, semiactive, thermic glossic fragiudults (NRCS, 2007). The parent material is Loess over a clayey residuum of weathered from cherty limestone. These soils generally have a fragipan at 20-36 inch depths. The core samples we took found the fragipan within these boundaries, being slightly deeper in the burley, while the down slope dark was a little shallower. In the top 24” of soil, the available water capacity is classified as moderate at about 0.19 inches of water per inch of soil. This soil is considered to have low natural fertility. The drainage is classified as moderately to well drained, with a pH naturally around 5. Soil analysis showed that liming was effective at keeping the pH at 6.4. These soils were determined to have medium phosphorous and potassium. UT extension recommended application rates for medium phosphorous is 75 lbs/acre of P_20_5 and 200 lbs/acre of K_20. Soybeans had been planted in rotation at the Springfield plots for the previous season.

Experimental Design

This study began as a fertigation study beginning in 2005. It consisted of six treatments.

D-H: Dry land with High Nitrogen applied preplant (200 lb/acre)

I-H: Irrigation with High Nitrogen applied preplant (200 lb/acre)

I-M: Irrigation with Medium Nitrogen applied preplant (150 lb/acre)

F-H: Fertigation with High Nitrogen split applications (100 preplant + 100 lb/acre)

F-M: Fertigation with Medium Nitrogen split applications (75 preplant + 75 lb/acre)

F-L: Fertigation with Low Nitrogen split applications (50 preplant + 50 lb/acre)

In 2006, we added two plasticulture treatments.

P-H: Plasticulture with High Nitrogen split applications (100 preplant + 100 lb/acre)

P-L: Plasticulture with Low Nitrogen split applications (50 preplant + 50lb/acre)

The irrigation medium treatment was also changed to an irrigation low treatment so that comparisons could be drawn between the plasticulture, irrigation and fertigation low treatments. The low level was chosen for comparison, as opposed to the medium as differences should be more evident in the low as compared to high than in the medium as compared to high rates.

These treatments were designed to lend themselves to a comparison study. The traditional growing practice, referred to in this paper as dryland, applies all N preplant and was used as the control. Two hundred pounds of N was applied as ammonium nitrate within two days before transplanting. Using this same protocol, irrigation was used to support precipitation that was not adequate to meet the tobacco plants expected water demand. Using the same protocol as the irrigation treatment a fertigation treatment was added. When compared to the dryland treatment, differences can be reasonably attributable to the importance of soil moisture. Fertigation applied half of the N as preplant with the other half split over three separate application periods at four, six and eight weeks after transplanting. Fertigation allowed for the isolation of the variable of N application timing when data was related to the irrigation treatments. Using the same fertigation protocol, a plastic mulch treatment was added. This isolates the affects of soil temperature, allowing for a determination of its importance as a growing condition.

Each of these introduced cultural practices, included a half N treatment of 100 lbs/acre. The fertigation treatment also included a medium N rate of 150 lb/acre, due to concerns that 100 lbs/acre may be too low to be able relate data to producer recommendations. From the literature, cultural and management practices that are designed to keep plants in optimal ranges with regards to soil water, N timing and soil temperature are expected to have an effect on N uptake and utilization by the plant. Comparisons from the low N treatment determine N efficiency of treatments.

Dryland – Consists of 200 lbs of N applied preplant. 200 lbs would be a general recommendation considering the soil type. There was no irrigation used. Plots were 40' long and 14' wide. This provided a plot containing four rows of plans spaced 42" wide and 20" between plants within rows for burley, and 24" for dark tobacco. The establishment of four rows per treatment allows for sampling and final yield and quality assessments to be taken from the interior 2 rows thus minimizing edge effects from other treatments and location on the outside of the field area.

Irrigation – Applies all N preplant as in the dryland treatment but also applies water based upon the 1” per week rule of thumb beginning four weeks after transplanting. This practice estimates the plant water demand to be about one inch per week, using Irrigation to support periods of inadequate precipitation. In the Buchanan et al. study, Irrigation evaluation included treatments using one inch per week, one inch per ten days and Irrigation to be implemented when soil water tensions surpassed 60 kPa. Yield results for these treatments were statistically the same. One inch per week was chosen in this experiment as it is both a common and practical practice as it requires only a rain gage in its management. Precipitation was measured by the weather stations existing at both Greeneville and Springfield. Irrigation is applied through a drip tape running next to the plant and out of the way for cultivations in association with weed control. Drip tape irrigation allows for precision application of water to the plant at rates low enough to encourage infiltration and avoid runoff. 1” of irrigation is a value calculated by plot area, using water meters to measure volume. Pressure gauges at the beginning and ending of lines holding drip tape help to maintain optimal drip tape pressures of 12 p.s.i. controlled by pressure regulators.

Fertigation **–** Applies half of the N as preplant, with the other half being applied over three separate N application events through the drip tape using liquid food grade urea. Urea is injected into the irrigation system using a venturi meter. If the 1” rule of thumb does not call for irrigation to be applied during the required time of N application, liquid N can be effectively applied in about a half hour. As the full run time to apply 1” is about 8 hours, a half an hour will not apply excessive irrigation. Timing of fertigation is intended to capture three periods of N demand by the plant. At four weeks after transplanting, the plant is 'established' and entering 'rapid growth' stage where about 80% of total biomass will be attained and N will be in high demand by the plant. 2 weeks later, the plant will be expected to be in the 'rapid growth' stage. At week 8 after transplanting, the plant will be entering 'flowering' where water and N will be in demand to help the fully expanded leaves mature and attain high GRI quality.

Plasticulture – Uses the same protocol as fertigation required a bedder to create raised beds were covered with a plastic mulch. Under the plastic mulch, we used the drip tape to make irrigation and fertigation applications. Irrigation followed the same protocol as the fertigated and irrigated plots, using the 1" per week of precipitation supported by irrigation. A 5' mulch width was used, which when tucked into the side of the bed, created about a 42" wide bed. The use of plastic mulch within the space constraints of a 14' wide treatment, which also required room on the edges of the plot for tractor wheels that would be making cultivations as well as spray applications, required us to plant two rows on the wider 42" plastic bed. The width of plant spacing within the plastic bed was closer to 36" as opposed to the 42" in all of the other treatments but the plants per area remained the same as the distance between beds increased to 54". We also used a double drip tape line under the plastic mulch to help keep run times of irrigation and fertigation the same as other treatments and to keep a drip tape line next to each plant.

Each treatment was controlled by a valve on the header line allowing for treatment plots to be fertigated independently. All plots using irrigation were managed using the same 1" per week of in precipitation supported by irrigation. Four controlling valves allowed for treatments to be treated independently. They consisted of irrigation only, fertigation high, medium and low. As the plasticulture followed the same N protocol as fertigation, the fertigation high and low lines were also used under the plastic mulch. The variable preplant N rates were controlled by hand spreading applicable N rates to each treatment plot. The variable fertigation rates were controlled by header line valves.

The experiment was set up in a randomized complete block design, with four blocks each containing one of the eight treatments. The six treatments in 2005 and the eight treatments in 2006 were replicated four times for statistical purposes. At Greeneville, the study used burley tobacco exclusively while the Springfield study was twice as large as it also included dark tobacco. As it was not practical to create plastic mulch beds independent between blocks in this design, two straight treatment lines of plastic were run across the four blocks for a total of 4 plasticulture high and four plasticulture low treatments. The plastic high and low were randomized within these lines. Figure 1 is representative of a treatment block map.

Springfield has a similar plot design for Burley, as it also consist of a randomized complete block design. But, the Springfield plot also consists of a dark tobacco set of blocks.

The following is a calendar of managerial practices that were performed at Springfield in 2005 and is used here as an example showing the sequence of events. This will approximate the procedures that need to be performed, when they will be done, and on which treatments they will take place. The exact dates will relate to time of transplant. Figure 2 is representative of the calendar of management events taking place at both Greeneville and Springfield.

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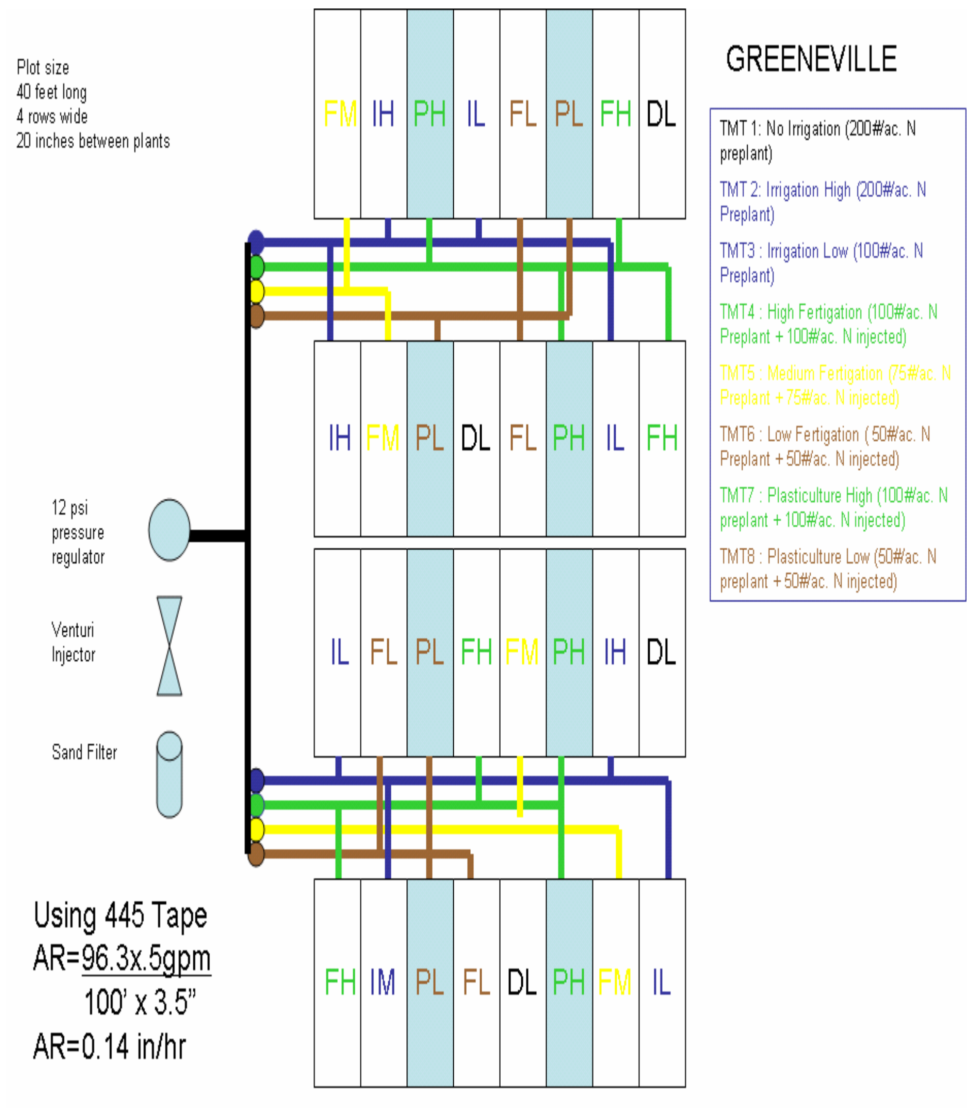


Figure 1. A representation of a treatment block map

End of September	Spray roundup 1qt./acre
Mid Winter	Turn ground
Mid May	Apply preplant N at prescribed treatment amounts
End of May	Sprayed herbicides & fungicides; Spartan 11oz/acre Command 3 me 1 qt./acre, Ridomil Gold 1 qt./acre **Plastic mulch applied between this spraying and transplanting**. **Transplanted tobacco** Admire 7.1 oz per acre in transplant water apply Orthene 97.75 lb/acre
Mid June	Cultivated all treatments but plasticulture Plasticulture excluded from all cultivations and herbicides associated with weed control
4 weeks after transplant	Fertigate the plasticulture and fertigation plots Begin irrigation using 1” per week guidelines
End of June	Sprayed Acrobat 50 WP 3 oz./acre, Dithane DF 12 oz./acre, Orthene 97.75 oz./acre
6 weeks after transplant	Fertigate the plasticulture and fertigation plots
Early July	Sprayed Tracer 3 oz./acre, Acrobat 50 WP 3 oz./acre, Dithane DF 12 oz./acre
8 weeks after transplant	Fertigate the plasticulture and fertigation plots
Mid July	Spray Tracer 3 oz./acre, Acrobat 50 WP 3 oz./acre, Dithane DF 12 oz./acre Spray Acrobat 50 WP 3 oz./acre, Dithane DF 12 oz./acre, Orthene 97.75 oz./acre, Actigard .50 oz./acre
Mid to late July	Sprayed Actigard .50 oz./acre, Warrior T 3 oz./acre
Early August	Top and spray sucker control chemicals; MH 1.5 gal/acre, Flupro 2 qt./acre, Royal Tac M 2 qt./acre
Mid August	Last irrigation as needed
End of August	Harvest and house plots

Figure 2. A calendar of events representative of management practices.

More important than specific dates is the chronology of events. Fertigation is to take place in the plasticulture and fertigation treatments at 4, 6 and 8 weeks after transplanting. Topping should occur after the last fertigation events have been applied. Irrigation can be applied with fertigation events as needed. Fertigation can be applied with minimal irrigation if precipitation has been sufficient.

Equipment

Cultural practices of irrigation, fertigation and plasticulture will require equipment that is unique to the usual equipment required for tobacco production. Each of these treatments required a developed irrigation source. Greeneville pumped water from a creek, while Springfield uses an irrigation pond. The use of a sand filter was required to keep the irrigation lines running cleanly. The use of header lines, lay flat, drip tape and plastic mulch can be seen in the plot plan figure. Plastic mulch was laid with the Rain-flo 2600 which creates a bed while pulling the plastic mulch taunt, tucking the drip tape lines run beneath the plastic.

Monitoring of the Growing Season

Soil water tension, soil temperature and petiole leaf nitrate concentrations were monitored during the season, using respectively; watermark sensors, hobo pendants and the Horiba Cardy monitor. Seasonal monitoring allowed for understanding the importance of each of cultural and management practices as they related to final yield, quality and TSNA. Treatments were evaluated upon their ability to maintain tobacco plants in optimal growing conditions.

Watermark sensors, attached to PVC pipe, were buried at 8” and 20”. Soil tensions were monitored in the dryland, irrigation and plasticulture treatments only. The irrigation protocol was the same for the fertigation and irrigation treatments, so we chose to monitor the fertigation high treatment as it used the same amount of N as the dryland treatment. N rates could be expected to affect plant biomass and thus plant water demand so similar N rates were used in this comparison. We chose the plasticulture high treatment as the protocol was the same as the fertigation high treatment, except for the use of plastic mulch. The objective of these placement positions is to quantify soil water tension in the tobacco root zone. 8” was chosen for the more shallow depth as cultivation is usually about 6” in depth, and a sensor that is 8” deep would be influenced by this cultivated strata, but should still be in relatively undisturbed soil allowing for a comparison between treatments and replicates. 20” was chosen as a maximal depth based upon a Georgia Agricultural Experiment flue-cured tobacco drought study which sited 8” to 20” as primary sites of soil water uptake with very little plant uptake from a depth beyond 24” (Maw and Stansell, 1997). The use of two monitors will assist in determining the extent of the wetting front due to the effects of rain and irrigation and soil drying due to plant uptake and evaporation. There have been studies regarding soil tension using irrigation versus dryland plots, but there is no data available regarding soil tension under plastic mulch for tobacco. Collecting tension data in time intervals will allow us to evaluate the effectiveness of each treatment in maintaining soil water tensions, and how these tensions relate to final yield, GRI quality and TSNA. Watermarks sensors were read in situ two to three times per week. On occasion, the personnel was not always available or conditions were too wet for field entry, but the two to three times per week was the ideal. These monitors were positioned in four replications in an attempt to account for variability between experimental units.

Soil temperatures were monitored at 4” depths using Hobo pendants. These thermocouplers log temperatures at half hour intervals, storing data until retrieved at the end of the growing season. Accuracy is listed as being within .85 degrees F. Temperature data was of primary interest during transplant when warmer soil temperatures were expected to achieve early establishment. As the plants mature in the field, leaf cover makes soil temperatures more uniform between treatments.

We will also measured the petiole leaf nitrates during the growing season by using the Horiba Cardy meter. Analysis of nitrates is normally performed in a laboratory using specialized equipment. Although such analyses are generally reliable, this approach is not ideally suited for testing because of the costs and unavoidable delay in supplying the results to the grower. The Cardy meter measures the voltage change across ion selective electrodes due to the concentration of nitrate in the test solution. Other ions such as chlorine and bicarbonate can confound readings. Yet, the Cardy meter is reliable to within 5% of conventional leaf analysis data. The Cardy meters are considered to be the most “popular” type of sap-testing equipment in use today, because of their simple operation and relatively modest cost (Bierman and Wall, 2007).

The measurement of nitrate concentrations in the leaf was used to determine the effectiveness by which the plant was able to reduce nitrates for growth. The measurements were taken prior to each of the three fertigation events. This captured the growth stages of ‘establishment’, ‘rapid growth’ and ‘flowering’. The Horiba Cardy monitor was originally intended for use in the fruit and vegetable industry, so we will evaluate how successful it is in measuring nitrates in vegetative growth crops such as tobacco. Leaves sampled were the first fully expanded leaf. Two leaf samples were taken from the center row of each plot. Sap was extracted from the petiole by the use of a garlic press on the stem attaching portion of the petiole. The Cardy meters successful ability to detect nitrates in the leaf makes it a potentially useful tool for both producers and purchasers of tobacco. Growers can use this fast, easy to use device to measure nitrates in the leaf and adjust their N cultural practices appropriately. Purchasers can use it to predict TSNA content after curing by measuring leaf nitrate content during the season. In a contract sales market, this can increase the certainty of agreements occurring between producers and purchasers. The Horiba monitor was evaluated in this study by its ability to recognize treatment effects, and rate applications consistently over time. Nitrate concentration data was used to draw correlations from petiole between soil water tension and temperature data as they relate to harvest quality and yield.

TSNA analysis was performed by the Philip Morris lab in the years of 2004-2005. Analysis in 2006 was performed by the lab of Dr. Lowell Bush at the University of Kentucky. Analysis consisted of an extraction utilizing alkaline methylene chloride. This extraction was analyzed using GC and chemiluminescent detection. This procedure has been demonstrated to be applicable to a variety of tobacco types and offers a broad range of TSNA values (Morgan et al., 2004).

The station protocol for curing is based on judgment and experience of the managers. After the tobacco was cut, spiked and hung on a scaffold, it was taken immediately to a conventional barn. In the barn, it would sit for two to three days before it was hung randomly. General protocol on curing in the barns consists of opening and closing doors as needed to keep the humidity right for a 'good' cure. Desired humidity is considered to be high at night and in the 60 to 70 % range in the afternoon. This is not monitored; it is done by experience.

Harvested yield data was a measurement of biomass achieved in the interior two sample rows projected into an acreage estimation. For quality assessment, the government grade quality known as the GRI (grade index) was used. As tobacco is a high value crop where quality factors into price, GRI was used to help predict total revenue from a crop. The GRI is composed of USDA standards that provide for eight grades of tobacco and six qualities within each grade. There are eighteen different tobacco colors, plus several combinations of colors, making the various choices of colors, qualities and types of tobacco number on the thousands. The use of color in judging leaf quality is “enormously” important as it is strongly correlated with other characteristics which cannot be measured by visual inspection (Abdullah, 1970). Grading always involves a certain level of subjectivity, particularly when different graders are used. The tobacco in this experiment is also to be graded as would any leaf in the market. Meaning, every leaf is not examined but estimates were made from bundles of leaves tied in “howls”. As this is a study in production practices, it is important to maintain the evaluations that will be used in the market place.

The third evaluation will consist of a Phillip Morris laboratory test for nitrosamine levels in the plant at harvest. Tobacco cured with low levels of nitrates should contain low nitrosamine levels from the lab analysis. This lab analysis will allow us to test this assumption.

Comparison Analysis

Yield and GRI data was analyzed using the SPSS ANOVA general linear model statistical tool, which will allow use the block design to determine significance at the 0.05 level of significance. This model was used to show statistical differences. Where there were differences, Duncans LSD was used to calculate differences between treatments. Where there were no statistical differences in the model, there was concluded to be no differences between any treatments. Included will in the category called GRI. This is the amount of dollars per pound that a particular treatment could be expected to earn under the quota market structure. The current market structure no longer uses GRI to determine price per pound but it is included as a frame of reference in determining the interactions of yield and revenue. A similar analysis with lab measured TSNA was used to determine treatment differences and where these significant differences may exist.

The effectiveness of the Horiba Cardy meter was measured using the ANOVA analysis. This analysis has taken into account the spread of measurements within a treatment to determine if the model can account for treatment differences at the 0.05 level of significance. The accuracy of the Horiba by it's effectiveness in portraying what we know about the physiology of plants in regards to nitrate accumulation from the literature review. Plant physiology would expect to see high leaf nitrates in early samples. These samples would expect to be similar as N uptake rates are similar as the plant becomes 'established' in the field. This is due to the plant taking up nitrate during early establishment at rates that are closely correlated to plant growth. During these first four weeks in the field, the only treatment differences consist of N rates and soil temperature. Successive samples would than begin to show a general decline in petiole nitrates with separation between treatments and in particular, between N rates as being evident.

The standard deviations of soil temperature between replications within a treatment was calculated from the Hobo pendent data. Some field variability is expected, and these differences were included in the ANOVA analysis to determine treatment differences. This analysis allowed us to determine if significant differences in temperature had a significant affect on yield.

Watermark sensors data was used to interpret how soil water tensions relate principally to the ability of the plant to reduce nitrate in the leaf to forms that can be used for plant growth. This assessment was compared to yield, GRI quality and TSNA concentrations of the plants at harvest, as well as season long measurements of petiole leaf nitrates. Statistical analysis of water tensions was not performed due to field variability and the varying water uptake rates due to varying biomass accumulations from treatments. If irrigation was based upon measurements of soil water tension, such analysis would have been more relevant.

CHAPTER IV

RESULTS

Yield

Examination of yields for all of the plot years and sites reveals consistent trends between treatments with some statistical differences. Although trends between treatments within a site and year were similar to trends shown elsewhere, there were considerable differences in yield totals between these sites and years. Yields were shown to be highly dependent upon growing condition variability due to some combination of precipitation, temperature and soil. Figure 3 displays yield results in graph form while table 2 displays yield values for each site and year.

The lowest yield totals came from Springfield 2006. This site had yield averages that were equal to or slightly less than yield averages over the previous 5 and 10 years for Robertson County. Springfield also showed statistical differences between treatments using the same total N rates. The highest yielding data plot came from Greeneville 2006. Yields were very high in comparison to Greene County averages over the previous 5 and 10 years. These yields were consistently about 500 lb/acre higher than Greeneville 2005. There was not as much statistical difference between cultural practices using similar N rates in this site year. As precipitation approached optimal, the importance of cultural practices was reduced.

The highest yielding treatments most often came from use of the high (200 lb/acre) N rate. The one exception was in Greeneville 2005 where irrigation medium had

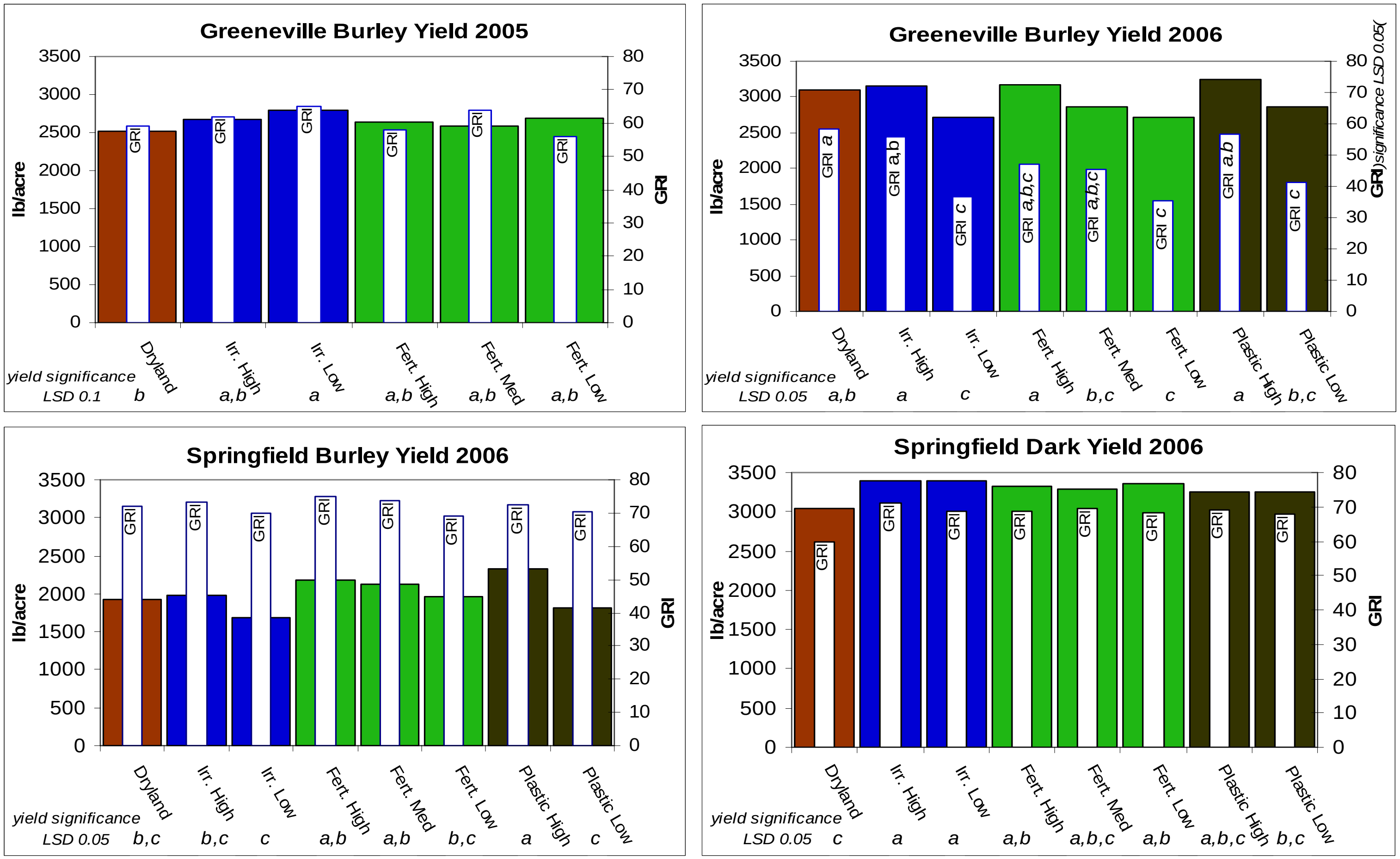


Figure 2. Yield values and statistical significance for each site and year.

Table 2. Yield values and statistical significance for each site and year.

2005 Yield	Greeneville Burley lb/acre	
Irr. High	*a,b*	2677
Irr. Med	*a*	2786
Fert. High	*a,b*	2632
Fert. Med	*a,b*	2580
Fert. Low	*a,b*	2683
total average		2640
LSD		225.3
ANOVA / Duncans	**Significance 0.1**	
Treatment		0.063
Block		0.47

2006 Yield	Greeneville Burley lb/acre	
Dryland	*a,b*	3094
Irr. High	*a*	3152
Irr. Low	*c*	2721
Fert. High	*a*	3174
Fert. Med	*b,c*	2866
Fert. Low	*c*	2713
Plastic High	*a*	3248
Plastic Low	*b,c*	2869
total average	2979	
LSD		225.3
ANOVA / Duncans	**Significance 0.05**	
Treatment		0.001
Block		0.093

2006 Yield	Springfield Burley lb/acre	
Dryland	*b,c*	1922
Irr. High	*b,c*	1974
Irr. Low	*c*	1693
Fert. High	*a,b*	2179
Fert. Med	*a,b*	2121
Fert. Low	*b,c*	1957
Plastic High	*a*	2332
Plastic Low	*c*	1812
total average		1999
LSD		245.7
ANOVA / Duncans	**Significance 0.05**	
Treatment		0.001
Block		0.118

2006 Yield	Springfield Dark lb/acre	
Dryland	*c*	3036
Irr. High	*a*	3383
Irr. Low	*a*	3386
Fert. High	*a,b*	3317
Fert. Med	*a,b,c*	3290
Fert. Low	*a,b*	3359
Plastic High	*a,b*	3360
Plastic Low	*b,c*	3257
total average		3266
LSD		228.6
ANOVA / Duncans	**Significance 0.05**	
Treatment		0.039
Block		0.006

the highest yield and fertigation low was also similarly high yielding. When looking at all sites and all years, of the four high N treatments of dryland, fertigation, irrigation and plasticulture, the dryland treatment was consistently the lowest yielding. This was predominately a trend with statistical differences between the four treatment comparisons revealed once in the plasticulture treatment in Springfield. If one of the four replications in the plasticulture at Greeneville were removed, as it was uncharacteristically low when compared to the other three, plasticulture would also have been significantly higher than dryland.

Low N treatments were consistently lower yielding than high N treatments within the same cultural practices. At Springfield, this was only trend but Greeneville 2006 showed dramatic, statistical differences. The Greeneville 2006 was a season characterized as precipitation being sufficient in timing and volume to meet the plants water demands. It was a good year to grow dryland tobacco. High yields here reflected the plants ability to utilize available soil N towards growth, with all high N treatments achieving very high yields. Low N treatment achieved good yields, but plants were limited in achieving yield potentials by low available N. At Springfield, yields were statistically the same for all low N treatments when compared to dryland high. At Greeneville 2006, yields were more reflective of N rates, with irrigation low, fertigation low, being significantly less than dryland high. As there was no statistical difference between plasticulture low and dryland, we could infer that the plastic shield either prevented N from leaching or the increased soil temperatures that enhanced rooting potential made more soil N available to the plant.

There was no consistent advantage gained by the use of fertigation over irrigation. It was expected that the lower residence time of total N in the field that fertigation affords would increase the amount of N available to the plant when the plant demanded it, but there was no measured efficiency gained with the use of fertigation.

Interestingly, the low N treatments in irrigation, fertigation and plasticulture were able to achieve statistically the same yields as the dryland high treatments at Greeneville 2005 and Springfield 2006. Precipitation was less than optimal at these sites, but cultural practices allowed these low N treatments to achieve an efficiency in N use from N applied.

There were five treatments that were tested in the three site years, dryland, irrigation high, fertigation high, medium and low. A statistical analysis that allows for the comparisons of treatments across site years could not be done as the data failed the Levene test for having standard deviations from treatment means that were not similar enough. Even if the Levene test were disregarded, the ANOVA did not find statistical differences among treatments. When this same statistical analysis was run for the Greeneville and Springfield experiments in 2006, where all treatments were the same, we had data that passed the Levene test and was significant at the 0.022 level. Table 3 displays the significance of yields compared together in 2006 at Greeneville and Springfield.

Table 3. The significance of yields compared together in 2006 Greeneville and Springfield.

2006 Yield comparison	Greeneville and Springfield combined
Dryland	*b,c*
Irr. High	*B*
Irr. Low	*D*
Fert. High	*a,b*
Fert. Med	*b,c*
Fert. Low	*c,d*
Plastic High	*A*
Plastic Low	*c,d*
ANOVA / Duncans	**Significance 0.05**
Treatment	0.022
error a (treatment * site)	0.093

GRI

For Grade Index, there were no statistical differences at Greeneville 2005 and Springfield 2006. You could perhaps note a trend that correlated GRI to N rates at these sites, but the numbers are very close. The differences in GRI were greatest between sites and years, meaning quality is primarily influenced by growing conditions. The site with the highest GRI was Springfield, which was roughly 25% higher in the high N treatments and 45% higher than the low N treatments at Greeneville in 2006.

In general, cultural practices and N rates had limited affect on GRI. The exception was Greeneville 2006 where there was a pronounced difference of GRI within treatments that reflected N rates. Figure 4 displays GRI results within the yield graph to show the relationships, while table 4 displays yield values for each site and year.

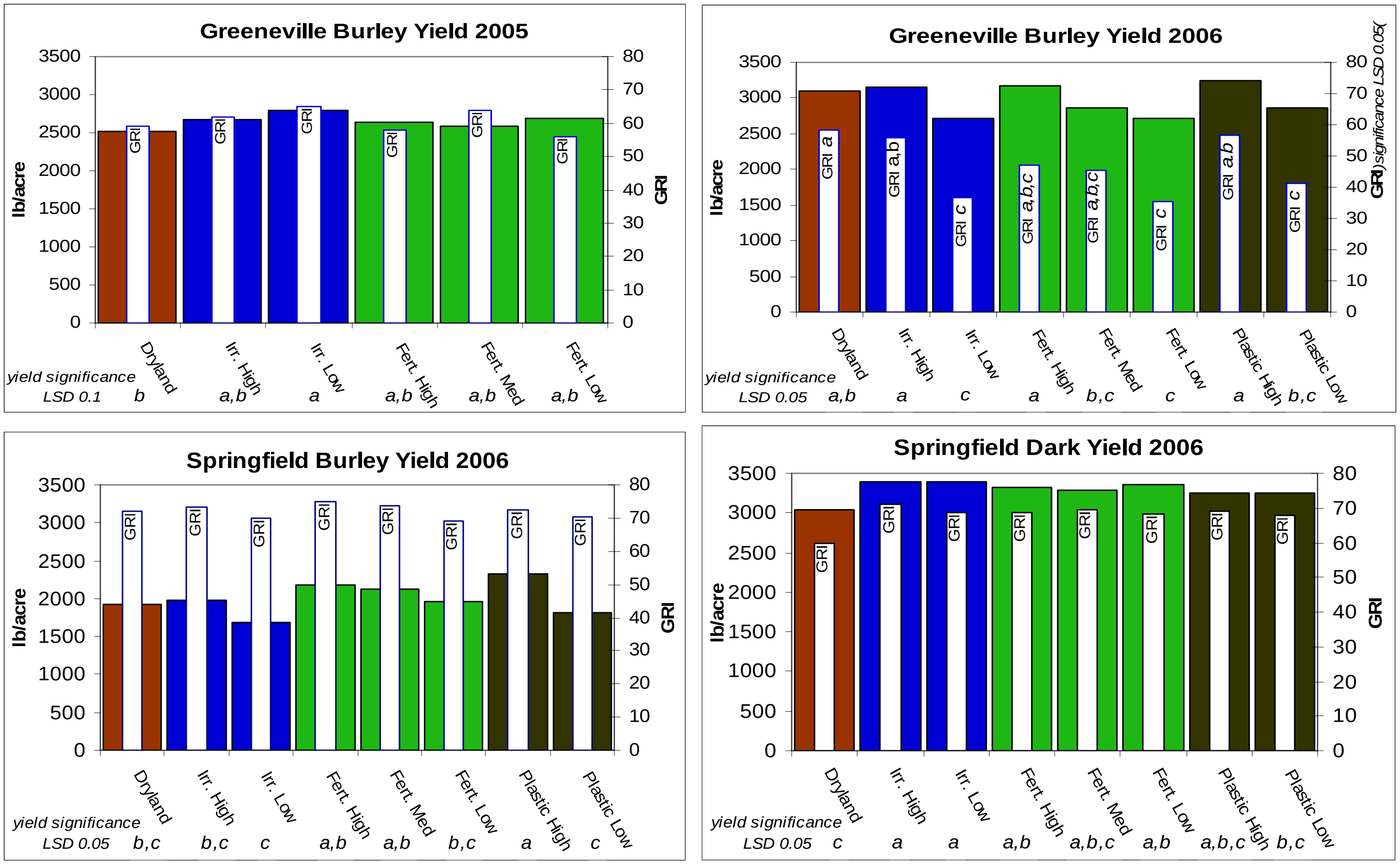


Figure 3. GRI values and statistical significance for each site and year.

Table 4. GRI values and statistical significance for each site and year.

2005 GRI	Greeneville Burley
Dryland	59.3
Irr. High	60.1
Irr. Med	65.6
Fert. High	58.4
Fert. Med	65.2
Fert. Low	62
total average	61.8
LSD	4.4
ANOVA / Duncans	**Significance 0.05**
Treatment	0.414
Block	0.007

2006 Yield	Greeneville Burley
Dryland	*a* 58.2
Irr. High	*a,b* 55.8
Irr. Low	*c* 36.9
Fert. High	*a,b,c* 47
Fert. Med	*ab,c* 45.3
Fert. Low	*c* 35.3
Plastic High	*a,b* 56.7
Plastic Low	*c* 41.1
total average	47.1
LSD	12.6
ANOVA / Duncans	**Significance 0.05**
Treatment	0.012
Block	0.016

2006 GRI	Springfield Burley
Dryland	72
Irr. High	*73.3*
Irr. Low	*70.1*
Fert. High	*75*
Fert. Med	*73.6*
Fert. Low	*68.9*
Plastic High	*72.5*
Plastic Low	*70.2*
total average	72
LSD	4.5
ANOVA / Duncans	**Significance 0.05**
Treatment	0.168
Block	0.753

2006 GRI	Springfield Dark
Dryland	*59.8*
Irr. High	*71.1*
Irr. Low	*68.7*
Fert. High	*68.5*
Fert. Med	*69.6*
Fert. Low	*68.4*
Plastic High	*68.9*
Plastic Low	*68*
total average	67.6
LSD	4.5
ANOVA / Duncans	**Significance 0.05**
Treatment	0.526
Block	0.725

TSNA

TSNA concentrations were most effected by cultural practices, and to a lesser degree, N rates. As TSNA concentrations and trends were reflected similarly between sites and years, TSNA is not heavily influenced by seasonal growing condition variability but is very reactive to cultural and management practices. As TSNA forms during curing, randomized curing placement in the barn attempted to control this factor. Other practices such as the time from topping to curing were not controlled. Some of the lowest TSNA concentrations were found in Springfield in 2006. This site also had the longest time duration between topping and harvest, which may have had some effect. Figure 5 displays TSNA in graph form while table 5 displays TSNA values and statistical differences.

Consistently, dryland treatments had the highest TSNA concentrations. In the four plot seasons consisting of Greeneville and Springfield, for 2005 and 2006, dryland, statistically had the highest TSNA concentrations. Soil moisture could be isolated as the one variable different from dryland and all of the other treatments. Treatments receiving irrigation had TSNA concentrations that were reduced by 30% - 50%. The one high TSNA coming from an irrigated treatment was the plasticulture high at Greeneville. This treatment received minimal irrigation due to a season of good precipitation, while the plastic prevented the plot from benefiting from the rain as much as non-mulched plots were able to.

In each of the sites within each season, we can see a trend where decreased N rates within a treatment resulted in a non-statistical trend of decreased TSNA

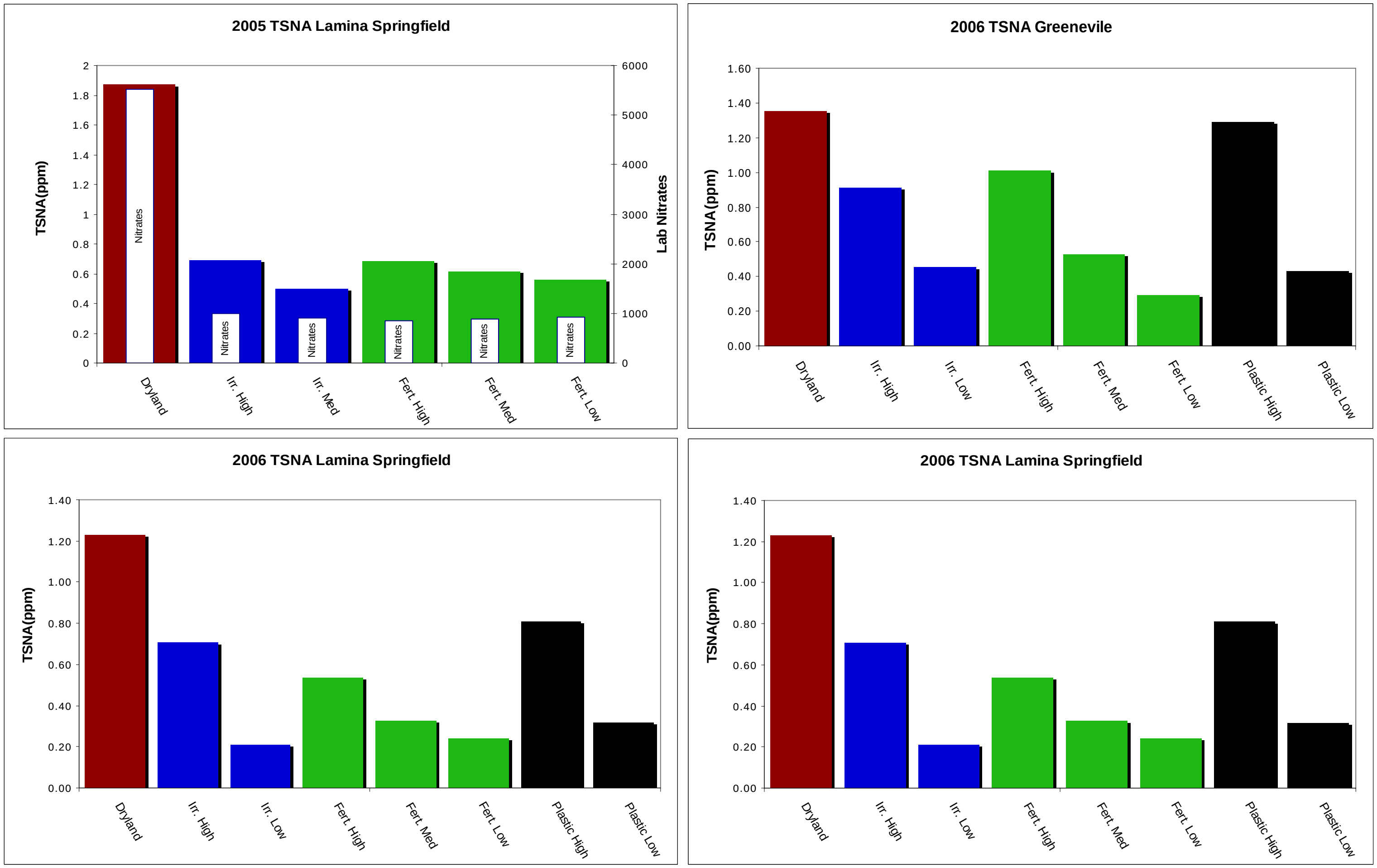


Figure 4. A graph of TSNA values for each site and year.

Table 5. TSNA values and statistical significance for each site and year.

TSNA Greeneville 2005	Mean		Standard Deviation
Dryland	*a*	1.54	0.4
Irr. High	*a*	1.23	0.59
Irr. Low	*a*	1.15	0.58
Fert. High	*a*	1.2	0.288
Fert. Med.	*b*	.61	0.26
Fert. Low	*b*	.59	0.39
Significance 0.1	LSD	.62	
Model		0.063	
Treatment		0.039	
Block		0.293	

TSNA Greeneville 2006	Mean		Standard Deviation
Dryland	*a*	1.35	0.53
Irr. High	*a,b*	.91	0.38
Irr. Low	*b*	.45	0.38
Fert. High	*a,b*	1.01	0.55
Fert. Med.	*b*	.53	0.26
Fert. Low	*b*	.29	0.07
Plastic High	*a*	1.29	0.43
Plastic Low	*b*	.43	0.21
Significance 0.05	LSD	.51	
Model		0.001	
Treatment		0.01	
Block		0.075	

TSNA Springfield 2005	Mean
Dryland	1.87
Irr. High	0.69
Irr. Low	0.5
Fert. High	0.68
Fert. Med.	0.62
Fert. Low	0.56

The full data was not included in the lab analysis. Springfield 2005 statistics could not be run.

TSNA Springfield 2006	Mean		Standard Deviation
Dryland	*a*	1.23	0.15
Irr. High	*b*	.71	0.26
Irr. Low	*c*	.21	0.03
Fert. High	*b,c*	.54	0.2
Fert. Med.	*b,c*	.33	0.08
Fert. Low	*b,c*	.24	0.03
Plastic High	*b*	.81	0.17
Plastic Low	*b,c*	.32	0.07
Significance 0.05	LSD	.2	
Model		0.01	
Treatment		0.2	
Block		0.272	

concentrations. But, these differences were not as large as those reflected in treatment comparisons.

There was no noticeable trend between fertigation and irrigation with regards to TSNA concentration. Some were high while others were lower, but both treatments were similar. Timing of N applications did not seem to affect TSNA.

Precipitation

Rainfall data was taken from NOAH weather stations located at both the Greeneville and Springfield experimental stations. Table 6 displays precipitation totals, including irrigation totals for Greeneville, 2006. Table 7 displays precipitation totals for Springfield, 2006.This data was used in the "Management of Irrigation Systems in Tennessee" (M.O.I.S.T) program developed by Dr. Brian Leib at the University of Tennessee. This program estimates the specific crop water demand that is sensitive to plant growth stages. Weekly precipitation and irrigation totals are considered a credit while plant water use is a debit. Soil water holding capacity is used to calculate a water depletion allowance. Precipitation amounts that are unable to maintain soil moisture levels within the depletion allowance denote plants that are beginning to enter drought stress. This is a rough approximation of available soil moisture chosen primarily for its ease of use by a producer. This program is useful for characterizing the effectiveness of precipitation and irrigation in meeting tobacco plant water demand. Figure 6 and 7 displays M.O.I.S.T data graphed for each site.

Table 6. Precipitation and Irrigation data used in the M.O.I.S.T. program.

Greeneville 2006 Burley Rainfall/Irrigation Data

#	Week Start	End	+ Effective Rain inches	+ Net Irrigation inches	- Crop Water Use inches	Moisture Depletion inches	Allowable Depletion inches
1	9-Jun	10-Jun	0.06		0.65	0.13	0.5
2	11-Jun	17-Jun	0.59		0.66	0.19	1.0
3	18-Jun	24-Jun	0.13		0.66	0.73	1.5
4	25-Jun	1-Jul	1.55		0.88	0.05	2.0
5	2-Jul	8-Jul	1.96		1.16	0.00	2.5
6	9-Jul	15-Jul	0.55	.2	1.43	0.00	3.0
7	16-Jul	22-Jul	1.27	1	1.54	0.27	3.2
8	23-Jul	29-Jul	1.23	1	1.52	0.00	3.2
9	30-Jul	5-Aug	0.35	1	1.50	0.15	3.2
10	6-Aug	12-Aug	3.47	.2	1.40	0.00	3.2
11	13-Aug	19-Aug	0.07		1.23	1.16	3.2
12	20-Aug	26-Aug	1.32		1.06	0.90	3.2

Total rain = 12.6 inches

Plant water demand = 13.5 inches

Total irrigation = 4.4 inches

Rain and irrigation = 17 inches

Table 7. Precipitation and Irrigation data used in the M.O.I.S.T. program.

Springfield 2006 Burley Rainfall/Irrigation Data

			+ Effective	+ Net	- Crop	= Soil Moisture	< Maximum Allowable
#	**Week Start**	**End**	**Rain inches**	**Irrigation Inches**	**Water Use inches**	**Depletion inches**	**Depletion Inches**
1	7-Jun	10-Jun	0		0.52	0.30	0.6
2	11-Jun	17-Jun	0.1		0.52	0.72	1.0
3	18-Jun	24-Jun	0.98		0.53	0.27	1.5
4	25-Jun	1-Jul	0.71		0.75	0.31	1.9
5	2-Jul	8-Jul	3.06		0.99	0.00	2.4
6	9-Jul	15-Jul	0.37	0.3	1.23	0.56	2.8
7	16-Jul	22-Jul	0.87	1	1.46	0.15	3.2
8	23-Jul	29-Jul	1.04	0.2	1.45	0.37	3.2
9	30-Jul	5-Aug	0.01	1	1.43	1.59	3.2
10	6-Aug	12-Aug	1.46		1.40	1.53	3.2
11	13-Aug	19-Aug	0.12	0.2	1.37	2.58	3.2
12	20-Aug	26-Aug	0.04	1	1.32	2.86	3.2
13	27-Aug	2-Sep	3.06		1.27	1.08	3.2
14	3-Sep	9-Sep	0.07	0.5	1.16	1.67	3.2
15	10-Sep	16-Sep	0.52	0.5	0.85	1.80	3.2
16	17-Sep	23-Sep	1.71		0.57	0.66	3.2
17	24-Sep	30-Sep	2.91		0.41	0.00	3.2

Total rain = 17 inches

Plant water demand = 17.3 inches

Total irrigation = 4.7 inches

Rain and irrigation = 21.7 inches

Heavy rains came very late in the season. These are the totals up to 8/28/06.

Rain before 8/28 = 8.7 inches

Plant water demand before 8/28 = 13 inches

Irrigation before 8/28 = 4.7 inches

Rain and irrigation before 8/28 = 13.4 inches

Greeneville M.O.I.S.T. 2006 Data Graphed

Non-Irrigated **Irrigated**

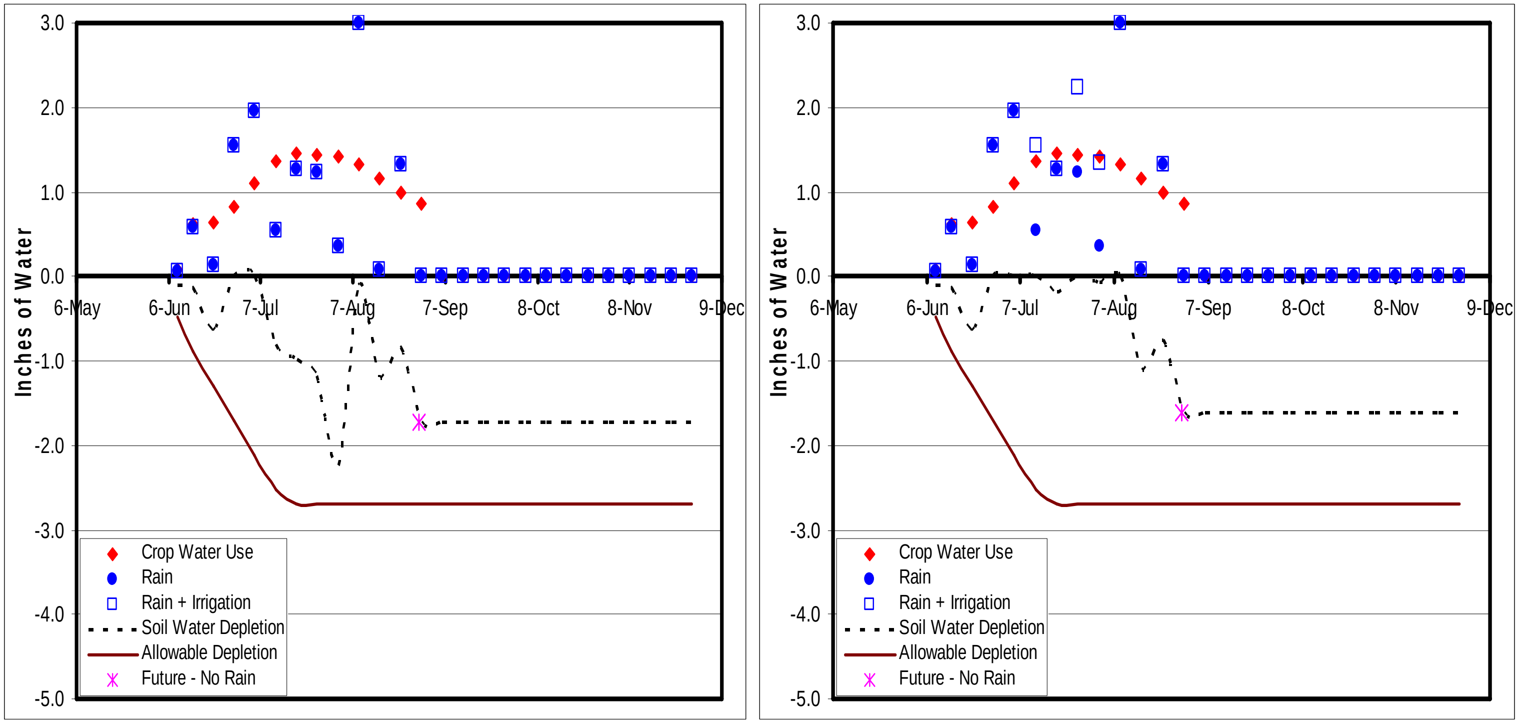


Figure 5. M.O.I.S.T data for Greeneville graphed.

Springfield Burley/Dark Moist 2006 Data Graphed

Non-Irrigate **Irrigated**

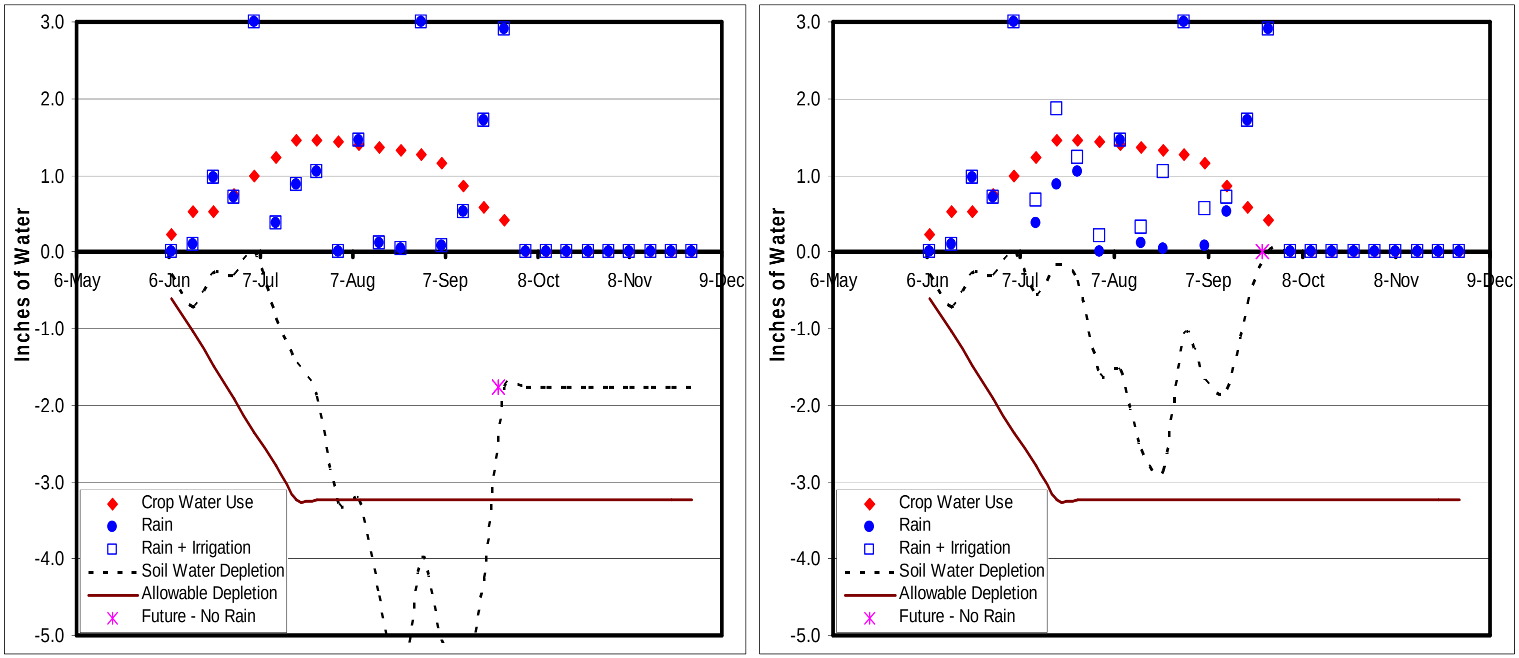


Figure 6. M.O.I.S.T data for Springfield graphed.

What is most apparent in this water budget, is that the rainfall at Greeneville in 2006 was sufficient in both amounts and timing to keep the plants water demand above the water depletion allowance threshold. There were light rains early in the season, while later season rains were heavier allowing the plant to meet higher water demands associated the rapid growth stage. There were three separate irrigation events that were followed by rains that would have negated the necessity of irrigation. It was a good season for growing dryland tobacco, reflected in the very high yield rates.

At Springfield in 2006, early rain was sufficient, but in the week of July 29th – August 5th, there was no rain. This dry period came at a time when the plants growth stage demanded about 1.5 inches of rain, which is the highest crop demand coefficient. This was followed by a rain of 1.46 inches during the week of August 6th -12th. Following this rain was two more dry weeks during August 13th – 26th, where there was only 0.16 inches of rain. Irrigation was effective in keeping available soil moisture above the allowable depletion allowance. Another point of interest is the season precipitation total. There was about 16.5 inches of rain in Springfield matched against a crop water demand of about 17.5 inches. But, precipitation events were poorly spaced during the season.

Precipitation data was taken from weather stations on location. The experimental stations at Greeneville and Springfield are NOAA collection sites. Data was collected daily from tipping bucket gauges.

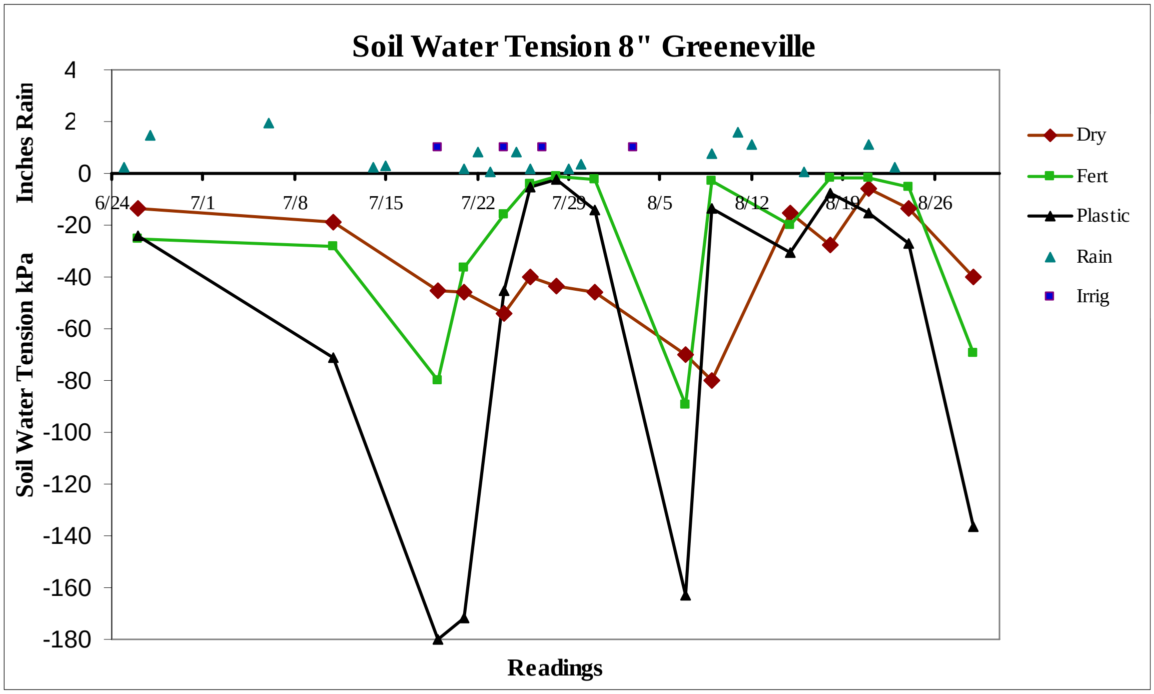
Soil Moisture

We have watermark data from the 2006 season at both Greeneville and Springfield at 8” and 20” depths. As we only measured soil water tension for this year, each reference to a site will be for 2006 only. The soil moisture, as measured by the sensors correlates fairly closely to the M.O.I.S.T. data graphed. At Greeneville, tensions rarely rose beyond -60 kPa, except for the mulch treatments that had shed rain. This was reflected in the plant water demand line staying above the depletion allowance line. Springfield shows a gradual drying of the soil profile at both 8” and 20” depths, passing the allowable depletion threshold in the first week of August, as reflected in the M.O.I.S.T water budget. At both sites, the dryland treatment consistently has the highest soil tensions at both depths. At Springfield, where there were the greatest differences in yield, the benefits of irrigation in maintaining soil moisture was the most evident.

At Greeneville, following the first 3 weeks from transplant (6/19/06 – 7/3/06), the growth of plants under the plastic mulch had noticeably more biomass than the fertigation and dryland treatments. This occurred despite the fact that soil water tensions at the 8” depth at Greeneville were much higher than the dryland and fertigation treatments. These high tensions are reflective of the additional amounts of soil water needed to support the increased rate of growth. The shedding of precipitation was ameliorated by translocation of deeper soil water as reflective in the low soil water tensions for all treatments at the 20” depth at this time. In order to support growth, the plastic mulch plants had effectively found water at deeper depths. Deep rooting is considered a desirable growth characteristic as shallow roots are more susceptible to desiccation during dry periods that frequently occur during the growing season. Figure 8 displays soil water tensions at 8 and 20 inches for the Greeneville, 2006 growing season.

The period between 7/11 and 7/19 is noteworthy. This is the period when the plant, having established itself, begins a second phase of development in which rapid growth occurs. There has only been 0.5” of rain that the plasticulture may not have derived a similar benefit from as the dryland and fertigation have. Yet, plasticulture soil tensions rise very rapidly from a reading of -71 to -182 kPa average in the soil water column between 8” – 20”. In the previous time period, since transplanting, the soil water tensions had only increased from -24 to -74 kPa. This rapid uptake of soil moisture would seem to indicate that the plant has effectively established roots, and is entering a stage of rapid growth either earlier or with more intensity than the other treatments.

At Springfield, soil water tensions are similar for all treatments for the first half of the growing season. What is important for this site, is that equipment problems at the end of July led to an irrigation treatment being missed. This came at a particularly bad time as the plants had entered rapid growth according to the calendar. There was only one irrigation event occurring in the middle of July, from transplant until the first week of August. The soil tensions during the first 6 weeks after transplanting are very similar at both Greeneville and Springfield. There is not an evident spike in water tensions for plastic and fertigation as there was at Greeneville. It is also important to note that precipitation totals from the beginning to June to the end of July were very similar (7.1” at Springfield, 7.7” at Greenfield). The total water (precipitation and irrigation) at Greeneville during the period in which rapid growth was expected to be occurring at 4-8 weeks after transplanting, was about 6.5”, while Springfield had about 4”. One would



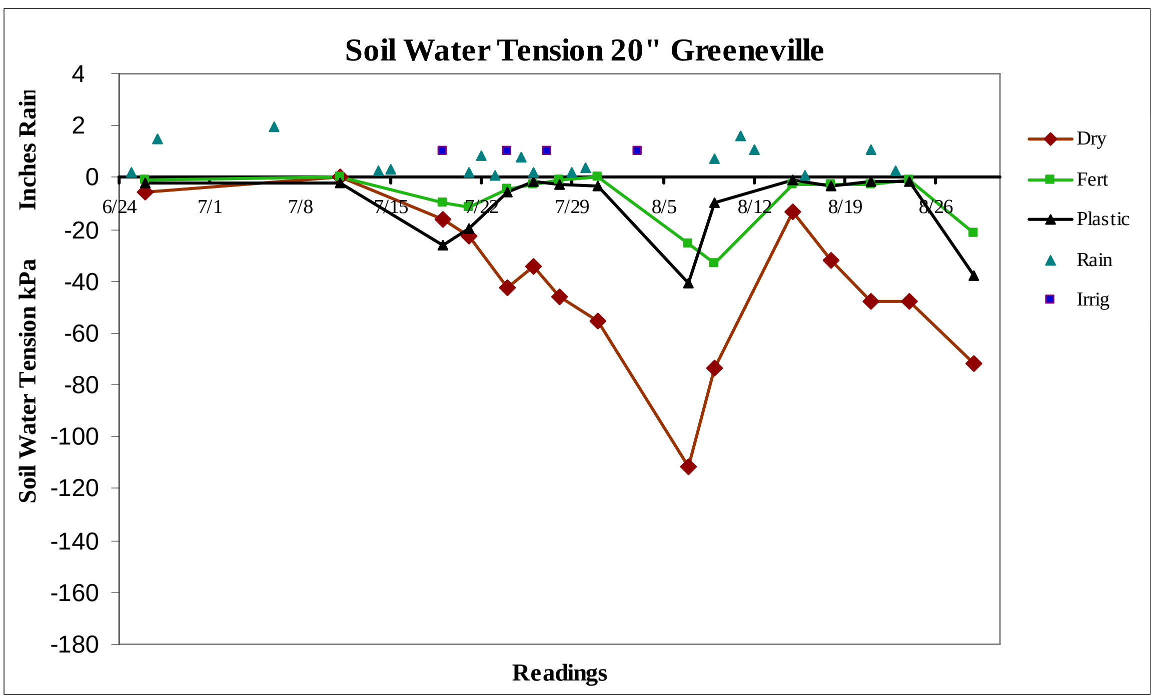


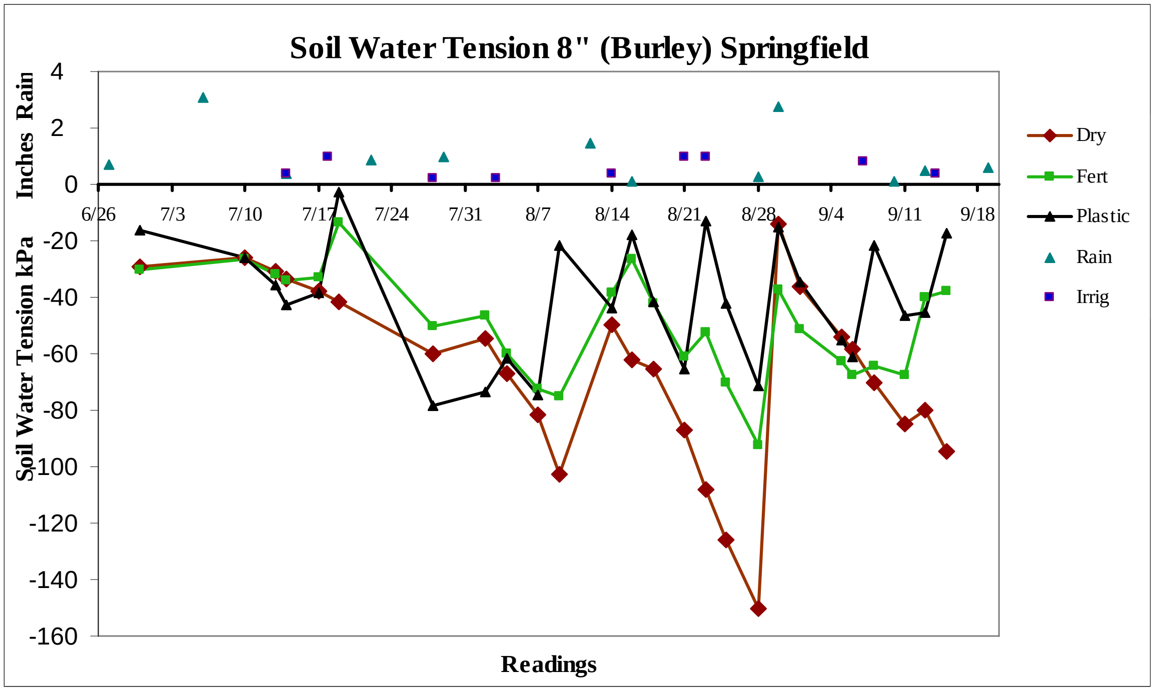
Figure 7. Soil water tension for Greeneville, 2006.

expect soil water tensions to be higher at Springfield where both total water since transplanting and also water during the period of rapid growth were less. The differences in tensions could be attributed to less biomass generated at Springfield. Soil water tensions could serve to regulate growth stages and biomass accumulation. Figure 9 displays soil water tensions at 8 and 20 inches for the Springfield, 2006 burley and Figure 10 displays tensions for dark tobacco during the Springfield, 2006 growing season.

During the second half of the growing season in Springfield, the treatments began to separate more with the dryland being the driest. There is an evident spike in water tensions that could be associated with flowering. At Springfield, it is occurring about two to three weeks later than the spike that occurred at Greeneville.

Soil Temperature

Season long soil temperatures for Greeneville and Highland Rim for 2006 are displayed in figure 11 for Greeneville and figure 12 for Springfield. Table 8 contains the average seasonal temperatures for each treatment at Greeneville in 2006 as well as the flux in daily temperatures for each treatment. Table 9 contains the average seasonal temperatures and daily flux in temperatures by treatment for Springfield in 2006. Soil temperatures were separated into two sections for analysis. The first section represented the establishment growth stage occurring between transplant and week four after transplant. During this period, neither irrigation nor fertigation was applied. Therefore, the dryland and fertigation treatments had the same management protocol within this period, aside from preplant N amounts. As expected, the temperatures of the dryland and fertigation are very similar at both Greeneville and Springfield. The second section,



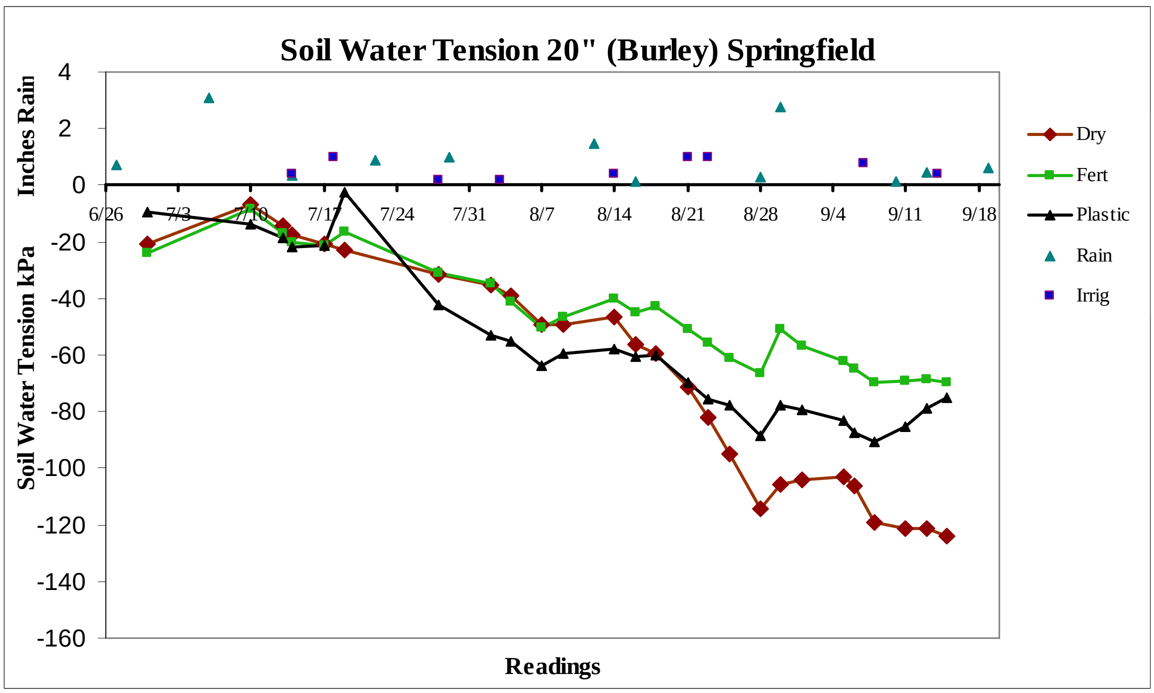
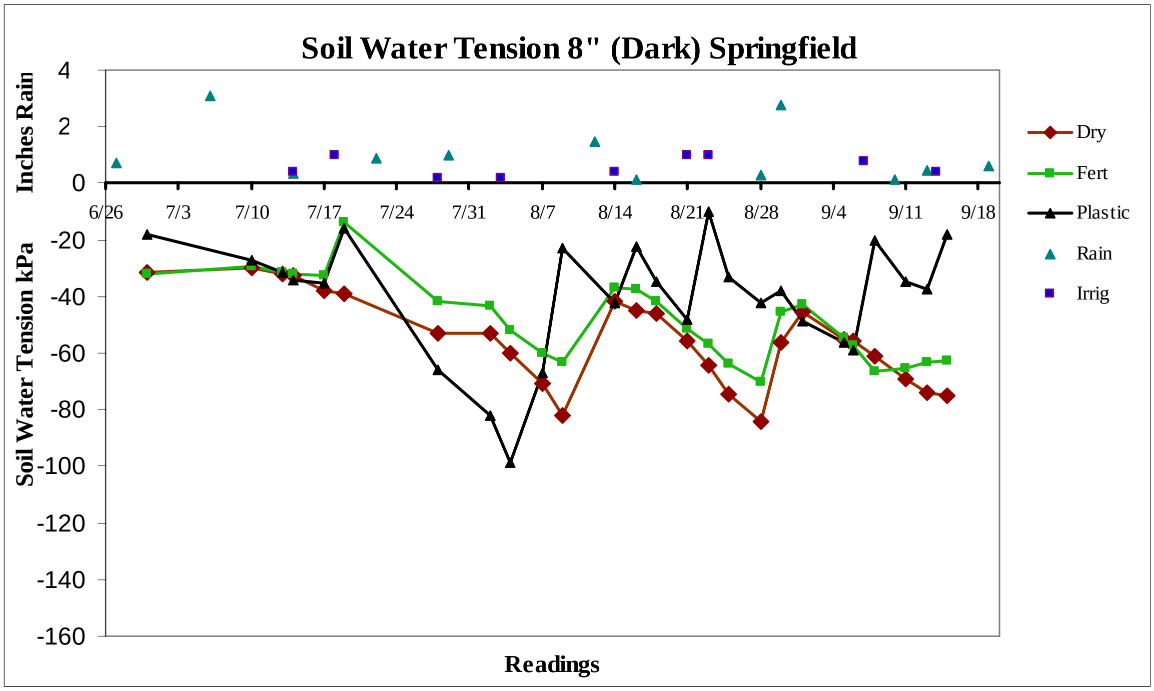


Figure 8. Soil water tension for Springfield (Burley), 2006.



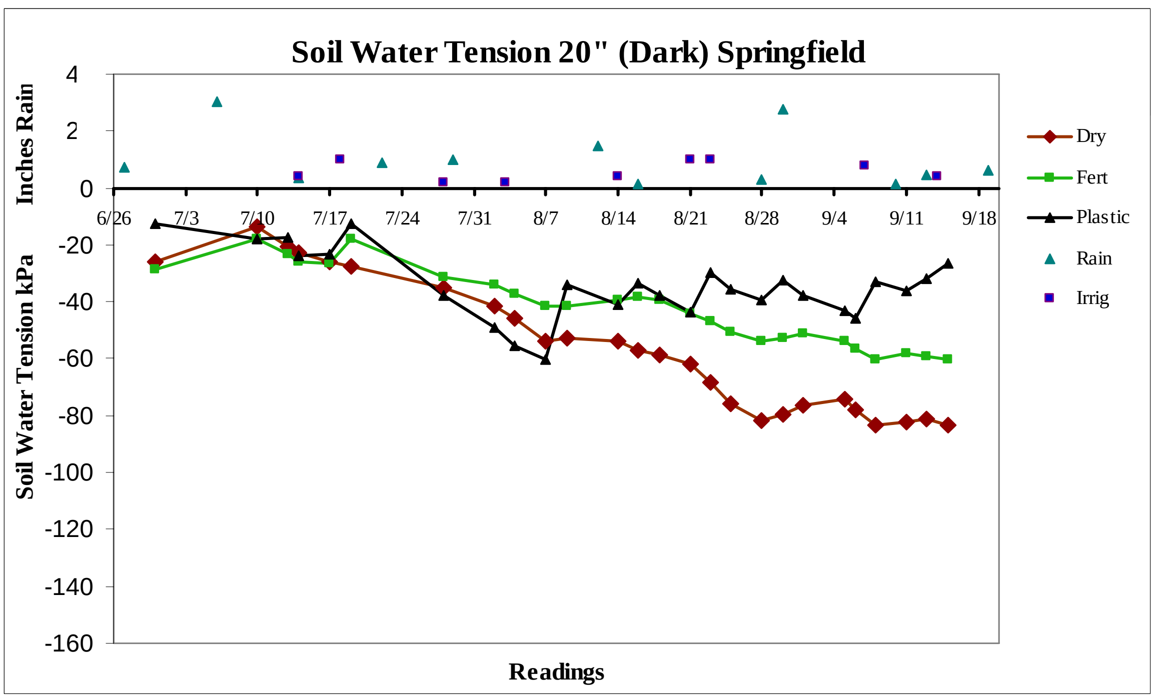
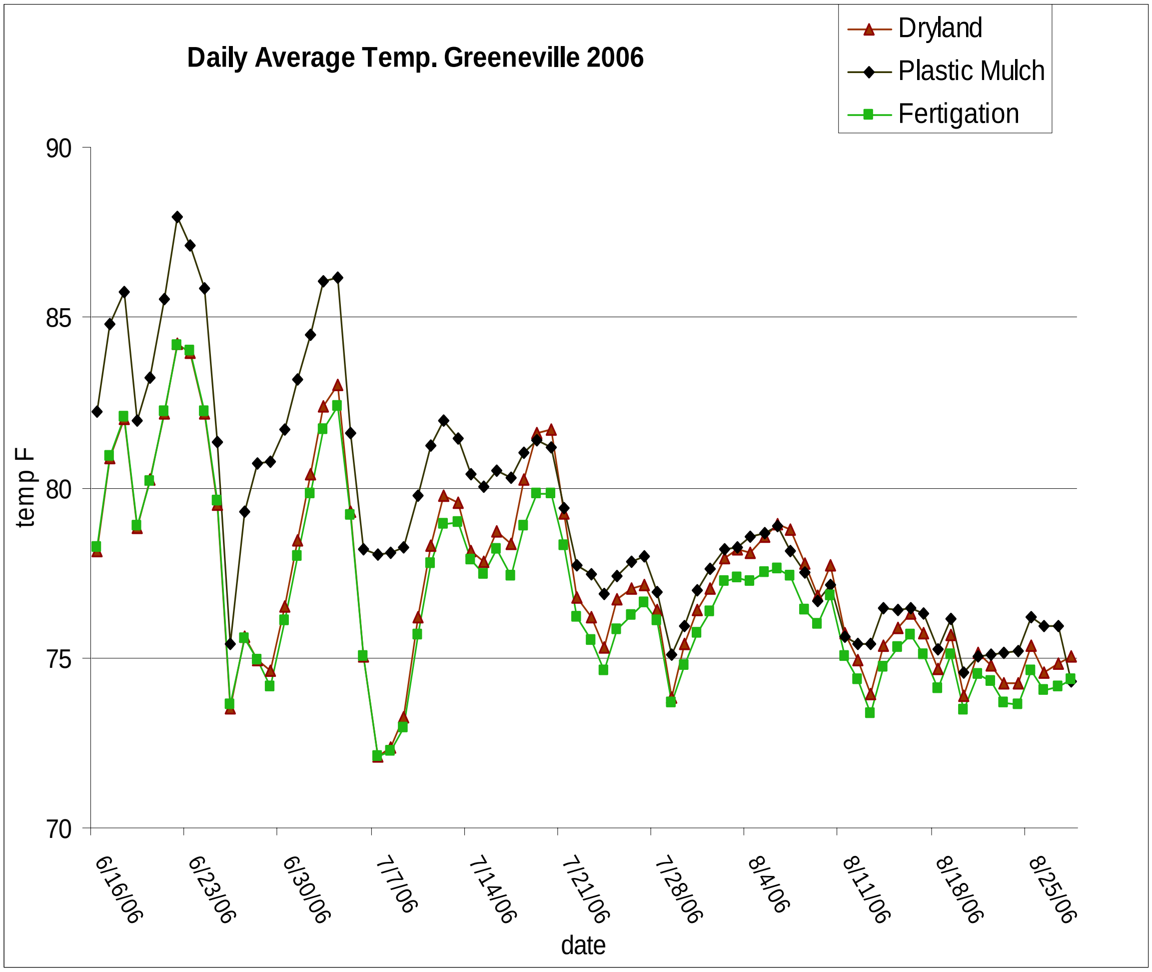


Figure 9. Soil water tension for Springfield (dark), 2006.



Average soil temperature of 4 replications for each treatment during growing season.

Figure 10. Season long soil temperatures by treatment for Greeneville, 2006.

Table 8. Average soil temperatures by treatment through the Greeneville, 2006 growing season, as well as the flux in daily temperatures for each treatment.

Season totals	**Dryland**	**Fertigation**	**Plastic**
Average of Hourly Temperatures Fahrenheit	77.36	76.81	79.12
Average flux of hourly Temperatures within a day	5.90	5.69	4.79

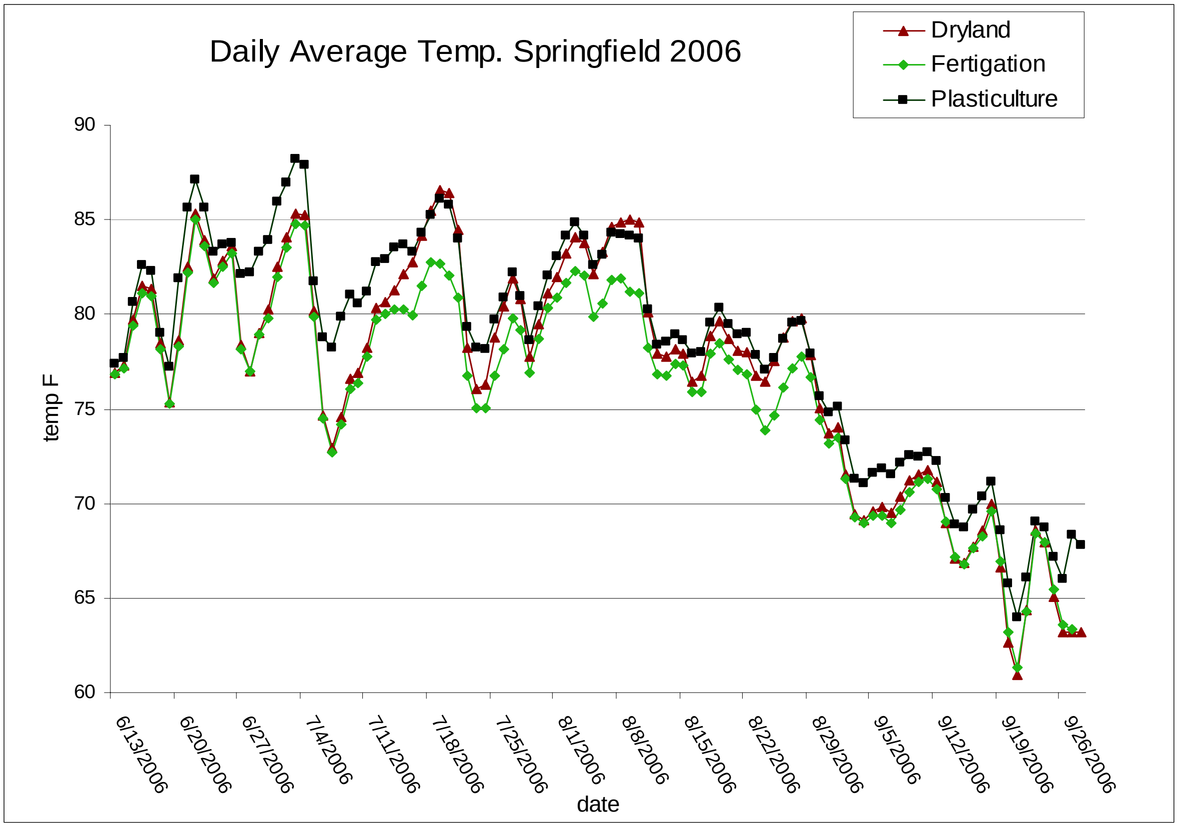


Figure 11. Season long soil temperatures by treatment for Springfield, 2006.

Table 9. Average soil temperatures by treatment through the Springfield, 2006 growing season, as well as the flux in daily temperatures for each treatment.

Season totals	**Dryland**	**Fertigation**	**Plastic**
Average of Hourly Temperatures	76.83	75.86	78.37
Average flux of Temperatures within a day	6.95	6.30	6.46

representing rapid growth, was in the four to six week period after transplant. Figure 13 displays soil temperatures for Greeneville, 2006 during weeks 1 – 4. Figure 14 displays soil temperature for the same time periods for Springfield, 2006.

During establishment the plastic mulch was effective in maintaining temperatures at about 4 degrees F higher. The additional 4 degrees provided soil temperatures that were at optimal levels (73 – 95 F) longer. For Springfield, plasticultrue treatments were in optimal ranges about ¾ of the time while the dryland and fertigation treatments were only in these optimal ranges about ½ the time. At Greeneville, all treatments generally had cooler soils than those in Springfield. The average daily temperature was only about one to two degrees cooler at Greeneville but the daily flux in temperatures was larger in Springfield. Because of this, plasticulture was in optimal temperatures a little over 60% of the time compared to dryland and fertigation at about 40% of the time. Tables 10 and 12 display temperatures in each treatment at each site. Tables 11 and 13 show how these treatments influenced the ability of the treatments to stay in optimal temperature ranges.

Rain events cooled the soil in all treatments and this was evident by the additional rain events experienced in Greeneville. For both sites, the plastic treatments did not become as cool following rain as the dryland and fertigation, and recovered soil warmth more rapidly by holding soil water against the cooling forces of evaporation. This is particularly evident on cool nights.

The standard deviation of temperatures within the plastic treatment were higher than both the dryland and fertigation. Heat loss due to evaporation was effectively blocked, but convective cooling, due to the greater distance from ambient temperatures than the other treatments accounts for the larger flux.

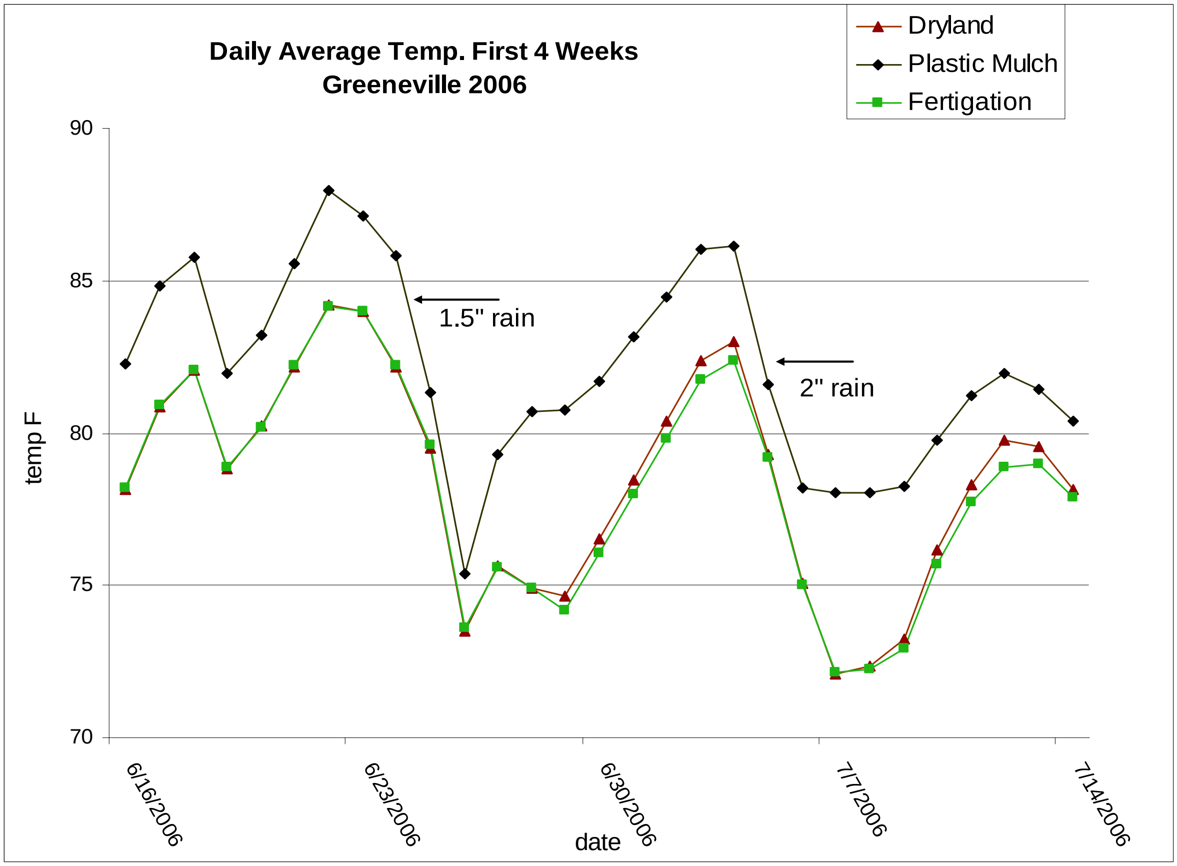


Figure 12. Soil temperatures for Greeneville, 2006 during the first four weeks from transplant.

Table 10. Soil Temperatures by treatment at Greeneville, 2006 during weeks 1–4.

4 Weeks From Transplanting	Dryland	Fertigation	Plastic
Average Daily Temperature F.	78.48	78.27	82.11
Average Flux of Daily Temperatures within a day	4.45	4.14	4.81
Total flux of Temperatures within the time period	5.82	5.60	6.00

Table 11. Percentage of Time Spent in Optimal Temperature Ranges of 73-95 F during weeks 1-4.

	Percent Time in Optimal Ranges	Percent Time Below 70 degrees F.
Dryland	42%	6%
Fertigation	41%	6%
Plasticulture	63%	0%

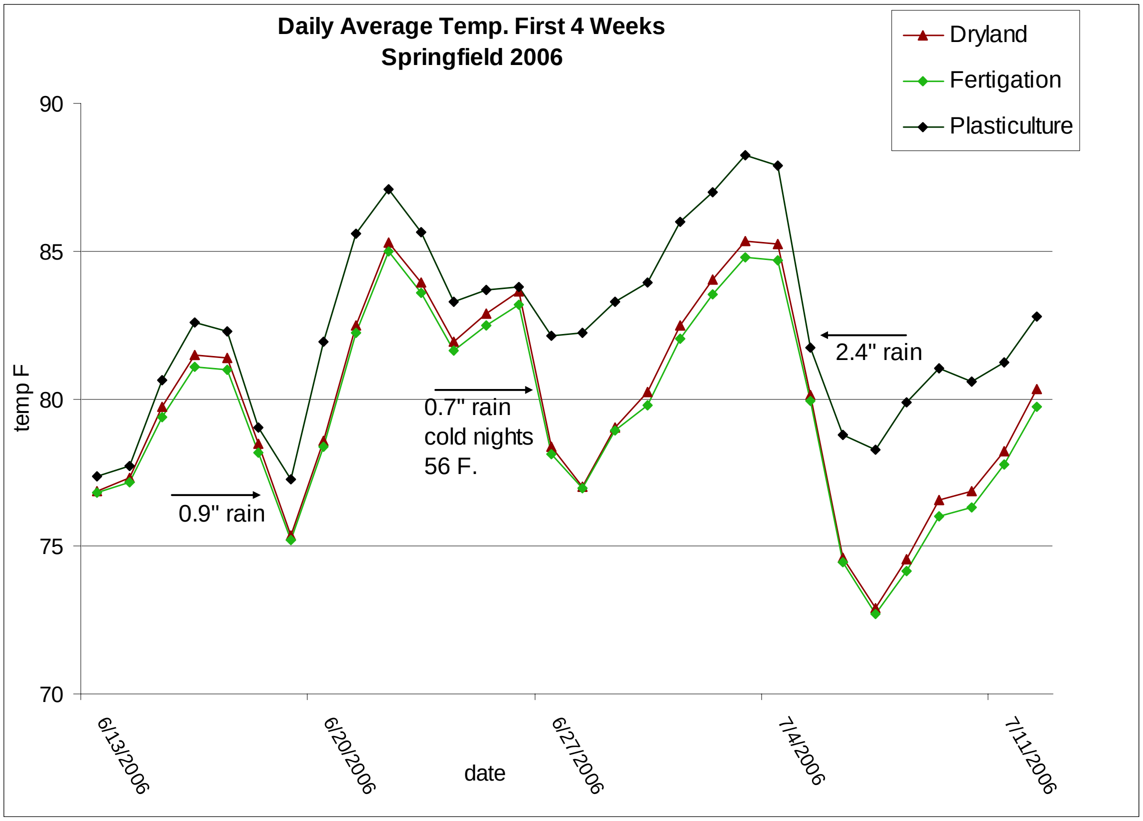


Figure 13. Soil temperatures for Springfield, 2006 during the first four weeks from transplant.

Table 12. Soil Temperatures by treatment at Springfield, 2006 during weeks 1–4.

4 Weeks From Transplanting	Dryland	Fertigation	Plastic
Average Daily Temperature F.	79.89	79.59	82.59
Average Flux of Daily Temperatures within a day	3.72	3.66	3.84
Total Flux of Temperatures	5.19	5.11	4.97

Table 13. Percentage of Time Spent in Optimal Temperature Ranges of 73-95 F during weeks 1-4.

	Percent Time in Optimal Ranges	Percent Time Below 70 degrees F.
Dryland	55%	2%
Fertigation	52%	2%
Plasticulture	76%	0%

During Rapid Growth, temperatures begin to become more equal as leaf coverage increased in plots. The effect of this leaf coverage was a slight cooling in soil temperatures during rapid growth, even though ambient temperatures were rising. dryland and plastic treatments were fairly equal in temperature and time in optimal ranges. The fertigation treatment, which included the use of irrigation, consistently had the coolest soil temperatures. The ability of the plastic to avoid the cooling effects of rain and evaporation, combined with rising ambient temperatures minimizing the effect of convective cooling, allowed the flux in daily temperatures in the plastic to be the lowest of the three treatments. Figures 15 and 16 display soil temperatures during weeks 4 – 6 at Greeneville and Springfield. Tables 14 and 16 display temperature averages by treatment. Tables 15 and 17 display the influence of treatment on maintaining optimal soil temperatures.

Petiole Nitrates as Measured by the Cardy Meter

The first nitrate analysis at four weeks after transplanting, for all treatments at all rates were fairly equal, with some trends showing decreased leaf nitrates with reduced preplant N levels. As the plant is taking up nitrate from the soil in response to soil concentration and plant demand, low N preplant was not a limiting factor during the establishment stage. Figure 17 displays the four nitrate samples in 2005 for Greeneville and Springfield. Figure 18 displays nitrate samples from 2006 for Greeneville and Springfield, while figure 19 displays nitrate samples from dark tobacco grown at Springfield.

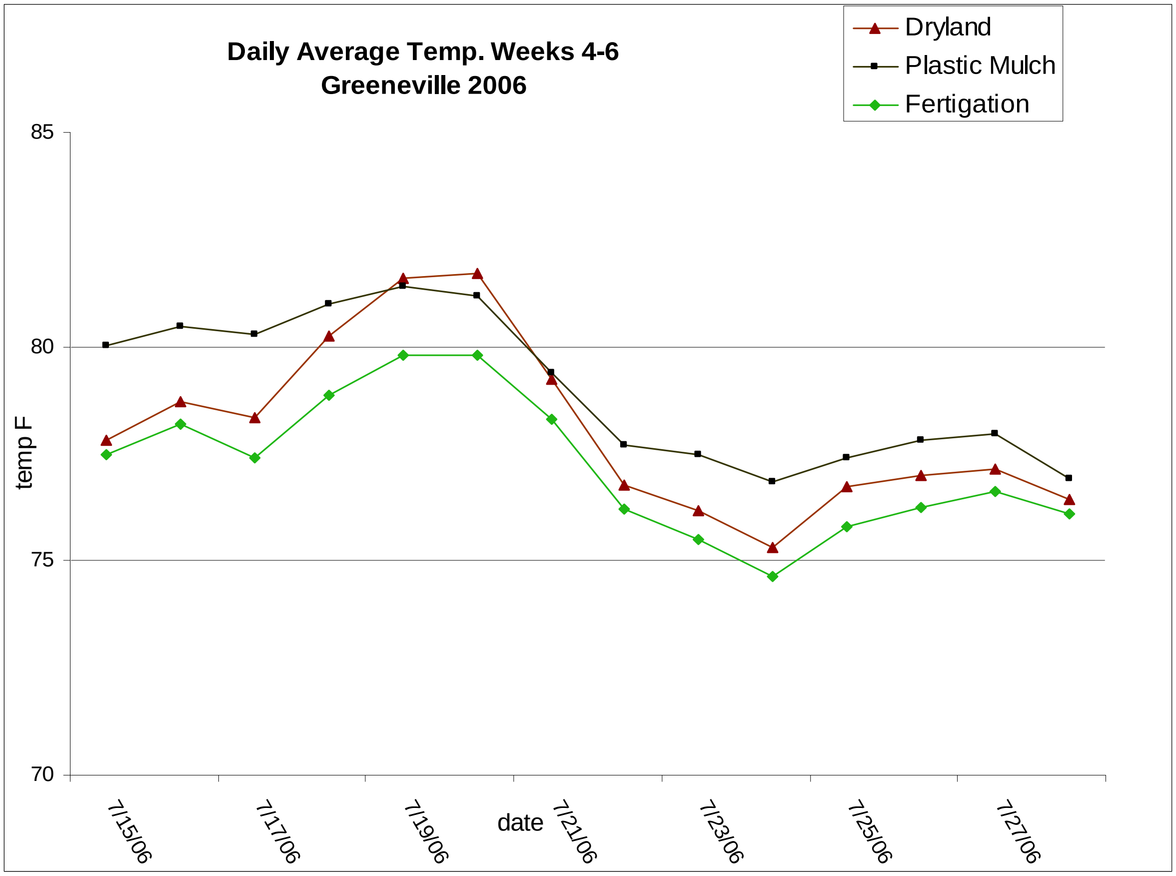


Figure 14. Soil temperatures for Greeneville, 2006 during weeks 4-6 from transplant.

Table 14. Soil Temperatures by treatment at Greeneville, 2006 during weeks 4-6.

4-6 Weeks From Transplanting (7/15/06-7/28/06)	Dryland	Fertigation	Plastic
Average Daily Temperature F.	78.09	77.21	78.97
Total Stdev. of Temperatures within the time period	3.55	2.59	2.59

Table 15. Percentage of Time Spent in Optimal Temperature Ranges of 73-95 F during weeks 4-6.

	Percent Time in Optimal Ranges
Dryland	34%
Fertigation	23%
Plasticulture	46%

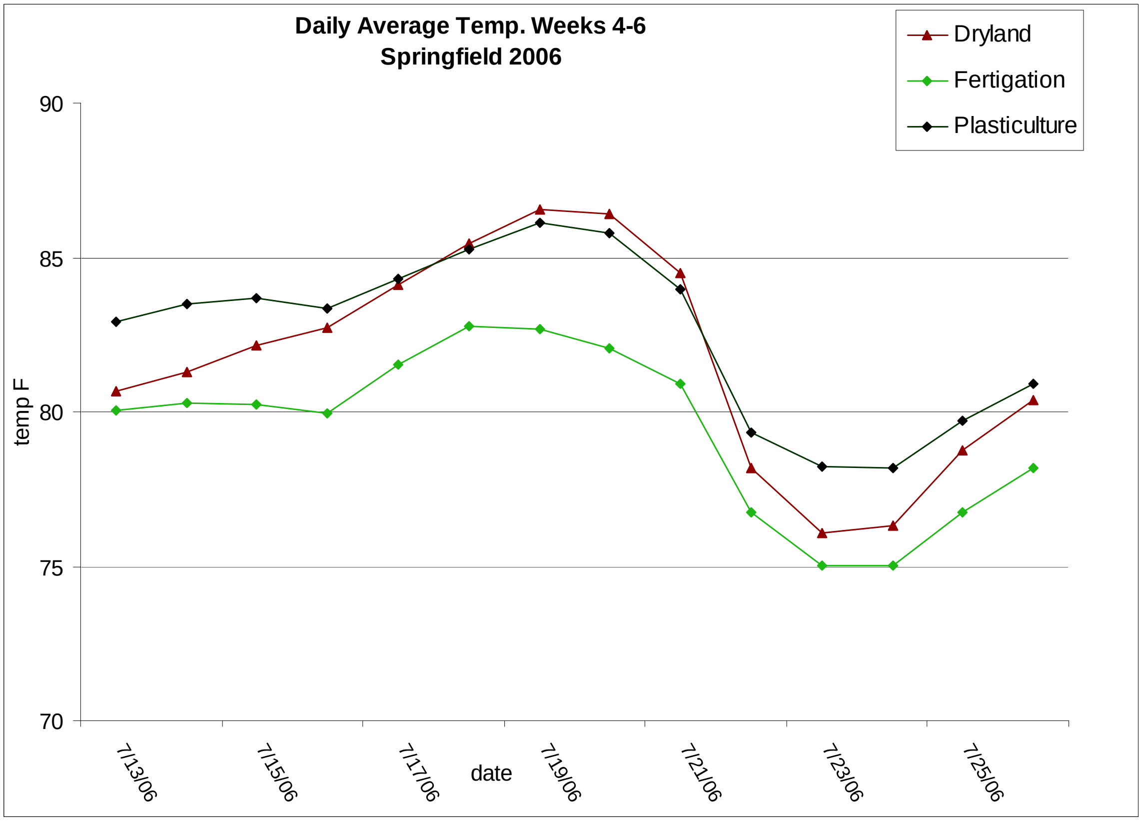


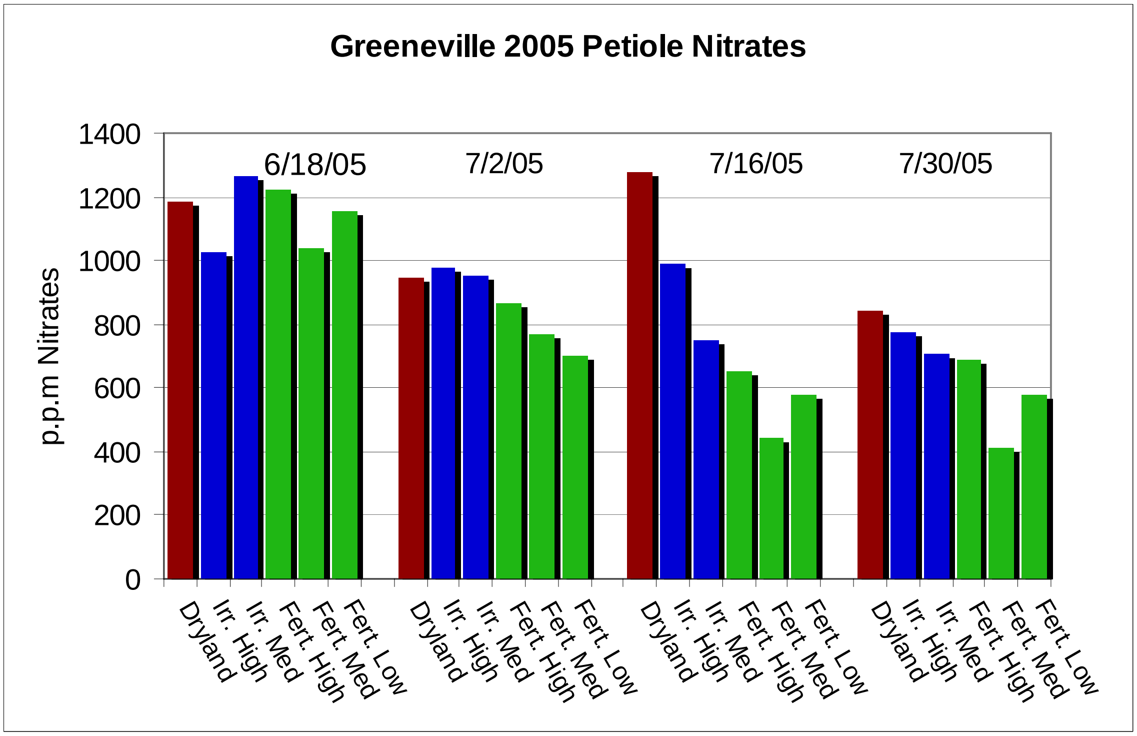
Figure 15. Soil temperatures for Springfield, 2006 during weeks 4-6 from transplant.

Table 16 Soil Temperatures by treatment at Springfield, 2006 during weeks 4-6.

4-6 Weeks From Transplanting (7/15/06-7/28/06)	Dryland	Fertigation	Plastic
Average Daily Temperature F.	81.74	79.34	82.28
Total Stdev. of Temperatures within the time period	4.19	3.14	3.34

Table 17. Percentage of Time Spent in Optimal Temperature Ranges of 73-95 F during weeks 4-6.

	Percent Time in Optimal Ranges
Dryland	72%
Fertigation	57%
Plasticulture	83%



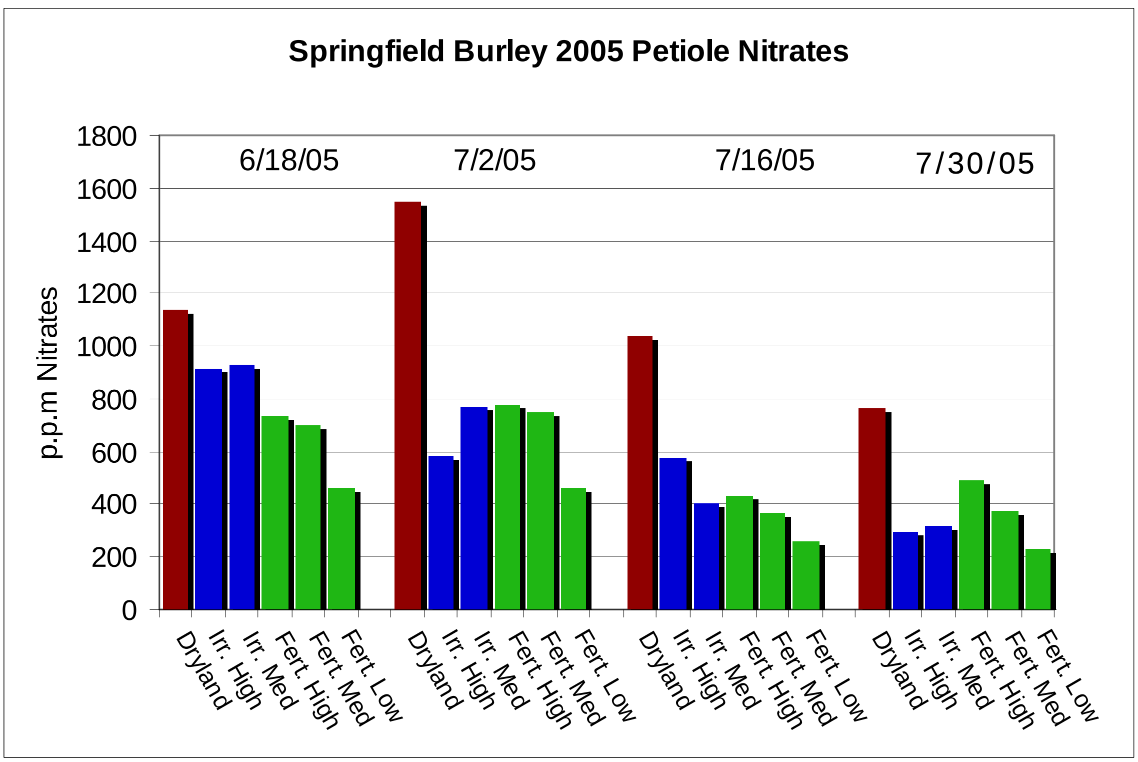
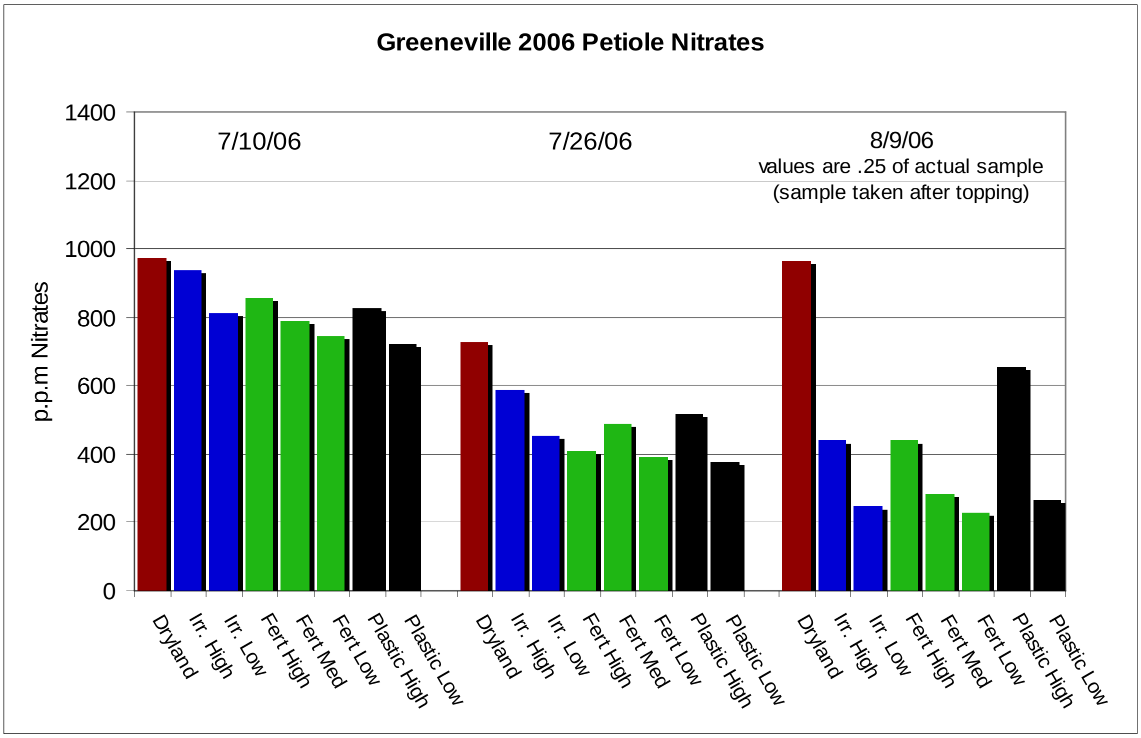


Figure 16. Nitrate values sampled by the Cardy meter during the 2005 growing season.



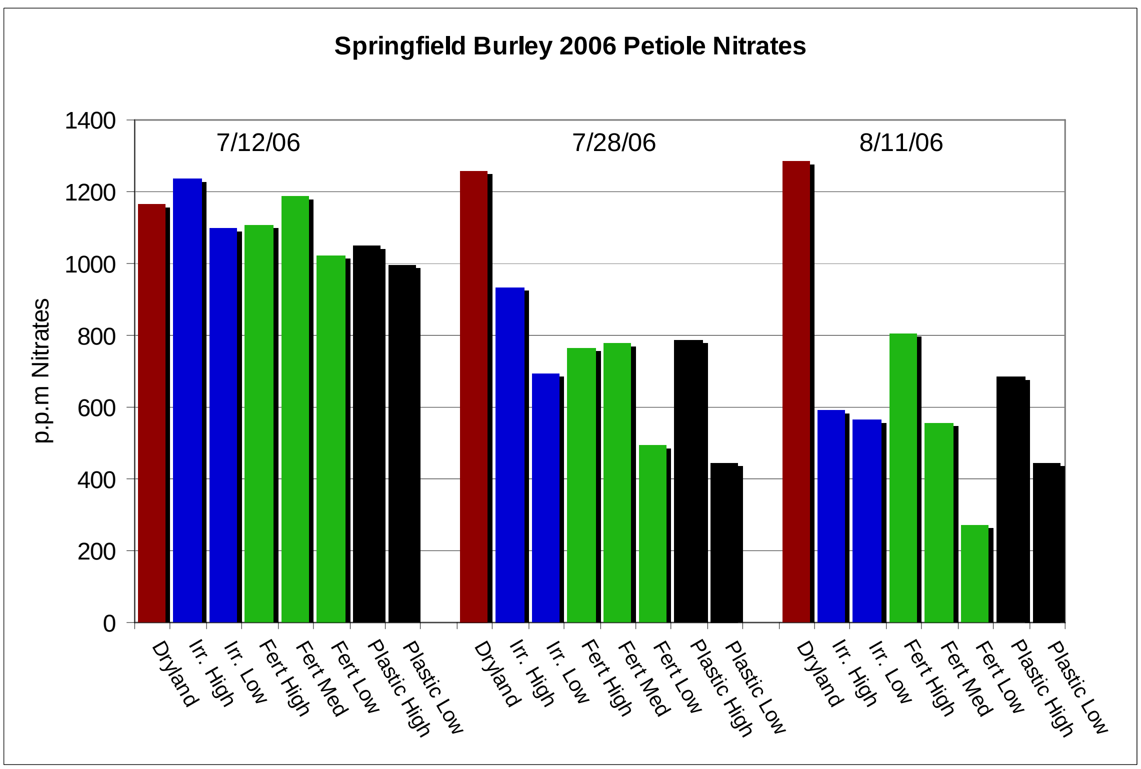
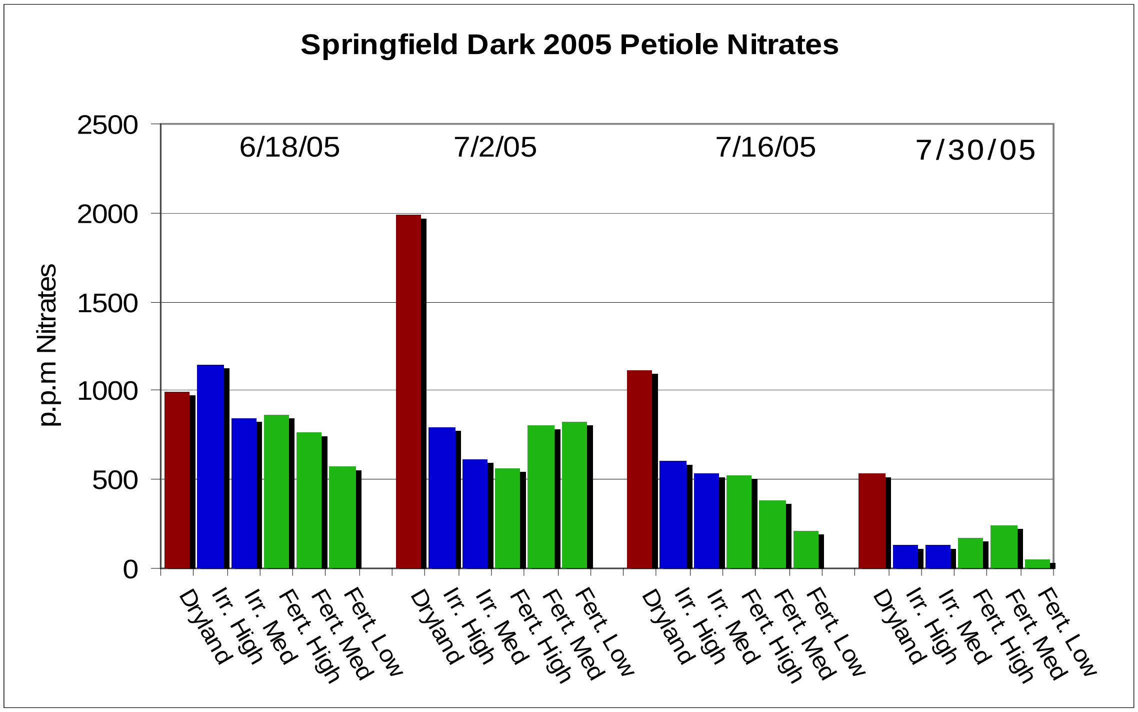


Figure 17. Nitrate values sampled by the Cardy meter during the 2006 growing season.



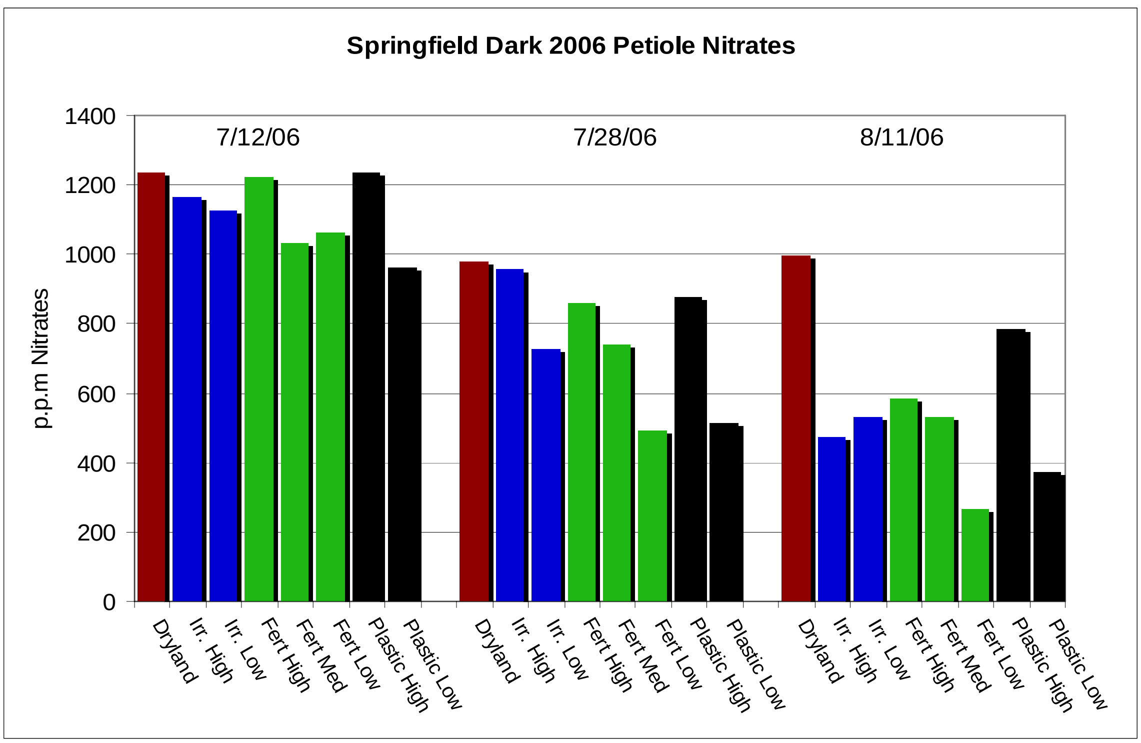


Figure 18. Nitrate values sampled by the Cardy meter for dark tobacco grown at Springfield in 2005 – 2006.

Tables 18 and 19 displays the associated nitrate sample values and statistical analysis from Greeneville and Springfield 2005, while tables 20 and 21 displays associated nitrate values and statistics from 2006. Tables 22 and 23 displays the associated nitrate values and statistics from dark tobacco grown at Springfield in 2005 – 2006.

The second sample, taken at week six, shows N p.p.m. concentrations dropping in all treatments, but remaining highest and less predictable in the dryland. In two of the four analysis, N concentrations increase in the dryland while all the other treatments decrease. Irrigation, with all N applied preplant was the next highest, followed by plastic and then fertigation being consistently the lowest. This is attributable to the additional biomass accumulated in the plastic treatments and the reduced concentrations of soil N in the fertigation and plasticulture treatments. For all sites and years, Greeneville 2006 showed the greatest drop in petiole nitrates from week 4 to week 6.

The third sample, taken at week eight, shows the most separation between treatments and N rates. In three out of four analysis, the dryland N concentrations have increased while all other treatments continue to decline. The notable exception is Greeneville in 2006 where nitrates had decreased most dramatically in the previous sampling. While the trends between treatments remain the same, N concentrations spike to be four times higher than the first reading which was usually the highest. What was different was the topping time. Early yellowing forced topping to occur before sampling. Provided this was not a problem with the Horiba monitor, this analysis captured the effects of topping on plant physiology. Topping is expected to cause rapid uptake of soil water and nutrients.

Table 18. Petiole nitrates measured at Greeneville, 2005.

Sample 1 Nitrates Greeneville 6/19/2005	Mean	Standard Deviation	Significant Differences
Dryland	1188	75	(model not
Irr. High	1028	161	significant)
Irr. Med.	1263	160	
Fert. High	1225	132	
Fert. Med.	1035	83	
Fert. Low	1153	173	
Significance 0.05			
Model	0.3		
Treatment	1.6		
Block	7.8	LSD	209.4

Sample 2 Nitrates Greeneville 7/3/2005	Mean	Standard Deviation	Significant Differences
Dryland	944	136	(model not
Irr. High	974	953	signicant)
Irr. Med.	953	105	
Fert. High	865	145	
Fert. Med.	768	118	
Fert. Low	698	93	
Significance 0.05			
Model	0.08		
Treatment	0.03		
Block	0.84	LSD	176.2

Sample 3 Nitrates Greeneville 7/17/2005	Mean	Standard Deviation	Significant Differences
Dryland	1276	480	a
Irr. High	988	95	a,b
Irr. Med.	748	156	b,c
Fert. High	650	167	b,c
Fert. Med.	440	56	c
Fert. Low	576	188	b,c
Significance 0.05			
Model	0		
Treatment	0		
Block	0.21	LSD	325

Sample 4 Nitrates Greeneville 7/31/2005	Mean	Standard Deviation	Significant Differences
Dryland	843	197	(model not
Irr. High	774	254	significant)
Irr. Med.	705	138	
Fert. High	690	174	
Fert. Med.	413	157	
Fert. Low	579	368	
Significance 0.05			
Model	0.07		
Treatment	0.1		
Block	0.08	LSD	295

Table 19. Petiole nitrates measured at Springfield, 2005.

Sample 1 Nitrates Springfield Burley 6/26/2005	Mean	Standard Deviation	Significant Differences
Dryland	1138	95	a
Irr. High	914	278	a,b
Irr. Med.	929	81	a,b
Fert. High	731	101	b,c
Fert. Med.	695	58	b,c
Fert. Low	461	87	c
Significance 0.05			
Model	0		
Treatment	0		
Block	0.39	LSD	200

Sample 2 Nitrates Springfield Burley 7/10/2005	Mean	Standard Deviation	Significant Differences
Dryland	1550	212	a
Irr. High	583	172	b
Irr. Med.	773	202	b
Fert. High	780	119	b
Fert. Med.	746	109	b
Fert. Low	463	83	b
Significance 0.05			
Model	0		
Treatment	0		
Block	0.68	LSD	240

Sample 3 Nitrates Springfield Burley 7/24/2005	Mean	Standard Deviation	Significant Differences
Dryland	1035	75	a
Irr. High	574	270	b
Irr. Med.	400	72	b
Fert. High	434	138	b
Fert. Med.	368	65	b
Fert. Low	259	140	b
Significance 0.05			
Model	0		
Treatment	0		
Block	9.49	LSD	230

Sample 4 Nitrates Springfield Burley 8/5/2005	Mean	Standard Deviation	Significant Differences
Dryland	857	86	a
Irr. High	295	233	b,c
Irr. Med.	315	124	b,c
Fert. High	554	166	b
Fert. Med.	409	75	b,c
Fert. Low	215	50	c
Significance 0.05			
Model	0		
Treatment	0		
Block	0.48	LSD	206

Table 20. Petiole nitrates measured at Greeneville 2006.

Sample 1 Nitrates Greeneville 7/10/2006	Mean	Standard Deviation	Significant Differences
Dryland	975	66	a
Irr. High	940	29	a,b
Irr. Low	811	50	c
Fert. High	856	55	a,b,c
Fert. Med.	789	69	c
Fert. Low	743	56	c
Plastic High	826	61	b,c
Plastic Low	724	53	c
Significance 0.05			
Model	0		
Treatment	0		
Block	0.85	LSD	84.3

Sample 2 Nitrates Greeneville 7/26/2006	Mean	Standard Deviation	Significant Differences
Dryland	728	82	a
Irr. High	588	50	a,b
Irr. Low	454	81	b
Fert. High	409	105	b
Fert. Med.	491	76	b
Fert. Low	393	123	b
Plastic High	516	158	b
Plastic Low	379	43	b
Significance 0.05			
Model	0		
Treatment	0		
Block	.109.423	LSD	138

Sample 3 Nitrates Greeneville 8/9/2006	Mean	Standard Deviation	Significant Differences
Dryland	3862	494	a
Irr. High	1763	210	c
Irr. Low	990	300	c
Fert. High	1763	544	c
Fert. Med.	1139	394	c
Fert. Low	923	494	c
Plastic High	2613	250	b
Plastic Low	1058	70	c
Significance 0.05			
Model	0		
Treatment	0		
Block	0.97	LSD	574

Table 21. Petiole nitrates measured at Springfield 2006.

Sample 1 Nitrates Springfield Burley 7/12/2006	Mean	Standard Deviation	Significant Differences
Dryland	1163	103	(model not
Irr. High	1236	113	significant)
Irr. Low	1100	108	
Fert. High	1106	97	
Fert. Med.	1200	108	
Fert. Low	1024	98	
Plastic High	1050	119	
Plastic Low	994	150	
Significance 0.05			
Model	0.05		
Treatment	0.05		
Block	0.19	LSD	155

Sample 2 Nitrates Springfield Burley 7/29/2006	Mean	Standard Deviation	Significant Differences
Dryland	1258	319	a
Irr. High	933	82	b
Irr. Low	694	47	b,c
Fert. High	763	86	b,c
Fert. Med.	711	77	b,c
Fert. Low	493	184	c
Plastic High	785	158	b,c
Plastic Low	444	88	c
Significance 0.05			
Model	0		
Treatment	0		
Block	0.88	LSD	239

Sample 3 Nitrates Springfield Burley 8/11/2006	Mean	Standard Deviation	Significant Differences
Dryland	1283	338	a
Irr. High	593	137	b,c
Irr. Low	724	336	b
Fert. High	804	264	b
Fert. Med.	490	75	b,c
Fert. Low	270	66	c
Plastic High	686	203	b,c
Plastic Low	443	151	b,c
Significance 0.05			
Model	0		
Treatment	0		
Block	0.04	LSD	276

Table 22. Petiole nitrates measured in dark tobacco Springfield 2005.

Sample 1 Nitrates Springfield Dark 6/26/2005	Mean	Standard Deviation	Significant Differences
Dryland	999	204	a
Irr. High	1143	161	a
Irr. Med.	848	155	a,b
Fert. High	863	164	a,b
Fert. Med.	766	138	a,b
Fert. Low	576	131	b
Significance 0.05			
Model	0.02		
Treatment	0.01		
Block	0.78	LSD	249

Sample 2 Nitrates Springfield Dark 7/10/2005	Mean	Standard Deviation	Significant Differences
Dryland	1983	597	a
Irr. High	794	73	b
Irr. Med.	615	168	b
Fert. High	566	118	b
Fert. Med.	800	534	b
Fert. Low	824	695	b
Significance 0.05			
Model	0		
Treatment	0		
Block	0.02	LSD	501

Sample 3 Nitrates Springfield Dark 7/24/2005	Mean	Standard Deviation	Significant Differences
Dryland	1118	274	a
Irr. High	604	72	b
Irr. Med.	532	138	b
Fert. High	518	10	b
Fert. Med.	385	45	b,c
Fert. Low	211	30	c
Significance 0.05			
Model	0		
Treatment	0		
Block	0.48	LSD	193

Sample 4 Nitrates Springfield Dark 8/5/2005	Mean	Standard Deviation	Significant Differences
Dryland	528	187	a
Irr. High	173	53	b
Irr. Med.	133	90	b
Fert. High	175	71	b
Fert. Med.	245	106	b
Fert. Low	49	12	b
Significance 0.05			
Model	0.03		
Treatment	0.02		
Block	0.74	LSD	147

Table 23. Petiole nitrates measured in dark tobacco Springfield, 2006.

Sample 1 Nitrates Springfield Dark 7/12/2006	Mean	Standard Deviation	Significant Differences
Dryland	1238	75	(model not
Irr. High	1165	205	significant)
Irr. Low	1125	65	
Fert. High	1225	119	
Fert. Med.	1033	113	
Fert. Low	1061	185	
Plastic High	1238	48	
Plastic Low	963	177	
Significance 0.05			
Model	0.08		
Treatment	0.06		
Block	0.34	LSD	191

Sample 2 Nitrates Springfield Dark 7/29/2006	Mean	Standard Deviation	Significant Differences
Dryland	980	2199	a
Irr. High	958	101	a
Irr. Low	725	195	a,b
Fert. High	859	72	a,b
Fert. Med.	739	225	a,b
Fert. Low	494	241	b
Plastic High	876	86	a,b
Plastic Low	514	125	b
Significance 0.05			
Model	0.02		
Treatment	0.01		
Block	0.99	LSD	260

Sample 3 Nitrates Springfield Dark 8/11/2006	Mean	Standard Deviation	Significant Differences
Dryland	995	286	a
Irr. High	474	129	b,c
Irr. Low	531	94	b,c
Fert. High	586	227	b,c
Fert. Med.	534	103	b,c
Fert. Low	268	46	c
Plastic High	783	132	a,b
Plastic Low	374	196	c
Significance 0.05			
Model	0		
Treatment	0		
Block	0.11	LSD	224

This fourth analysis was only performed in 2005. The reasoning being that this analysis would not be helpful to growers as it is too late in the season to make further N applications. It is also very difficult to get in the field at this time as leaf coverage is so extensive, that there is a high risk of breaking off leaves confounding yield results. This sample showed a continuing decline in petiole nitrates for all treatments but the fertigation. At the high, medium and low rates, petiole nitrate either remained at previous sample levels or had slightly risen.

The Horiba Cardy meter was able to consistently recognize treatment and N rate differences as the growing season progressed through samplings at 6 and 8 weeks after transplanting. The dryland high N treatments maintained high leaf nitrates through the entire growing season while all the other treatments, that included irrigation showed nitrates declining.

The correlation between the third N sample taken at eight weeks after transplanting and the TSNA analysis was averaged at all sites to be 0.81.

CHAPTER V

DISCUSSION

This research attempted to provide tools which would characterize the growing environment with regards to soil water tension and soil temperature, as they related to conditions that would optimize the uptake and utilization of soil nitrogen. This information can be used, in conjunction with cultural practices that will allow for season long adjustments to maximize yield, quality and nitrate content at harvest.

Soil Water Tension

As a basis for comparison, we used an unpublished, five year study conducted by Dr. Buchanan at the University of Tennessee, that found it to be profitable for producers to water when water tensions exceeded -40 kPa. Our data is in agreement. When the soil water tension was averaged for each treatment between the 8" and 20" depths, we found that the yield and quality was similarly affected.

At Greeneville, where precipitation volume and timing was calculated to meet plant growth needs, we saw very little affect due to irrigation. Table 24 displays soil

Table 24. Greeneville soil water tensions as they relate to yield, quality and TSNA.

Greeneville 2006	Dryland High N	Irrigation High N	Fertigation High N	Plasticulture High N
Soil Water Tension season avg.	-39 kPa	(-17 kPa)*	-17 kPa	-36 kPa
Yield lb/acre	3094	3151	3174	3248
GRI	58	56	47	57
Nitrosamines p.p.m.	1.35	0.91	1.01	1.29

* Soil water tension was not measured in the irrigation high treatment, but they are assumed to be the same as fertigation high as they followed the same irrigation protocol.

water tension averages through the growing season as they relate to yield and quality at Greeneville 2006.

Seasonal averages show the dryland and plasticulture soil water tension to be similar. TSNA and Grade index were also similar. As the grade index quality of a plant will be more reactive to nitrogen deficiency than yield will be, the data shows that the decreased water tension in the fertigated treatment resulted in lower TSNA, but also in a lower GRI. As the plastic mulch shed precipitation and there were only 3 irrigation events, the soil water tension, as expected, was high in the plasticulture treatment. As the precipitation during the Springfield growing season was not as optimal as Greeneville in 2006, soil water tensions were, on average, highest in the dryland. Irrigation events helped keep the soil water tensions in the plasticulture from becoming too high. This resulted in significant differences in yield between the plasticulture and dryland treatments. Table 25 displays soil water tension as it relates to yield, quality and TSNA at Springfield 2006.

A closer examination of water tensions during the season shows that the watermarks were effective in capturing increased tensions as the plants entered the growth stages of 'rapid growth' and 'flowering'. 'Rapid growth' requires soil moisture to

Table 25. Springfield soil water tensions as they relate to yield, quality and TSNA.

Springfield 2006	**Dryland High N**	**Irrigation High N**	**Fertigation High N**	**Plasticulture High N**
Soil Water Tension season avg.	-66 kPa	(-48 kPa)*	-48 kPa	-50 kPa
Yield lb/acre	1922	1974	2179	2332
GRI	72	73	75	73
Nitrosamines p.p.m.	1.23	0.71	.54	.81

* Soil water tension was not measured in the irrigation high treatment, but they are assumed to be the same as fertigation high as they followed the same irrigation protocol.

contribute towards plant biomass accumulation, where ‘flowering’ physiologically triggers the plant to increase uptake of water and nutrients in the soil to support reproduction.

We can conclude that soil water tension is not only effective in calculating optimal parameters as they relate to yield and GRI, but also effective in estimating the plants ability to utilize petiole nitrates towards growth as opposed to accumulating nitrates contributing to high TSNA levels after curing. A correlation between soil water tension for each treatment at Greeneville, at weeks 4-8 after transplanting (July 12th – August 9th 2005) and the average petiole nitrates measured during this period revealed a 0.92 correlation. Table 26 displays the data used to calculate this correlation.

This compares well as the biomass from these treatments were statistically the same. At Springfield, the correlation was not as favorable, but interestingly, it was replicated well between the burley (0.64) and dark tobacco (0.68). Also it is noted that water tensions were similar under all treatments. The poor correlations could be attributed to the statistical differences in biomass measured in yield. Perhaps the larger plants exerted higher water tension on the soil, but were still able to effectively reduce nitrates towards growth. As these three different cultural practices included three different soil temperatures, and we only have one year of soil water tensions, future studies correlating soil water tension to one cultural practice with similar yields may hold promise for using soil water tension as a predictor for leaf petiole nitrates.

Table 26. Soil water tensions correlated with petiole nitrate concentrations.

Greeneville 7/11/06-8/6/06	Average soil water tension kPa between 8”-20”	Petiole leaf nitrate p.p.m. average among 4 replications
Dryland	49	847
Fertigation	19	425
Plasticulture	42	585
Correlation	**0.92**	

Springfield Burley 7/13/06-8/11/06	Average soil water tension kPa between 8”-20”	Petiole leaf nitrate p.p.m.
Dryland	46	1270
Fertigation	40	783
Plasticulture	44	735
Correlation	**0.64**	

Springfield Burley 7/13/06-8/11/06	Average soil water tension kPa between 8”-20”	Petiole leaf nitrate p.p.m.
Dryland	55	988
Fertigation	46	723
Plasticulture	57	829
Correlation	**0.68**	

Leaf Petiole Nitrates

Leaf petiole nitrate concentration was measured using the Horiba hand held monitor. Sample measurements performed at 4, 6 and 8 weeks after transplanting is intended to capture the growth stages of ‘establishment’ entering into ‘rapid growth’, ‘rapid growth’, and ‘flowering’. Currently, N rate recommendations are based on averages of yield tests that do not allow themselves readily for adjustments due to the variability in soil conditions and precipitation that can affect availability. Noting the difficulty in estimating the amount of N applied to the soil that is going to be available for the plant when growth stages demand, it would seem to reason that it would be more accurate to measure nitrates in leaf. If the Horiba proves accurate, it can be used as a tool to help further define optimal levels and timing of fertilizer N applications and also the ability of the plant to reduce nitrate into forms useable by the plant for growth.

The first samples, which capture the growth stage of ‘establishment’ entering ‘rapid growth’, are all equally high, as expected. During this time of plant development, seedlings take up nitrate at rates that are in equilibrium to the concentration of nitrates in the soil, and also correlate closely to plant growth. Meaning, plant growth may be held back to maintain the equilibrium. During the next two samples, plant physiology changes and uptake rate is more closely correlated to root growth rates. A high accumulation of nitrates in the leaves will slow plant growth and thus prevent further accumulation of nitrates. The ‘rapid growth’ and ‘flowering stage’ petiole nitrate concentration, which have been correlated with high soil water tensions, will thus be more closely linked to the ability of the plant to reduce nitrate into organic forms that can be used to support growth. If the Horiba performs well, nitrate concentration in the leaf can than be used to define optimal growing conditions, so long as nitrogen is not limiting.

The Horiba’s accuracy has been evaluated by its ability to consistently detect cultural practices and rates of applications over different replications, different sites and different years. As expected the first samples taken are all equally high in all four different cultural practices. During the next two samplings, we begin to get separation between treatments and also between rates. These separations are consistent through the four sample/site years. We also find that the petiole leaf nitrates are closely correlated to the soil water tension measurements. The higher tensions measured in the plasticulture treatments are reflected in the higher leaf petiole nitrates measured at Greeneville. The plasticulture treatments petiole nitrates are not as high as the dryland treatments. This can be attributed to two factors. 1) Root temperatures were closer to optimal under the plastic mulch than they were in the dryland treatments. The warmer soils encouraged early root development that allowed the plant to better forage for nutrients and water during summer stress, which is reflected in the earlier ‘spike’ in water demand and increased soil tensions reflecting a better root structure. 2) The plasticulture treatments achieved much of their growth early in the plants life when the nitrate reductace activity was maximized. Delayed growth may achieve similar yields, but it is achieved through inefficient use of nitrogen. The literature suggests that plant must effectively ‘force feed’ its self nitrates to achieve sufficient amounts of organic N when NRA has declined later in the plants life.

Petiole leaf nitrate measurements would be most helpful for producers if this information can be learned early in the plants development. The application of urea to the soil, requires time for the microbial community to convert it into nitrates which can be taken up by the plant. Because of this delay, this data does not give us enough information to effectively change N practices early enough into the growing season. It is hoped that further experimentation, perhaps a refinement of protocol will provide such information. At the least, this information can be used in future growing seasons once a producer can define how much nitrate measured in the leaf is sufficient to maximize yield and quality.

Lab measured TSNA after curing correlates closely to the petiole leaf nitrate samples taken during the ‘flowering’ stage of development. On average, the correlation for all sites is 0.81, with the highest being Springfield in 2005 at 0.91 and the lowest being Springfield in 2006 at 0.73.

Correlation and r square values of petiole nitrates and TSNA for each site and year are displayed. nitrates and TSNA. Table 27 displays the r square values for each site and the slope equation used to find each correlation line.

If all the site years are grouped together as one data set, the correlation drops to 0.56. This is due to the data being clustered around site years. This suggests that growing conditions unique to the site will influence the TSNA and petiole nitrate relationship. The correlations within these site years holds the potential for the predictability of TSNA concentration after harvest by measuring petiole nitrates during the season. This information can be used by growers as they evaluate the effectiveness of their cultural practices. It can also be used by purchasers of leaf that want to evaluate quality of leaf nitrate content without time consuming and expensive lab analysis. This is expected to enhance the communication between producers and purchasers with regards to cultural practices in a contract market structure.

All of the data combined has an r squared of 0.56, a Pearson Correlation of 0.748 and is significant at the 0.01 level of significance for a 2-tailed correlation.

Although there is not enough data to justify a statistical analysis with conclusions, there also appears to be a relationship between TSNA and soil water tension as measured from week four through week 8. Figure 21 displays the correlation between soil water tensions and TSNA.

There is also a relationship between petiole nitrates and soil water tensions measured from week 4 - 8 displayed in figure 22. The r-squared is not strong, but it is important to note that the two data points that fall below the correlation line are the two plasticulture treatments. As could be expected, the nitrate concentration for these two

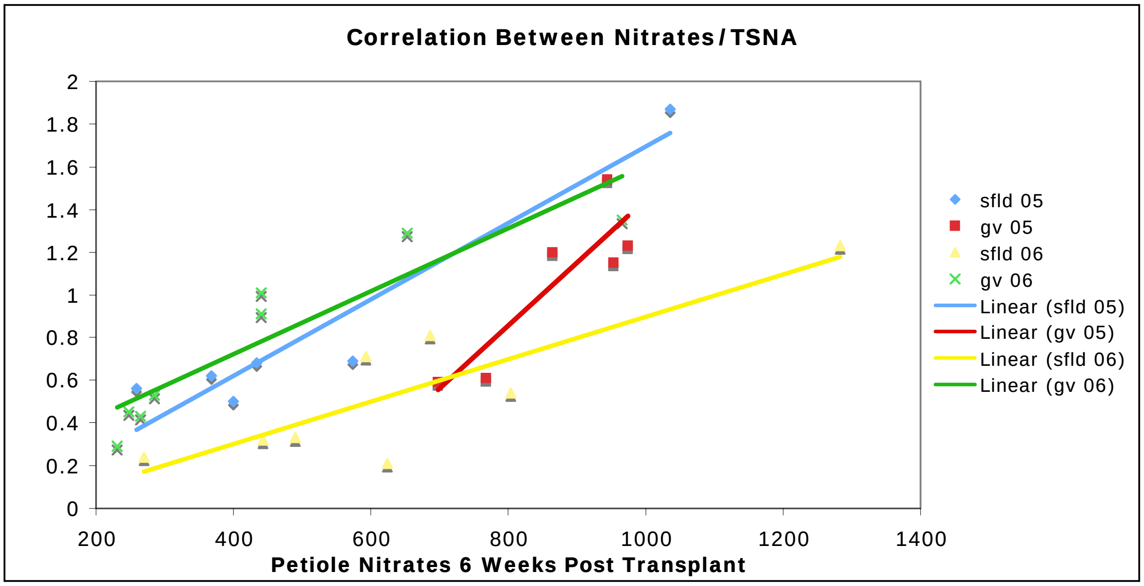


Figure 19. Correlations between petiole nitrates and TSNA at each site and year.

Table 27. R square values and equations of petiole nitrates and TNSA for each site and year.

	R square	Equation
Springfield 2005	0.907	y=0.0018x-0.0971
Greeneville 2005	0.777	y=0.003x-1.5088
Springfield 2006	0.731	y=0.001x-0.0964
Greeneville 2006	0.838	y=0.0015x+0.1319
(average of four sites)	0.813	
all data points together	0.560	y=-0.0011x+0.1028

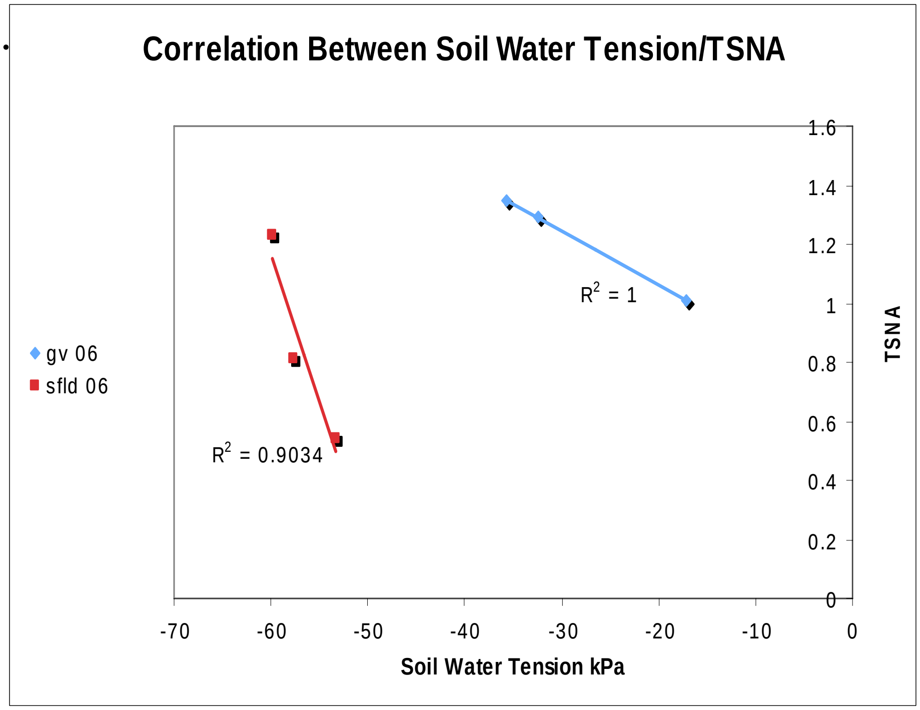


Figure 20. Correlation between soil water tension and TSNA

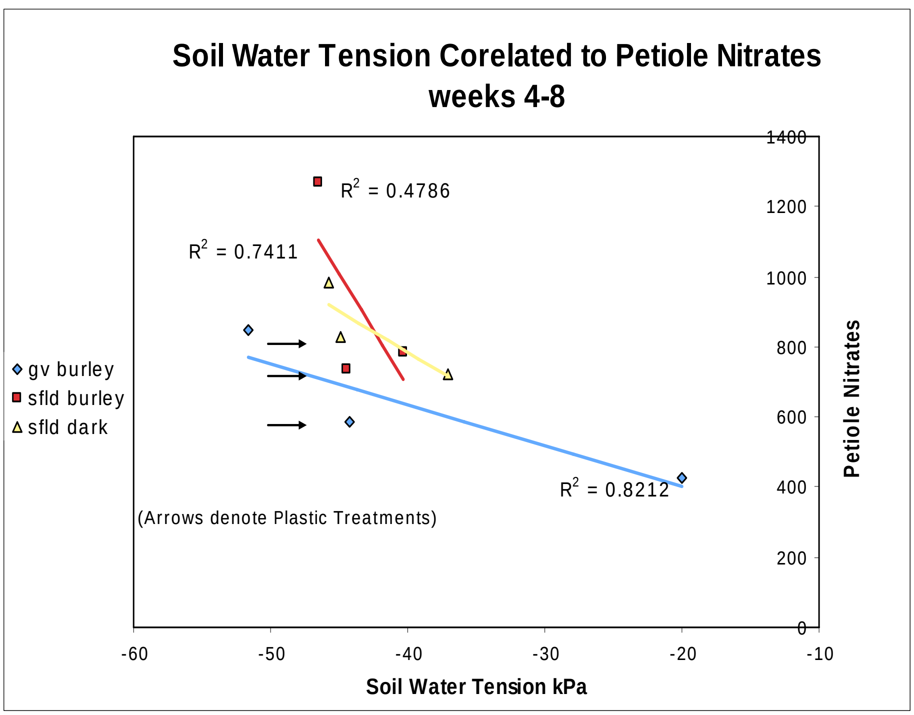


Figure 21. Correlation between soil water tension and petiole nitrates.

treatments are below what the linear model would predict. This could be due to the increased biomass of the plant utilizing more petiole nitrates, as well as increased rooting potential in the plasticulture plots allowing the plant to better forage for soil water and N.

Temperature

As tobacco is a tropical plant, we are interested in measuring the affects of temperature as they relate to yield, GRI and TSNA at harvest. There have been few studies in the field regarding soil temperature, perhaps as it is a variable for which we have little control over. Even if the producer does not attempt to control soil temperature, a basic understanding of it will help to properly identify when the plant is expected to enter into rapid growth and also a rough idea of the rooting potential that the plant has achieved. An understanding of these two factors will allow the producer to more accurately adjust the timing of fertigation and the amount of irrigation to be supplied. For instance, ‘establishment’ in warm soils can be expected to optimize rooting potential allowing the plant to enter ‘rapid growth’ earlier and perhaps be better able to forage for water and nutrients. Whereas the opposite growth characteristics could be expected during ‘establishment’ in colder soil temperatures. This scenario may require a greater attention to irrigation.

Hobo Pendents were used to monitor soil temperature at a depth of 4”. From this data we were able to determine the different treatments affects on temperature, how this relates to yield, quality and TSNA. Wet soils are generally colder soils due to evaporative cooling. In fact, some of the variable results from no-till tobacco have been attributed to cold, wet soils. The use of irrigation is than expected to cool soils, while the use of plastic mulch is expected to raise soil temperatures.

The Hobo Pendents were able to capture this effect as irrigation at Springfield, beginning in week 4 through week 6 lowered soil temperatures by about 3 degrees when compared to the dryland treatments. The plasticulture treatments were about 3 degrees warmer than the dryland and fertigated treatments during ‘establishment’. At Greeneville, where there was more precipitation, the plasticulture treatments, due to their ability to shed rain as well as capture and retain heat, were about 4 F. warmer than the dryland and fertigated treatments. During the 4-6 week period of rapid growth, the increased precipitation made the dryland soil temperature only about 1 F. warmer than the fertigated treatments. Interestingly, the plasticulture treatment was only about 1 F. warmer than the dryland during weeks 4 – 6 after transplanting.

The Hobo Pendents were very accurate when replications were compared within a treatment. The calculated average daily temperature for each replicant in each treatment shows that the standard deviation between replicants within a treatment and averaged them through the growing season. The average standard deviation of replicants within treatments was less than 0.5 degrees F. for the dryland and fertigation. Considering field variability, it could be concluded that the Hobo Pendents proved accurate in measuring soil temperature. The standard deviations were higher for the plasticulture treatments, meaning there was more variability in the mulched plots. Table 28 displays the standard deviation of temperatures within sites and treatments for the Horriba Pendents.

Table 28. Standard deviation of Horriba measured temperatures within sites and treatments.

Greeneville	Dryland	Fertigation	Plasticulture
Average stdev. Within treatments	0.48 F.	0.50 F.	0.69 F.
Springfield	**Dryland**	**Fertigation**	**Plasticulture**
Average stdev. Within treatments	0.48 F.	0.41 F.	1.26 F.

Temperatures during the first four weeks, representing establishment, were about 4 F. higher in the plasticulture than in the dryland or fertigated treatments. The dryland and fertigated treatments were essentially the same as there was no irrigation provided during this period making management protocols the same.

The data from the Hobo Pendents accurately characterized the expected soil temperature conditions. Even if neither plastic mulch nor irrigation is used as a cultural practice, this information can be of use in allowing greater predictability within the growing environment.

Using the growing season monitoring, we are able to integrate this information to help characterize the effects on plant growth and development.

During the period of establishment, transplants will be taking up nitrate in equilibrium to the soil nitrate concentration. As Springfield soils had lower soil tensions during ‘establishment’, it could be deduced that the higher soil moisture made more nitrate available. At Springfield, there was 3.05 inches of precipitation occurring during the 7/10/06 – 7/17/06 period which met the plants water demand as it entered ‘rapid growth’. This is represented in petiole leaf nitrate measurements being about 15% higher at Springfield than they are at Greeneville during this period. As Greeneville precipitation was deemed sufficient by the M.O.I.S.T. program, and due to the fact that large preplants of N would not make N limiting, perhaps this data could be used to further classify what is optimal.

The second petiole nitrate sampling was expected to capture the plants during the ‘rapid stage’ growth. During this time, there was about 2.7 inches of rain at Greeneville, as opposed to only about 1.1 inches at Springfield. After ‘establishment’ it is expected that nitrate concentration in the leaf will switch from luxury consumption to being reflective of the plants ability to reduce nitrate into organic forms that can be utilized for plant growth. Considering the precipitation, we should expect a greater decline in the leaf nitrates at Greeneville than at Springfield. We do note a more pronounced decrease in leaf nitrates at Greeneville for the dryland Treatments. Leaf nitrates p.p.m. in the dryland are about 700 at Greeneville, as compared to about 1200, which is actually an increase in leaf nitrates, at Springfield. If soil moisture is important in nitrate reductace, we should not see as pronounced a difference between Greeneville and Springfield in treatments that include irrigation. We note a difference of 600 p.p.m. at Greeneville and 900 p.p.m. at Springfield. We could deduce that irrigation kept the differences from being as pronounced as the dryland treatments, and also, the differences in precipitation created more optimal conditions for nitrate reductace at Greeneville. It is difficult to correlate soil water tensions to leaf nitrate concentration during this 4-6 week after transplant sampling, as the plant is undergoing physiological changes at different times based upon when they exit ‘establishment’ and enter ‘rapid growth’. This will affect the rate of nitrate uptake. The more rapidly the plant becomes established and ceases to uptake nitrate in relation to the soil nitrate concentration, the more rapidly the plant will begin to see a decrease in nitrate leaf accumulation as plants entering ‘rapid growth’ early will be using nitrate to support growth. The general trend during this period is water tensions averaging about -10 centibars higher in dryland soils, with fertigation and plasticulture treatment fairly equal at both sites.

As we progress into the 6-8 weeks after transplanting, we can now assume that plants in each treatment have attained the new nitrate equilibrium uptake rate. The N uptake rate during this period is more closely correlated to root growth than it is to plant growth or soil nitrate concentration. As such, we can expect to be able to draw correlations between leaf nitrate concentration and soil water tension as it relates to the plants ability to reduce nitrate. At Greeneville, during 2006, the sample was taken after topping causing a sudden spike in nitrate accumulation in the plant. Because of this, we could not use the data to draw a correlation between soil water tensions and nitrate accumulation.

Cultural Practices

The objective of this research was to use cultural practices that would allow themselves for adjustment within the growing season to best achieve optimal growing conditions. With effective growing season monitoring, nitrogen fertilization rates and timing can be better adjusted to match the plants ability to uptake and utilize nitrates. This research used the methods of a comparison study to isolate the importance of growing condition variables with respect to nitrogen efficiency. In order to best isolate the variables of soil water tension, soil temperature and nitrogen fertilization rate and timing, we needed to keep all cultural practices the same, except for a single variable of interest. In some respects, this “crippled” the true potential of these cultural practices.

For instance, one of the most desirable attributes of using fertigation is its ability to allow for adjustment of nitrogen applied during the season. During a season of high precipitation, and large biomass as witnessed at Greeneville during the 2006 season, we could anticipate leaching of nitrogen, and loss of soil nitrate concentration. Leaf nitrate monitoring confirmed as much. But, in order to keep the comparisons in tact, we did not adjust the amount of nitrogen applied. To do so would confound the affects of split application timing by making it, in part, a nitrogen rate study. Also, at Greeneville during the 2006 season, we were able to measure very high soil water tensions with watermark sensors under the plastic mulch as it shed precipitation. It is likely that additional irrigation could have produced more favorable yields and qualities for plasticulture treatments, but we would confound the isolated affects of soil temperature with variable irrigation rates. In general, each cultural practice tested holds the potential for better results when used in conjunction with growing conditions monitoring to help keep tobacco plants in optimal growing conditions longer. But, we decided that it was important to keep comparisons intact so as best to isolate growing condition variables for use in further delineation of optimal conditions. If positive results could be achieved under such strict controls, it is hoped that future research can use the parameters defined in this study for further refinement.

This study was designed to introduce an isolated variable for comparisons. For instance, the irrigation treatments followed the same protocol as the dryland treatments, except for the use of irrigation when precipitation did not provide 1” of rain per week. This allowed us to make comparisons to isolate the effectiveness of irrigation on nitrogen efficiency. Likewise, the fertigation treatment included the same protocol as Irrigation treatments but applied nitrogen at split application rates. This comparison allowed for determination of the importance of “spoon feeding” nitrogen. The plasticulture treatment used the same protocol as the fertigation treatment, but included the use of a plastic mulch covering the plant beds. The expected warmer soils associated with the mulch use allowed for the isolation of the importance of soil temperature on nitrogen efficiency.

Dryland v. Irrigation

As this experiment was designed for step by step comparisons, conclusions can best be drawn from these comparisons. Table 29 displays the yield, GRI and TSNA values of dryland and irrigation for comparisons to be made between all sites and years.

The use of irrigation will not provide substantial increases in yield or GRI during periods of normal to good precipitation. If a producer can develop an irrigation system, it should be thought of as insurance against drier seasons. This data could also aid in timing of irrigation events. As the plant enters the growth stages of ‘rapid growth’ and ‘flowering’ there is an evident spike in water demand.

What is important to note is the dramatic differences in TSNA after harvest. If purchasers are willing to pay a premium for low TSNA, than these results could be read to show that irrigation was able to achieve similar yields and GRI while attaining low TSNA. irrigation was a component of each new cultural practice. Even during a season characterized by precipitation being sufficient in volume and timing to meet plant water demands, irrigation treatments were successfully able to decrease TSNA concentration by about 30%. During drier growing seasons, TSNA was reduced by 50% or more. As the

Table 29. Yield, GRI and TSNA for dryland and irrigation at all sites and years.

Greeneville 2005	Dryland 200 lbs preplant	Irrigation 200 lbs preplant	% change
Yield lb/acre	2523	2678	6%
GRI	59	62	5%
TSNA	1.54	1.23	-20%

Springfield 2005	Dryland 200 lbs preplant	Irrigation 200 lbs preplant	% change
Yield lb/acre	(no data)	(no data)	
GRI	(no data)	(no data)	
TSNA	1.87	0.69	- 73%

Greeneville 2006	Dryland 200 lbs preplant	Irrigation 200 lbs preplant	% change with Irrigation
Yield lb/acre	3094	3152	2%
GRI	58.2	55.8	- 4%
TSNA	1.35	0.91	- 33%

Springfield Burley 2006	Dryland 200 lbs preplant	Irrigation 200 lbs preplant	% change
Yield lb/acre	1922	1974	3%
GRI	72	73.3	2%
TSNA	1.23	0.71	- 42%

Springfield Dark 2006	Dryland 200 lbs preplant	Irrigation 200 lbs preplant	% change with Irrigation
Yield lb/acre	3036	3385	10%
GRI	59.8	71.1	16%
TSNA	1.35	0.91	- 33%

TSNA measurements showed only limited reaction to either treatment effect of N rate within practices utilizing irrigation, it can be concluded that irrigation is the most important component in attaining high yielding, high GRI quality and low TSNA tobacco leaf.

Irrigation v. Fertigation

If the irrigation system and drip tape are in place, the producer has the option of using fertigation to apply N. This comparison isolates the affects of fertilizer timing, determining if ‘spoon feeding’ creates an efficiency of nitrogen use.

Fertigation showed little improvement over irrigation. Table 30 displays the yield, GRI and TSNA values of irrigation and fertigation for comparisons to be made between all sites and years. One site showed decreased TSNA content of 24%, but this result was not consistent. It could not be concluded that fertigation failed at this point as it was able to attain similar results as irrigation using preplant without being used to its full potential. The main benefit of fertigation is the ability it provides the grower to adapt to conditions. By choosing to keep comparisons intact, we did not adjust fertigation timing or rates to conditions. It is also possible that experimentation into the N fertilizer chosen, and the timing in which it is applied could enhance the benefits of fertigation. Calcium nitrate may be a better choice of N as it is more readily available to the plant, whereas Urea involves a lag period during which soil microbes transform Urea into plant available nitrate. In hind sight, as we examine spikes in water tension denoting a change in growth stage, our applications seemed to be a little late.

Table 30.Yield, GRI and TSNA for irrigation and fertigation at all sites and years.

Greeneville 2005	Irrigation 200 lbs preplant	Fertigation 100 lbs preplant 100 lbs over 3 split applications	% change with Fertigation
Yield lb/acre	2678	2633	- 2%
GRI	62	58	- 4%
TSNA	1.23	1.20	- 2%
Springfield 2005	**Irrigation 200 lbs preplant**	**Fertigation 100 lbs preplant 100 lbs over 3 split applications**	**% change with Fertigation**
Yield lb/acre	(no data)	(no data)	
GRI	(no data)	(no data)	
TSNA	0.69	0.68	1 %
Greeneville 2006	**Irrigation 200 lbs preplant**	**Fertigation 100 lbs preplant 100 lbs over 3 split applications**	**% change with Fertigation**
Yield lb/acre	3152	3174	1%
GRI	55.8	47	- 16%
TSNA	0.91	1.01	10%
Springfield Burley 2006	**Irrigation 200 lbs preplant**	**Fertigation 100 lbs preplant 100 lbs over 3 split applications**	**% change with Fertigation**
Yield lb/acre	1974	2179	9%
GRI	73.3	75	2%
TSNA	0.71	0.54	- 24%
Springfield Dark 2006	**Irrigation 200 lbs preplant**	**Fertigation 100 lbs preplant 100 lbs over 3 split applications**	**% change with Fertigation**
Yield lb/acre	3385	3318	- 2%
GRI	71.1	68.5	- 4%
TSNA	na	na	Na

Fertigation v. Plasticulture

As a cultural practice, there are many benefits that plasticulture provides that are not measured in this study. Primarily, the plastic mulch provides a photosynthetic shield preventing weed germination. Weeds are a particular problem for tobacco as the tobacco plant is susceptible to damage from many popular herbicides. Herbicides that can be used with tobacco provide no control for common weeds such as groundcheery, jimsonweed, horsenettle, cocklebur, bermudagrass and rhizome johnsongrass. When rotating crops in avoidance of these weeds, tobacco is very sensitive to persistent herbicides such as atrazine, princep and some soybean herbicides. Dry weather, lack of Traditional practices call for a combination of soil applied herbicides and timely, shallow cultivations (Denton, 2006).post season tilling and high herbicide rates will contribute to the risk of carryover.

Cultivations pose further risks to both the tobacco plant and to the field it's grown in. Cultivations can potentially damage tobacco leaves and roots. Soil compaction that results from tractor passes has been shown to greatly diminish macropores and irreparably deform soil structure. Diminishing field disturbance can help reduce soil compaction, enhance soil microbe activity, decrease soil crusting and increase infiltration rates and soil capillary activity. The ability to avoid weeds is a solution to a big problem in tobacco farming. Where there is no crop residue or ground cover, cultivations exacerbate soil erosion problems, but without cultivation weeds easily encroach and compete for nutrients and water. The ability to avoid weeds provides the grower with more options in field selection as rotation of crop need not rely as heavily upon particular weed exposure, and provides long term soil stability and protection. Plasticulture promises many potential improvements in resource conservation, environmental protection and long term soil structure stability that come from limiting cultivation.

Avoiding the necessity of accessing rows for cultivations and for fertilization can potentially have an impact upon plant spacing. The traditional row size and scale has been determined by the necessity of being able to drive a tractor down the row aisles. If you no longer require tractor determined spacing, rows can be spaced with intentions of avoiding some diseases such as blue mold. Traditionally, tobacco is thought to grow best, ‘shoulder to shoulder’, as these confines allow them to support each other and avoid dislodging during winds. As there are few examples of alternative spacing, this practice has not been tested. It is possible though, that if plasticulture is successful, that row spacing could be reconsidered allowing each plant to photosynthesis better and help limit the passing of airborne pathogens and insects.

There is also the potential for early planting that can allow for better use of barn space for curing by staggering harvest periods within a field. There is also the potential of even double cropping with another crop that can make use of the plastic mulch.

It is difficult to isolate the effect of soil temperature on yield, GRI quality and TSNA as soil tensions were often high during important growth stage timings of ‘rapid growth’ and ‘flowering’.

Plasticulture was introduced as a cultural practice in this study in the 2006 growing season. Therefore, we have no data from 2005. Table 31 displays the yield, GRI and TSNA values of irrigation and fertigation for comparisons to be made at all sites and years.

Table 31. Yield, GRI and TSNA for fertigation and irrigation at all sites and years.

Greeneville 2006	Fertigation 100 lbs preplant 100 lbs over 3 split applications	Plasticulture 100 + 100lbs	% change with Plasticulture
Yield lb/acre	3174	3248	2%
GRI	47	56.7	17%
TSNA	1.01	1.29	12%
Springfield Burley 2006	**Fertigation 100 lbs preplant 100 lbs over 3 split applications**	**Plasticulture 100 + 100 lbs**	**% change with Plasticulture**
Yield lb/acre	2179	2332	7%
GRI	75	72.5	- 3%
TSNA	0.54	0.81	33%
Springfield Dark 2006	**Fertigation 100 lbs preplant 100 lbs over 3 split applications**	**Fertigation 100 + 100lbs**	**% change with Fertigation**
Yield lb/acre	3318	3257	- 2%
GRI	68.5%	68.9%	1%
TSNA	na	na	na

Plasticulture gave slightly increased yields, but the high TSNA content is indicative of the high soil water tension under the plastic mulch. The fact that similar yields were attained despite the disparity in tensions could be a measure of the ability of the plastic mulch to enhance rooting potential. We would have to measure the turgor pressure of the plants to determine this effect though. As yields were similar between the two treatments, we could conclude that the cooler soil temperatures brought on by irrigation starting at week four after transplanting, did not have an adverse effect on final yield, or GRI quality.

If plasticulture is to be considered as a cultural practice, there are some concerns that need to be addressed. When transplants are first put into the field, there is an adjustment period before the plant can be considered ‘established’. During the time, the plant must adjust to temperature and light differences as well as establish roots. Transplants will often suffer what looks to be drought stress. The resulting drooping can be particularly harsh on plastic mulch which is often much warmer than bare soil. In both seasons, particularly in the very dry Spring of 2007, we lost more transplants using plastic mulch than other treatments. To avoid these losses, transplants should be planted into moist soil, and the recommendation of 0.5" of rain/irrigation following transplanting should be adhered to if transplant losses are to be minimized.

Reduced N Rate Treatments

From these results, it would seem that each cultural practice has promise in increasing N efficiency when compared to the dryland treatments. When used in conjunction with season monitoring, these cultural practices offer the producer greater control over the growing environment. With this control, the producer need not apply excess nitrogen as insurance against losses. Monitoring will help provide information on the plants ability to both uptake and utilize N. It is hoped that eventually, this precision will allow producer to attain high yielding, high quality, low TSNA tobacco while applying less N. This study included reduced rate N application in each new cultural practice to see if the cultural practice in and of itself was able to achieve an N efficiency. Again, the practices were somewhat handicapped as they were not used to their full potential, but it was more important to keep the comparisons intact. Also, if positive results could be achieved under this strict protocol, further research and refinement could than we warranted.

The data shows that the dryland only achieved statistically higher yields and graded index quality when compared to low N treatments in the irrigation and fertigation at Greeneville in 2006. Here, high precipitation is expected to have leached nitrate from the soil and also, increased plant biomass contributed to making N limiting in the low N treatments. These results suggest that N recommended rates are near the minimum when plant growing seasons are optimized and high yields are to be expected.

At Greeneville in 2005, where yields are on average with expected yields over the past 10 years for the region, low N fertigation and medium N irrigation showed a trend of attaining the highest yields and quality for all treatments, including high N treatments within similar cultural practices. There was no benefit to applying additional N, and the use of irrigation and fertility timing through fertigation enhanced N efficiency when compared to the dryland high treatment.

At Springfield in 2006, the irrigation low and fertigation low had 14% and 10% lower yields respectively than the irrigation high and fertigation high treatments. Roughly speaking, the addition of 100 lbs of N per acre resulted in about 60 lbs per acre more yield. If you were to estimate price per pound to be about $1.60, this would account for about 100 dollars, which would not seem profitable. For the plasticulture treatment, the results were much more drastic. The low N treatment results in a yield decrease of about 22%. This is due partly to the plasticulture high consistently having the highest yields. The difference here was significant and accounts for about 500 lb/acre yield. Soil water tension at the 20” depth was consistently -20 kPa higher than the fertigated treatments which may also account for some of the differences.

At Greeneville in 2006, the differences were similarly 14% lower for both irrigation low and fertigation low treatments. As yields were generally much higher at Greeneville, these percent differences account for about a 450 lb/acre difference making them both significantly different. There were also significant difference in GRI for irrigation, but not fertigation. Perhaps the fertigation application was effective in preventing some of the leaching that adversely affected GRI by limiting the residency time of soil N. In this instance, revenue is more difficult to average as the GRI affects price, but keeping with the $1.60 a pound, total revenue would suffer by over $700. In this instance, the additional 100 lb/acre N that was applied was very profitable.

At Greeneville, the plasticulture treatments did not perform as poorly in the low N treatments as they did at Springfield. Here, yields suffered only about 12% when using low N. The GRI was statistically the same, perhaps due to the ability to avoid leaching of N which proved limiting under the low N treatment. Again, because yields were high, this would still account for about 375 lb/acre yield difference. The additional 100 lb/acre of N would than still be profitable. Aside from the 'spikes' in soil water tension that occurred as the plant entered 'rapid growth' and 'flowering', tensions were similar under plasticulture and fertigation regimes with only about a -10 kPa difference. This may account for the plasticulture yield loss in the low N treatments not being as dramatic as they were at Springfield.

The use of low N management practices showed mixed results which seemed to reflect the growing season more than the cultural practice. Table 32 displays the differences in yield that came from using reduced N rates within each treatment. Based upon yield and the graded index, the use of high N during a season of very good growing conditions, such as Greeneville 2006, outweighs the risk of applying too much N during an average growing season, such as Greeneville 2005.

It is also important to note that the TSNA concentration in each low N treatment was considerably lower than the corresponding high N treatment within the same cultural practices. A very rough calculation of the highly variable values would estimate that TSNA could be lower by at least half when using low N rates. This could become very important if a purchasers contracts will pay a premium for low TSNA leaf. The losses in yield could be offset by the expected decreases in TSNA. Table 33 displays the differences in TSNA that came with reduced N rate practices.

What can be concluded from the variable results attained in the low N analysis is that the ability of the producer to adapt to growing conditions during the season can increase N efficiency and profitability. During years of high biomass and high precipitation, additional N applications by fertigation can be profitable. At Springfield in both 2005 and 2006, it could be said that the additional 100 lbs/acre of N was costly and wasteful.

Table 32. Yield differences that came with reduced N rate practices.

Yield (lb/acre)	Irr. High	Irr. Low	%	Fert. High	Fert. Low	%	Plastic High	Plastic Low	%
Greeneville 2005	2677	2786 (med)	- 4%	2632	2684	- 2%	Not used	Not used	
Greeneville 2006	3152	2721	14%	3174	2713	14%	3248	2869	12%
Springfield 2006	1974	1693	14%	2179	1957	10%	2332	1812	22%

Table 33. TSNA differences that came with using reduced N rates.

TSNA (p.p.m)	Irr. High	Irr. Low	% change	Fert. High	Fert. Low	% change	Plastic High	Plastic Low	% change
Greeneville 2005	1.23	1.15 (med)	7%	1.20	0.59	51%	Not used	Not used	
Springfield 2005	.69	.50	27%	0.68	0.56	18%	Not used	Not used	
Greeneville 2006	0.91	0.45	51%	1.01	0.29	71%	1.24	0.43	65%
Springfield 2006	0.71	0.21	70%	0.54	0.24	55%	0.4	0.15	72%

CHAPTER VI

CONCLUSION

This research compared the effects of cultural and management practices on yield, GRI quality and TSNA concentration in burley tobacco production. We also included a Dark tobacco treatment at Springfield, but we only had yield and GRI results from 2006 due to high winds dislodging too many plants in 2005. While nitrogen is necessary to attain high yielding, high quality tobacco, nitrates that accumulate in the leaf at harvest are strongly correlated with high TSNA concentration. The hypothesis of this study is that optimization of growing conditions, through the use of growing practices would enhance the ability of the plant to uptake and utilize soil nitrogen towards growth, while subsequently reducing nitrate accumulation in the leaf thus lowering TSNA. The results of this study are summarized in the form of recommendations for growers considering the benefits of each cultural and N management practice.

Dryland

Yield is highly dependent upon environmental conditions, such as soil, light intensity, precipitation and temperature. Dryland burley grown in Greeneville in 2006 yielded on average over 500 lbs/acre more than burley grown in 2005 in another plot at the same experimental station. None of the other cultural practices in Greeneville 2005, including irrigation came close to attaining these yields of dryland 2006. The yields in Springfield were even lower at over a 1,000 lbs./acre less than Greeneville 2006. In optimal growing conditions (most easily recognized from monitoring as precipitation and soil water tension), such as Greeneville 2006, dryland is proven to be a reasonable growing practice. But, even in this year, there is a trend showing dryland to be the lowest yielding of the four cultural practices that include irrigation, fertigation and plasticulture. As growing conditions become less than ideal, the advantages of irrigation, fertigation and plasticulture using the same amount of N increase in importance for yield and can become significant.

GRI is closely related to plant biomass as measured by yield. The more nitrogen that is utilized towards attaining biomass, the lower the GRI will be. This study shows that recommended rates are near the minimum in attaining high GRI quality leaf. In Greeneville 2006, where the biomass was the highest, GRI for dryland was the lowest at 58. In 2005, GRI was similarly low at 59. As biomass dropped at Springfield, GRI in the Dryland rose dramatically to 72. In this study, a high GRI reflects nitrogen not utilized towards growth. GRI is no longer used to determine price per pound, but even when GRI was used, it would not dramatically affect revenue when calculated with yield. In the instance of Springfield 2006, a high GRI would be indicative of N applications that were too high.

TSNA was consistently the highest in the dryland for all site/years, and was shown to be the least reactive to the same uncontrollable environmental conditions that had impacted yield. Even when yields (Greeneville 2006) or GRI (Springfield 2005) were very high, TSNA concentration was consistently and significantly much higher in the dryland when compared to all other treatments. TSNA is very reactive to cultural and management practices. In 2005, when cured leaves were measured for nitrate concentration, the p.p.m. in the dryland were generally 5 to 6 times higher than all the other treatments which were equally low.

Irrigation

A grower considering using irrigation at the same 200lb/acre N preplant can expect yields that show trends of being higher than dryland. These trends are not significant using the 0.05 level of significance, but as they are consistent results, this practice could still prove profitable. During a season with ‘good’ to ‘optimal’ precipitation at seen at both sites in 2006, irrigation improved yields by only about 60 lbs/acre. As precipitation became more sporadic, such as 2005, irrigation improved yields in the burley by about 150 lbs/acre. The use of irrigation may not always prove profitable in a year, but should give more consistent yields through the years. It is also worth noting that irrigation improved dark tobacco yields by 350 lbs/acre.

There was little benefit in GRI when using irrigation. In the one site year of dark tobacco, GRI improved from 60 to 71 through the use of irrigation, but all the burley site/years were equal, with only a slight but consistent trend of improvement over Dryland GRI.

The most dramatic effects were found in TSNA with the use of irrigation. Even during a season of optimal precipitation, such as Greeneville 2006, irrigation of only three events reduced TSNA by about 30%. As shown in soil water tension measurements, the irrigation treatments had more consistently lower tensions than the dryland treatments which showed tensions building through the profile during the season. Consistently lower soil water tension has proven to be important in reducing TSNA.

During a season of ‘good’ precipitation, such as Springfield 2006, irrigation of 5 events reduced TSNA by 50%. In 2005, where we did not monitor soil water tension, irrigation reduced TSNA by 20% at Greeneville and 65% at Springfield.

Fertigation

If a grower has invested in drip-tape irrigation, they have the system in place to make split applications of N. While using the same high N season totals of 200 lbs/acre does not yield a significant nor consistent increase in yield over the use irrigation, the increases over the three site years average to be about 170 lbs/acre when using fertigation. This is due primarily to the good yielding site/year of fertigation at Springfield in 2006.

The GRI for irrigated and fertigated treatments was similar in 3 out of 4 site/years. At Greeneville in 2006, the GRI difference was not significant, but had dropped from 56 in the Irrigated treatments to 47 in the fertigated treatments. It could be concluded that liquid urea is more susceptible to leaching during a season of high precipitation.

There is no consistent benefit in TSNA concentration in using fertigation over irrigation as they were very similar.

While there generally seems to be no benefit to making split applications of N in 200 lb/acre practices, there still could be potential in the use of fertigation. This cultural practice is worth consideration as what fertigation does offer in increased control for the grower over soil N concentration. Growers apply large amounts of N preplant as this N is necessary during good growing years to optimize yield and GRI quality. The reward of a good growing year outweighs the risk of the cost of N fertilizer which may not be needed during less than optimal growing years. The use of fertigation allows the grower to adjust N management during the growing season thus reducing uncertainty and therefore reducing costs. It is possible that future fertigation studies can refine this practice to make it more efficient. For instance, petiole analysis shows petiole N in fertigated treatments to be higher towards the end of the season than Irrigated treatments. Perhaps N could be applied either earlier or in tapering amounts. Also for consideration is the source of N. Perhaps a more readily available source of N, such as calcium nitrate would be more effective in allowing N uptake to match growth stages and thus reduce the amount of time that applied N is susceptible to leaching.

Plasticulture

With a drip-tape system in place, a grower may want to consider the benefits of plasticulture. Yields within this practice, using 200 lb/acre N were consistently and once out of the two times used, was significantly the highest. The most notable difference between fertigation and plasticulture practices is soil temperature. During the first four weeks of establishment, the plastic mulch was able to keep soil temperatures in optimal ranges of 73-95 degrees F. about 33% longer than dryland and fertigated treatments. Plasticulture, yields were higher than all other treatments averaging about 200 lbs/acre more than irrigation and fertigation treatments.

GRI quality for plasticulture was similar to other 200 lb/acre N treatments. The one exception would be Greeneville in 2006. Here, the GRI in fertigated treatments suffered. Even though plasticulture used fertigation methods, the plastic mulch helped to protect soil N from leaching due to high precipitation keeping GRI comparable to dryland.

TSNA concentration in plasticulture had mixed results. Although TSNA was generally lower than dryland treatments, the plasticulture generally had higher TSNA than irrigation and fertigation using the same high 200 lb/acre N. Most noticeable is the high TSNA in the plasticulture at Greeneville in 2006 where it is only slightly lower (5%) than the dryland TSNA. This is likely due to the correlation between soil water tension and TSNA as established in all treatments using irrigation. Because precipitation was sufficient in timing and volume to allow growers to skip most irrigation events based upon the 1” rain/Irrigation rule, there were only three irrigation events. The plastic mulch prevented the plasticulture treatments from fully benefiting from precipitation causing soil water tensions to rise. It is possible that better TSNA results could be attained from this treatment if it were irrigation were scheduled upon soil water tensions instead of rain. It is also possible that such management practices could benefit yield.

Reduced N Rates

Reducing N in conjunction with cultural practices was successful in attaining similar or higher yields than the dryland high N treatments in 3 out of 4 site years. At Greeneville 2006 and the burley plots at Springfield in 2006, yields had declined with reduced N rates. At Greeneville, where high N rates were needed to attain the plants full biomass potential in a very good growing environment, the differences were statistical. The differences were not great enough at Springfield to be statistical. Because it was not as optimal growing environment in Springfield 2006 for dryland treatments, the low N treatments in each cultural practice were still able to achieve statistically similar yields as the high N dryland treatment. As one of the highest yielding plots in Greeneville 2006 was fertigation high, fertigation, used to it's full potential would allow a grower to adapt to these optimal conditions during the growing season by applying more N, while also being able to back off of total N applied during less than optimal growing seasons.

The differences in N rates as they relate to GRI was only noticeable in Greeneville 2006. Here, low N treatments had statistically lower GRI than high N treatments within the same cultural practice and were also significantly lower when compared to dryland practices. The exception was plasticulture low, which was able to attain significantly similar GRI as the dryland. This could be due to the plastic mulch protecting soil N from the effects of leaching.

The petiole nitrate analysis showed the low N treatments in all cultural practices dropping more rapidly through the growing season than in the high N treatments. This is reflected in the TSNA analysis that shows reducing N rates had successfully reduced TSNA. In Springfield 2006 and Greeneville 2005 and 2006, the use of low N management practices successfully lowered TSNA by at least an additional 50% within the same cultural practices. These gains are in addition to the dramatic reduction in TSNA resulting from the use of irrigation in these practices when compared to dryland. The results were not as dramatic in Springfield 2005, but showed a similar trend. This trend was also evident in all medium N treatments.

Summary

New contract markets allow purchasers of leaf to have input over the cultural and management practices used to attain leaf of their desired quality characteristics such as reduced TSNA. While the use of irrigation may not show dramatic increases in yields during average growing seasons, that benefits in consistently and dramatically reducing TSNA are evident in this study. Furthermore, reduction in N rates may reduce yields and GRI quality in good growing seasons, but the use of fertigation has promise in allowing growers to adapt N applications to plant demands during the growing season thus allowing yields to be maximized and TSNA concentration minimized. The Horiba hand held monitor has the potential through further testing to help define what optimal N petiole leaf concentrations should be during different growth stages enhancing the effectiveness of fertigation. Plasticulture experimentation has supported the importance of soil temperature in plant establishment. These results can useful in consideration of transplant timing. Although, one year's results cannot determine the effectiveness of plasticulture to consistently achieve high yields, there are many benefits that this practice does offer that could offset help to further offset its costs. Primarily, it gives the grower more control over the growing environment allowing for more consistent results.

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