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dissertation entitled

Effects of Nitrogen Application Practices on Tart Cherry Tree Response and Nitrate Movement Under Trickle Irrigation

presented by

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has been accepted towards fulfillment of the requirements for

MS degree in AET

Major professor

Date 3/14/86

EFFECTS OF NITROGEN APPLICATION PRACTICES ON TART CHERRY TREE RESPONSE AND NITRATE MOVEMENT UNDER TRICKLE IRRIGATION

By

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A THESIS

Submitted to
MICHIGAN STATE UNIVERSITY
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

1986

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ABSTRACT

EFFECTS OF NITROGEN APPLICATION PRACTICES ON TART CHERRY TREE RESPONSE AND NITRATE MOVEMENT UNDER TRICKLE IRRIGATION

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The primary goal of this research was to promote optimal growth and vigor of tart cherry trees while minimizing potential nitrate contamination of groundwater in fruit growing areas of Northwest Michigan. Pertinent literature on cherry fertilization practices and nitrate movement was reviewed. The research focused upon both tree response and nitrate movement.

Specific objectives of this research were to determine the effects of nitrogen application method, timing, and amount, upon the response of young tart cherry trees, and upon the nitrate content of soil water below the tree rooting depth over time. Surface applications of pelletized nitrogen fertilizer, and application through fertilizer injection in a trickle irrigation system were studied under field conditions.

High leaf nitrogen levels indicated the presence of residual nitrogen in the soil and in the trees. This led to the suppresion of some growth differences. Reducing the nitrogen application rate did not inhibit growth response regardless of method of application. Trees under trickle application had the highest leaf nitrogen. Nitrogen

application by injection through the trickle system proved to be a viable alternative to surface application.

Nitrate movement from the root zone varied with time and method of application. More movement occurred under fertilizer treatments than under the control. Nitrate concentration at a depth of 1.8 m (6 ft) remained low throughout the summer as relatively little water moved beyond the root zone. Fall surface applications were the least efficient due to nitrate movement past the root zone during the winter when root activity was minimal. Trickle and spring split surface applications provided nitrogen to the roots when root activity was high.

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ACKNOWLEDGEMENTS

First and foremost, the author would like to thank Dr. Vince Bralts for his guidance, encouragement, and especially his friendship. His contagious enthusiasm, his willingness to learn and let learn, and his generous support have been tremendous during this period of learning and maturing.

A very, very special thanks must go to Dr. Chuck Kesner, with whom it has been an honor and a pleasure to work. Likewise, to Dr. Boyd Ellis, whose high quality teaching and guidance were always readily given, a very special thank you.

To Dr. Donald Edwards and to Dr. Ted Loudon, many thanks for your support, guidance and teaching.

I must also extend my sincerest thanks to Bill Klein and Jackie Baase at the Northwest Michigan Horticultural Research Station. To everyone else in the Department of Agricultural Engineering and elsewhere who assisted me along the way, thank you.

Finally, to my family a very special thanks for your endless support. Also, to my above average dog and constant companion, Pupper, who kept me company during those lonely work nights. And most of all to my exceptionally patient and loving wife Catherine, for everything. We did it.

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I. INTRODUCTION

Environmental quality and industrial productivity are worthy concerns. Often the two oppose one another. Negative effects of man's industry on the natural environment are seen in the air, water and soil around us. Furthermore, the term "healthy environment" if carried to its fullest definition, will encompass economic opportunity, productivity, and growth. Fortunately, new technology occasionally affords us an opportunity to maintain or increase productivity, while reducing the negative impacts of our industry on the natural environment.

Groundwater is a natural resource which has received a great deal of attention in recent years, largely due to severe contamination of many aquifers. Groundwater contaminants include hydrocarbons, heavy metals, and other inorganic and organic toxins. One important groundwater contaminant, and the one with which this research is concerned, is nitrate nitrogen.

Nitrate nitrogen in groundwater may arise from natural geologic sources, or its presence may stem from man-made alterations to the environment. These man made sources include 1) septic system operation and waste disposal 2) land reshaping, and 3) industrial sources, including the

application of nitrogen fertilizers to agricultural land. This research concerns the agricultural contribution to groundwater nitrate contamination.

Movement of nitrogen fertilizers from agricultural land is important not only because of the potential for nitrate contamination of groundwater, but also because leached nitrogen represents less than a maximum return on fertilizer dollars invested. Thus, nitrate movement beyond the rooting zone represents both a loss for farmers and a threat to groundwater quality.

The bulk of research on nitrate movement from agricultural land has centered on row crop production. However, since the early 1970's a significant amount of attention has been focused on nitrate movement through sandy orchard soils (Bingham et al, 1971; Pratt et al, 1972). Nightingale (1972) found that in general, orchard soils had greater concentrations of nitrate than did soils under row or trench crops. Because of their low fertility and water holding capacities, sandy soils generally possess a high potential for nitrate leaching.

A high percentage of cherry orchards in Northwest Michigan are located on sandy loam or loamy sand soils. High nitrate concentrations in well water have been found in the region and agricultural sources as well as residential and commercial land uses have been suspect.

At a well site surrounded by extensive cherry orchards near Traverse City, Michigan, Rajagopal (1978) found nitrate concentrations almost double the Federal drinking water standard for domestic water supplies. The Northwest Regional Planning and Development Commission assessed 1200 wells in the Traverse City area, and found that eleven percent had nitrate concentrations in excess of the Federal standard (Weaver and Grant, 1980). The same study identified home sewage, geologic, industrial and agricultural sources as potential contributors to the nitrate problem.

Since 1980 several studies seeking to identify the major source of groundwater nitrate contamination in Northwest Michigan have been conducted. Ellis and Hughes (1982) took monthly soil samples to a depth of 1.8 meter (6 feet) at two sites in cherry orchards on the Old Mission Peninsula in order to evaluate the contribution of fertilizer nitrogen to the nitrate problem. Where rates of 112 kilogram/hectare, 168 kg/ha, 224 kg/ha, and 280 kg/ha (100, 150, 200 and 250 pounds/acre) of nitrogen as ammonium nitrate were applied, high levels of nitrate were found in the profile at depths over 1.2 m (4 ft) as late in the year as October. In all cases, this nitrate was apparently leached beyond the 1.8 m (6 ft) depth by the spring snowmelt.

Based upon this evidence, Ellis and Hughes recommended that fall fertilization, and applications in excess of 112 kg/ha (100 lb/a) of nitrogen per year be discontinued. Fertilization rates in the area have generally been of the order of 112 - 168 kg/ha (100 - 150 lb/acre) of nitrogen as

ammonium nitrate per year. At times the rate has been known to be as high as 269 kg/ha (240 lb/acre) per year (Iversen, 1979). For this reason, it seems unlikely that the recommended application rate of 112 kg/ha (100 lb/acre) per year will be followed.

Excessive fertilizer application rates represent an attempt on the part of growers to maintain sufficient levels of nitrogen within the root zone throughout the growing season despite unpredictable and often severe fertilizer movement which can occur on the local sandy soils during periods of heavy rainfall and snow melt. Furthermore, the practice of fall fertilizer application has arisen. Extended periods of minimal rainfall during the early growing season are thought to leave the dry fertilizer lying useless at the soil surface. In order to compensate for leaching losses which occur with especially heavy precipitation and snowmelt from late fall through early spring, fall fertilizer applications far in excess of crop requirements are often made, and the problem of nitrate loss is compounded.

Clearly the need for a more controlled method of nitrogen application exists. Nitrogen application through fertilizer injection in trickle irrigation systems, a relatively recent technological development, has been considered as a potential solution (Bralts, 1981).

The number of acres under trickle irrigation systems in Michigan has grown significantly over the past ten years so

that today over 16,188 hectares (40,000 acres) across the state are under trickle irrigation (Irrigation Journal, 1983). Almost all new orchards in Michigan are equipped with a trickle irrigation system at the time of planting. Fertilizer injection in trickle irrigation systems on the other hand, has not kept pace with the rapid rise in use of the systems themselves, in part because of nonuniformity of application within existing trickle systems. To avoid poor distribution of both water and nutrients, system uniformity of 80% or better is recommended. Bralts (1981) reported the range of system uniformities in the Grand Traverse Bay region to be from 26 percent to 88 percent.

A study of the performance of various fertilizer injection techniques revealed that uniformity of fertilizer application did not differ significantly from uniformity of water application for four common injector designs (Hahn et al, 1983). Furthermore, a method which allows growers to rapidly estimate system uniformity has recently become available (Bralts and Kesner, 1982). These gains, along with an overall increase in knowledge of proper system design and maintenance, and the availability of high quality trickle system components, has made the widespread acceptance and implementation of fertilizer application through trickle irrigation systems a viable alternative to conventional surface nitrogen application.

In terms of growth and yield, fertilizer application through trickle irrigation systems has been reported to be

very efficient (Miller et al, 1976; Smith et al, 1979; Coston et al, 1978; Chesness and Couvillon, 1980). Recommended rates for Michigan orchards are now generally based on one half the recommended conventional surface rates.

Reductions in nitrogen application rate alone could potentially reduce nitrate contamination of groundwater. Even greater reductions may be possible due to the ease of performing multiple applications with fertilizer injection and thereby maintaining more uniform concentrations of nitrogen within the root zone. The advantages of splitting nitrogen applications have been recognized and noted by many researchers, although relatively few studies have been conducted on perennial tree crops. When nitrogen is applied in several smaller split applications, as opposed to fewer, larger applications, the likelihood of nitrate leaching diminishes. Singh and Sekhon (1976) found considerably more nitrate was lost when all nitrogen was applied in a single application. Gerwing et al, (1979) found that splitting the nitrogen application to corn substantially lowered the maximum nitrate concentrations in soil solution below the root zone. However, greater energy and labor inputs as well as increased soil compaction, erosion, and implement damage to the crop would likely result from multiple applications under conventional fertilization practices. These limitations are minimal with application via fertilizer injection.

A. SCOPE AND OBJECTIVES

The overall goal of this research was to promote optimal growth and vigor of tart cherry trees while minimizing potential nitrate contamination of groundwater in fruit growing areas of Northwest Michigan. To accomplish this goal, the effects of various nitrogen application practices on fruit trees under trickle irrigation were determined, since the extent to which fertilizer injection will be practiced depends on its ability to provide the desired growth response. Additionally, the effects of application practices on nitrate movement were evaluated. This research focused both upon tree response and nitrate movement.

The specific objectives of this research were to determine the effects of nitrogen fertilizer application method, timing of application, and amount of fertilizer upon:

1. the response of young tart cherry trees, and

2. the nitrate content of soil water below the tree rooting depth over time.

II. REVIEW OF LITERATURE

To achieve the goal of promoting optimal growth, vigor and yield of tart cherry trees with minimal nitrate contamination of groundwater from nitrogen fertilizers in Northwest Michigan, a literature review of pertinent topics must be completed. Concerns are A) cherry fertilization practices, B)trickle irrigation and fertilizer injection, C) nitrogen and nitrate leaching, and D) nitrogen balance techniques.

A. CHERRY FERTILIZATION PRACTICES

Early studies related to cherry fertilization established the benefits of increased growth and yield due to nitrogen fertilization (Roberts and Potter, 1919; Chandler, 1925; and Tukey, 1927). Roberts and Potter (1919) reported an increase in yield of nearly 7.7 kg (17 lb) per tree from eight year old Early Richmond cherries fertilized with 1.4 kg (3 lb) of dried blood and 0.45 kg (1 lb) of sodium nitrate per tree. To maintain highest production they concluded, seasonal growth of at least 0.30 m (1 ft) should be encouraged through the application of nitrogen. Such growth allows development of many lateral buds into spurs, from which the most fruit is produced.

Tukey (1927) further substantiated this idea by showing that nitrogen treatments first increased growth and then increased yield. He applied 1.02 kg (2.25 lb) of sodium nitrate per tree to sixteen year old Montmorency cherry trees at bud break and observed clear increases in shoot growth for all trees receiving nitrogen after the first season. No difference in yield was observed until the second year of nitrogen application. Differences in the third season's yield were greater still.

Tukey explained these yield differences based upon Montmorency growth and fruiting habits. The first year response is an increase in shoot growth. The second season some of these longer shoots bear fruit while some form spurs, and in the third season the spurs bear fruit. Over the three years of the study trunk diameter of nitrogen fertilized trees was greater than nonfertilized trees.

Gardner (1930) divided the desired growing and bearing habits of cherry into three stages. He specifically cited 1) vigorous average shoot growth of 0.30 - 0.36 m (1.0 - 1.17 ft) during the first few years, during which time little fruit is produced but a large bearing surface is developed for later production, 2) average shoot growth of 0.15 - 0.30 m (0.50 - 1.0 ft) while trees bear heavily and gradually increase in productivity until full size is attained, and 3) after attaining full size and productivity, maintenance of 0.10 - 0.20 m (0.33 - 0.67 ft) of average shoot growth to maintain "practically indefinite" yields.

The idea of using terminal growth as a guide to nitrogen applications remained central to discussions on cherry fertilization until the advent of leaf analysis programs.

Gardner also found fall fertilized trees to outgrow and outyield spring fertilized trees, but admitted that the data was not sufficient to warrant recommending fall applications. This may be the first reference to timing of nitrogen application in cherries. It should be noted that discussion of specific application rates does not appear in any of the literature yet mentioned.

Overholser (1944) reviewed literature pertaining to fertilizing cherries and reported that sour cherries three to ten years old generally receive approximately 0.23 kg (0.5 lb) of actual nitrogen, mature trees about 0.45 kg (1.0 lb), and old, weak or declining trees about 0.68 kg (1.5 lb). He reported that most nitrogen applications are made in late winter or early spring, but indicated that supplemental nitrogen between cherry set and harvest may aid fruit bud formation at a time when the crop load is making greatest demands upon the trees. He also warned against large nitrogen applications late in the growing season, which may increase the susceptibility to winter injury.

Childers (1973) reported a shift to orchard floor management employing a herbicide strip, permanent sod cover between rows, and irrigation. He referred to Gardner (1930) and recommended that fertilizer play a major role in maintaining desired growth. He reported that the more nitrogen added, up to the point where vegetative growth is excessive, the higher the yields.

Today, nitrogen requirements for cherry trees may be established by 1) leaf analyses, 2) soil tests and 3) observance of deficiency symptoms. Factors which affect the amount of nitrogen needed include crop load, cultivar, tree age, soil type, soil management practice and pruning. Kenworthy et al. (1975) stated that leaf analysis is the best method for established fruit plantings.

Leaf analysis may be used to confirm a nutrient shortage or excess. In Michigan, leaf samples are collected between July 1 and August 15 (Kenworthy and Hull, 1973), and may be analyzed for nitrogen, phosphorus, potassium, magnesium, calcium, manganese, iron, cobalt, boron, zinc and aluminum. By far the most commonly applied nutrient to Michigan fruit crops is nitrogen.

Kenworthy et al. (1975) suggested application of only nitrogen unless other nutrient needs were demonstrated, and recommended applying nitrogen in the fall after a killing frost or as early in the spring as possible, at suggested rates of 0.11 - 0.22 kg (0.25 - 0.50 lb) of actual nitrogen per tree per year of age. These rates translate for stone fruit to 84 to 112 kg of actual nitrogen per hectare (75 - 100 lb/acre).

However, Iversen (1979) reported nitrogen applications in Michigan ranged from less than 112 kg/ha (100 lb/acre) of nitrogen to over 269 kg/ha (240 lb/acre). Iversen's findings are indicative at least in part, of a perceived need on the part of fruit growers to compensate for leaching losses. A significant overall trend toward increased tree fruit leaf sample nitrogen was observed in data analyzed at the Plant Analysis Laboratory, Department of Horticulture, Michigan State University between 1955 and 1977 (Kenworthy et al., 1975).

Application times vary, but single applications of the total nitrogen rate in late fall (November) or early spring (April) are most common. Split applications are somewhat less common but are still often practiced (Kesner, 1985). Split applications involve applying half of the nitrogen in the fall, and half in early spring, or half in both early and late spring.

Historically application timing has been aimed to effect fruit set and fruit development, and recommendations likely resulted from research where nitrogen was applied to soils very deficient in nitrogen (Overholser, 1944). Growth and yield responses were dramatic under these conditions. From more recent research, the importance of nitrogen reserves in tree growth has become apparent (Taylor and May, 1967; Taylor and Von Den Ende, 1969; Taylor et al., 1975). This has tended to change the thinking concerning when nitrogen applications should be made. Work done by Weinbaum et al. (1984) indicated that soil derived nitrogen is partitioned preferentially into vegetative growth after uptake, and does not affect reproductive tissue until the following season. This work suggests that fertilizer nitrogen should be applied strictly based upon when conditions for root uptake are the most favorable.

Many studies of nitrate leaching under various crops have shown that smaller, more frequent nitrogen applications reduce leaching and enhance uptake by the crop (Singh and Sekhon, 1976; Kanwar et al., 1983). One of the most efficient methods to precisely apply fertilizer nitrogen to fruit tree roots during the growing season is by injection into trickle irrigation systems (Chesness and Couvillon, 1980; Smith et al., 1979; Coston et al., 1978).

B. TRICKLE IRRIGATION AND FERTILIZER INJECTION

Application of chemicals through irrigation systems, or chemigation, has been hailed as a means for reducing costs and limiting losses of chemicals to the environment. Research has shown a potential for application of fertilizer (fertigation), herbicides, insecticides, and fungicides through irrigation systems. Since most new orchards in Michigan are established with supplementary irrigation, primarily trickle, the injection of fertilizer through these systems is even more appropriate.

Trickle irrigation, also known as drip or daily flow, provides low volume water applications delivered directly to the base of the plant. Most commonly associated with tree crops, this type of irrigation is also well suited to vineyards, brambles and vegetables. The terms trickle irrigation and drip irrigation can be used synonymously, but trickle irrigation will be used throughout this publication.

1. System Components

A complete trickle irrigation system consists of a water source, a pump, pressure gauges, filters, a fertilizer injector, backflow prevention devices, control valves, flow meters, pressure regulators and a mainline, submain, and lateral line network with emitters. (Figure 1)

The mainline, submain and lateral line network deliver water to the emitters, which may be located individually or

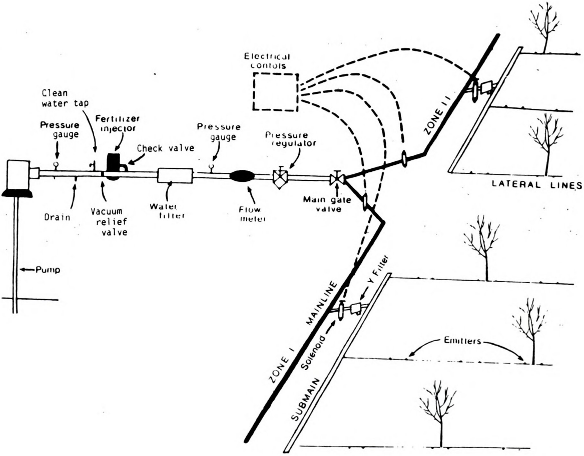


Figure 1. Complete Trickle Irrigation System

in groups near the base of the plant. The mainline and submain are usually polyvinyl chloride (PVC) pipe, their diameter being dependent upon hydraulic parameters including flow rate, slope and allowable friction head loss. Mainline and submain are often buried to limit damage from extreme temperatures, sunlight and farm equipment. Lateral lines of flexible PVC or polyethylene (PE) tubing generally run parallel to the crop row on the soil surface or several centimeters beneath it. Emitters are attached directly to the lateral, or may be fastened on short extension tubes if the lateral line is buried. Extension tubes afford easy inspection, cleaning, and uniformity testing.

A variety of emitter types exist, generally classified as one of the following: 1) orifice type, 2) partially pressure compensating, or 3) fully pressure compensating. (Goldberg, 1976; Bralts, 1981). Use of a particular design depends upon the type of crop to be irrigated, the desired flow rate, and the local topography. Trickle irrigation systems on tree fruits in Northwest Michigan are generally equipped with emitters having some pressure compensating characteristics.

Within each irrigation zone of 20.2 - 50.6 ha (50 - 125 acres), there are several submain units consisting of the submain and lateral lines, and covering 1.0 - 5.1 ha (2.5 - 12.5 acres) (Bralts, 1983). These separate irrigation zones provide irrigators with greater flexibility in water management decisions since they can be irrigated independently.

2. Application Fundamentals

Important considerations for trickle irrigation are soil wetting patterns, size of root zone, and moisture holding capacity of the soil. These factors affect the amount and timing of water application as well as number and location of emitters.

Soil wetting patterns (Figure 2) vary with soil texture. In coarse sandy soils, gravity affects water movement more so than in loams or clays, and a cylindrical

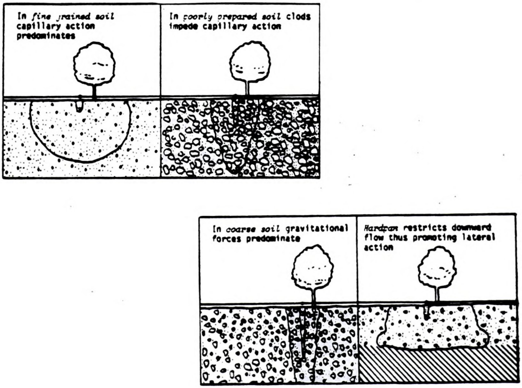


Figure 2. Soil Wetting Patterns (NRAES 1980)

wetted volume or spike, will result. Since at least 25% of the root zone should be irrigated (Kenworthy, 1972), it may be necessary to group emitters on course textured soils. One, two or three 3.8 Liter/hour (1.0 gallon/hour) emitters are recommended for fruit trees depending upon soil texture (NRAES, 1980). Recommendations for emitter location relative to the trunk vary from 0.20 - 0.91 m (0.67 - 3.0 ft).

Methods for scheduling water applications to fruit trees include direct measures of soil moisture, monitoring tree growth, and replacement of estimated evapotranspiration. One common method of scheduling trickle irrigation for fruit trees in Michigan is to replace 50 % of pan evaporation (Kesner 1981). Others have suggested replacement of 75 % of pan evaporation.

Kenworthy (1972) proposed a simple rule-of-thumb for Michigan fruit trees. He assumed that 1) mature trees occupy 50% of the orchard floor, and 2) replacement of 75% of open pan evaporation is required. He used 20 year pan evaporation data for July, the month of greatest evapotranspiration in Michigan. Using these values, Kenworthy recommended an application rate of 380 L/hr/ha (100 gal/hr/acre) for a system with continuous flow. To allow time for soil moisture equalization and drainage, he limited the duration of irrigation to no more than 12 hours per day. Thus, in a mature orchard with 247 trees/ha (100 trees/acre), a flow rate of 7.6 L/hour (2.0 gal/hr) per tree

for 12 hours daily would be required. For younger trees the amount of irrigation depends on tree age: 1 hour for each year of tree age up to the maximum of 12 hours for trees 12 years old and older. This method of scheduling is widely used by Michigan fruit growers (Burgess et al., 1984).

Burgess et al. (1984) reported that the Kenworthy rule of thumb and 75 % evaporation pan techniques were both practical and effective in irrigation scheduling of stone fruit. However, the 75 % evaporation pan technique used significantly less water throughout the season than the Kenworthy rule of thumb, yet vegetative growth and yield between the two were not significantly different at the 5 % level of significance.

Regardless of the method of scheduling, consideration must be given to soil moisture holding capacity. Bralts et al. (1984) stressed the need to estimate the extent of wetted root zone and to apply no more water than can be held in 50% of the soil profile for a specified soil texture. An estimate of the size of the root zone is also required. Kesner (1981) suggested an area bounded by a circle starting with a diameter of 0.91 meter (3.0 ft) for one year old fruit trees, increasing by 0.30 m (1.0 ft) for each year of growth.

3. Emitter Discharge Uniformity

Emitter discharge uniformity is a measure of variation in emitter discharge, and is an important consideration in fertilizer application through injection in trickle irrigation systems. Bralts et al. (1984) recommended statistical uniformity of 80% or above before fertilizer injection should proceed, and identified 1) hydraulic design, 2) manufacturers' variation of emitters, and 3) emitter plugging as contributing to nonuniformity within a trickle irrigation system. The following section, which closely follows a paper by Bralts and Kesner (1983) examines uniformity and trickle system evaluation.

A method for in field estimation of the statistical uniformity of a submain unit is important to irrigators considering fertilizer injection. Statistically sound field evaluation allows measurement of variation from hydraulic design, manufacturers' variation, and emitter plugging, and provides for application of confidence levels to the uniformity estimate.

Bralts (1983) outlined the development of field uniformity estimation for trickle irrigation system submain units beginning with Christiansen's formula for sprinkler irrigation uniformity and Wilcox and Swailes statistical uniformity coefficient for sprinkler irrigation. Measurements of depth of water were used in sprinkler system evaluations. Substitution of emitter flow rate for the depth of water, made possible the application of these uniformity principles to trickle system evaluation.

Statistical uniformity (U_s) can be determined using the coefficient of variation (V_q), defined as the standard deviation (S_{vq}) of emitter flow divided by the mean flow (q)

in the following equation:

$$U_s = 100\ (1 - V_q) = 100\ (1 - S_{vq}/\bar{q}) \qquad [1]$$

Confidence limits for the coefficient of variation (Vq) can be expressed:

$$P(V_q - t_{\alpha/2}\ S_{vq} \leq V_q^* \leq V_q + t_{\alpha/2}\ S_{vq}) = 1 - \alpha \qquad [2]$$

where V_q = sample coefficient of variation,

$t_{\alpha/2}$ = student t value for given α,

α = confidence level desired,

V_q^* = actual coefficient of variation,

and S_{vq} = standard deviation of the coefficient of variation calculated from the equation:

$$S_{vq} = \frac{V_q}{\sqrt{2n}} \sqrt{1 + 2(V_q^2)} \qquad [3]$$

Using the above equations, confidence limits may be applied to the statistical uniformity (U_s). Bralts and Kesner (1983) translated these statistical equations into a uniformity calculator suitable for field evaluation (Figure 3). This nomograph is based upon the assumption that emitter flow is normally distributed. The inverse of flow rate, namely the time required to fill a selected volume, is used in the procedure, and the nomograph is based upon the fact that for any given coefficient of variation, the sum of the observations in the upper portion of the distribution and the sum of the observations in the lower

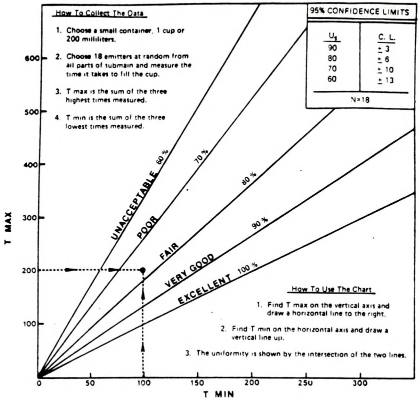


Figure 3. Statistical Field Uniformity Nomograph (Bralts and Kesner, 1982)

the fact that for any given coefficient of variation, the sum of the observations in the upper portion of the distribution and the sum of the observations in the lower portion of the distribution vary linearly.

4. Injector Performance

Bralts et al. (1984) described four major methods of injection used in Trickle irrigation systems. They are the 1) venturi injector, 2) positive displacement pump injector, batch tank injector, and 4) bladder tank injector. (Figure 4) The following descriptions are taken from Bralts et al. (1984).

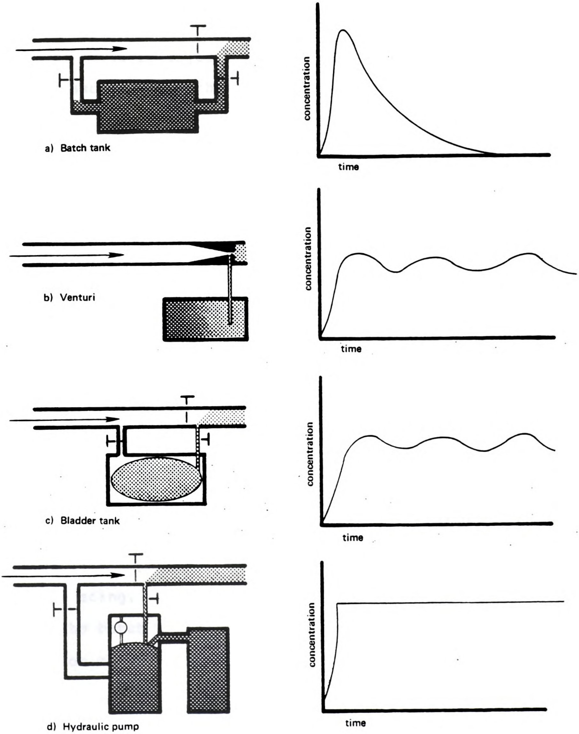


Figure 4. Fertilizer Injection Methods and Fertilizer Concentration Over Time (Bralts et al., 1984)

The venturi injector operates by means of a pressure differential induced by a constriction within the mainline at the site of injection. For this reason, some reduction of pressure within the system can be expected with its use. Similar pressure losses may occur with any injector that is driven by system pressure, such as a proportional pump. In such cases it may be necessary to increase pressure to offset the pressure loss due to the injector in order to ensure proper emitter performance, since emitters function best at the pressure for which they were designed.

A positive displacement pump may be used to take up solution and inject it into the mainline. The posititive displacement pump may be operated by a gasoline engine or electric motor, or may be a proportional hydraulic pump which operates on system water pressure. Pumps operated by external power can be easily controlled, and thus provide for complete command of injection rate and duration of application. This is convenient for the grower, since total fertilizer applied is simply a function of the time the pump is operating.

The batch tank injector is a tank for holding the stock solution through which some portion of the irrigation water is diverted by creating a pressure gradient between the inlet and outlet of the tank. The tank volume depends upon the desired dilution ratio and the size of the zone or block to be fertilized. The batch tank system is inexpensive and convenient to use and does not require an outside power source.

The bladder tank injector consists of a flexible inner liner separating the stock solution from the entering irrigation water. As the bladder is collapsed by mainline pressure, stock solution is forced from the bladder and injected into the system. The bladder tank system has an advantage over the batch tank method in that the rate of fertilizer injection can be more easily controlled.

The venturi, bladder tank, and positive displacement pump injectors maintain a fairly constant injection rate and a constant concentration of fertilizer in the irrigation water. With the batch tank method however, the initial concentration of fertilizer in solution is higher than the concentration at a later time. The decrease in fertilizer concentration in the tank over time is not linear. Thus, each batch should be completely used on any one given submain unit or crop zone. If the system is shut down before the batch is completely used, the grower has no way of determining the precise amount of fertilizer applied.

Despite the differences in fertilizer concentration in the system over time, the uniformity of fertilizer application is not affected by injector type. Using the coefficient of variation to assess the uniformity of water and fertilizer application, Hahn et al. (1983) found that for the batch tank, venturi, bladder tank, and hydraulic pump, the uniformity of fertilizer application did not differ significantly from the uniformity of water application. Uniformity of fertilizer application was shown to be dependent strictly upon the uniformity of water application. Emitter location within the submain unit and method of injection did not alter this relationship. However, it was acknowledged that differences in injector performance with respect to fertilizer concentration in the system with time might have a bearing upon adaptability to specific grower situations, convenience and grower acceptance.

5. Water Quality Considerations

Water quality is important in trickle irrigation system operation and maintenance since emitter plugging can result. Municipal, surface and well water sources may be used for trickle irrigation systems, but water quality determines the degree of preventive maintenance required. Bucks et al. (1979) identified potential physical, chemical and biological contributors to trickle system clogging, and developed a water-classification system for evaluating the clogging potential of trickle irrigation water sources. Physical contaminants include suspended sand, silt and clay. Chemical contributors to plugging include precipitates of calcium or magnesium carbonate, calcium sulfate and certain fertilizer compounds. Biological sources of plugging are bacteria and algae. Filtration, field inspection, chemical treatment and pipeline flushing are recommended for controlling plugging problems.

Proper filtration to remove suspended sand, silt, clay, and algae may be accomplished by pressure filters which include screen, centrifugal and media pack designs, or gravity filters which are primarily settling or sediment reservoirs. Initial water quality and emitter design dictate specific filtration requirements. Most existing trickle irrigation systems in Michigan fruit orchards utilize deep well water supplies and use 100 to 200 mesh screen type filters (Kesner, 1981).

Chemical precipitation, high concentrations of dissolved compounds, and bacteria problems may require chemical treatment. Calcium or magnesium precipitates can form when water with high calcium or magnesium levels is used. Sulfuric acid, chlorine gas and other chemicals have been used in conjunction with filtration to prevent or correct precipitation problems.

Another aspect of water quality concerns protecting the system operator, water source, and crop from concentrated chemical solutions. The ASAE IMC (1982) identified potential hazards and suggested precautions for application of chemicals through irrigation systems. A water source at the injection site for washing off chemicals contacting the skin is recommended for operator safety. Protective clothing and labeling of stock solutions is also suggested. Water source contamination and crop damage from exposure to concentrated fertilizer solution may be prevented by using backflow prevention devices and interlocking of fertilizer injector and water pump.

When using a positive displacement injector pump powered by an outside energy source, the pumping plant and the fertilizer injection pump must be interlocked, so that if the irrigation pump stops, the injection pump will also stop, preventing the fertilizer injector from filling the entire irrigation network with concentrated stock solution. Venturi, batch tank, bladder tank, and proportional pump injectors are synchronized with the irrigation pump since they operate relative to water flow.

A check valve in the fertilizer injection line may be needed to prevent irrigation water from flowing into the stock solution tank should the injector stop functioning. Without this check valve, irrigation water could enter the stock solution tank, overflowing it, and causing concentrated stock solution to spill on the ground where it could leach back into the groundwater.

Additionally, some form of backflow prevention device should be used to prevent the irrigation water containing fertilizer from draining back to the water source. Check valves or vacuum relief valves located between the irrigation pump and the fertilizer injector keep the water and fertilizer mixture from flowing back to the water source. Currently, backflow prevention devices are not required in Michigan but are strongly recommended. They are required by law in several other states including Wisconsin.

6. Fertilizers

Fertilizer materials used for injection in trickle irrigation systems must be soluble (Goldberg, 1976). Nitrogen, the plant nutrient most often applied through trickle irrigation systems, is therefore generally applied as calcium nitrate, ammonium nitrate or urea, three of the most soluble formulations. Most nitrogen sources will not directly increase plugging problems. However, aqua ammonia and anhydrous ammonia tend to indirectly increase emitter plugging by increasing the pH of irrigation waters, and consequently increasing precipitation of calcium and magnesium carbonates (Goldberg, 1976).

Fertilizer should be free of residues or precipitate-forming impurities. Water source compatibility should be investigated prior to injection, since some fertilizers will react with dissolved substances in the water to form precipitates. Bralts et al. (1984) gives more information on fertilizer-water compatibility.

Nitrate (NO_3) is most commonly the form in which plants take up nitrogen. Hence, fertilizer in the nitrate form injected into irrigation becomes immediately available to most plants (Goldberg, 1976). Usually, the ammonia form (NH_3) will remain in the soil for a longer time and will become available to the plant or move through the soil profile only after conversion to the nitrate form.

Due to the low solubility of most phosphorus fertilizers, and the increased likelihood of precipitate formation, it is generally recommended that phosphorus be applied by means other than through the trickle system

(Goldberg, 1976). Rauschkolb et al. (1976) applied phosphorus through a trickle system but warned of potential plugging problems. Micronutrients including zinc (Lindsey and New, 1974), copper and iron may also be applied, but only the more soluble chelated forms should be used. Potassium may also be applied with little or no increased plugging problems. The remainder of this paper will deal strictly with nitrogen application through fertigation.

7. Nitrogen Distribution

Distribution of nitrogen from a trickle system emitter affects the amount of nitrate leaching and uptake that will occur. Bar-Yosef and Sheikholslami (1976) conducted laboratory experiments of simultaneous distribution of water and nitrate in clay and sandy soils irrigated and fertilized from a trickle source. Air dry soil was passed through a 2 mm (0.08 inch) sieve and packed uniformly in plastic containers 45 cm (17.7 in) high and 46 cm (18.1 in) in diameter. Average bulk density of the sandy soil was 1.60 g/cm^3 (99.9 lb/ft^3). Accommodations were made for controlling evaporation rate and sampling was accomplished with a metal tube at various distances. Nitrate as potassium nitrate was applied at either 4.2 or 42 mL/minute (0.0011 - 0.011 gpm) near the soil surface at the center of the container. Nitrate adsorption on both soils was negligible and in the sandy soil neither nitrification nor denitrification were significant.

With no initial nitrate concentration in the sandy soil, nitrate concentrations within the wetted soil volume after one irrigation were uniform. After the second irrigation, nitrate accumulation near the boundary of the wetted volume was observed. Treatments with the higher discharge rate showed the same trend only to greater depth.

When identical amounts of water were added, but the discharge rate in the sandy soil was increased from 4.2 to 42 mL/m (0.0011 - 0.011 gpm), vertical movement of the wetting front increased and horizontal movement decreased. Unlike the clay soil in which denitrification did occur, the nitrate concentration in the sandy soil solution did not drop significantly below that of the trickle solution. This is an important consideration when dealing with a nitrogen balance on sandy orchard soils such as those studied in this experiment.

8. Growth Response To Fertilizer Injection

Nitrogen application through trickle irrigation systems has been reported to be more efficient than banding followed by trickle or furrow irrigation. Miller et al. (1976) evaluated six treatments on fresh-market tomatoes. Treatments were 0) furrow irrigation with no added nitrogen, 1) furrow irrigation and banded nitrogen at planting, 2) drip irrigation and banded nitrogen at planting, 3) drip irrigation and drip applied nitrogen at planting, 4) drip irrigation and drip applied nitrogen split into two treatments at planting and flowering, and 5) drip irrigation and drip applied nitrogen split at planting, thinning, flowering and fruiting. Tomato yield and plant nitrogen at six sampling dates throughout the season were measured.

In treatment 2, emitter location relative to banded fertilizer caused lower levels of plant nitrogen. Analysis of soil samples showed that nitrogen had accumulated at the outer edge of the wetted zone where it was less available to the plants. However, treatments 3, 4 and 5 gave a higher percentage of plant nitrogen, with the exception of treatment 3 at the sixth sampling date. It was concluded that furrow irrigation was superior to trickle irrigation when the fertilizer was banded and the given emitter orientation was used. Fertilization through the trickle system was the most efficient method of those evaluated.

Fertigation of tree fruit crops has been studied by several researchers. Potential indicators of fruit tree response are terminal growth measurements, leaf analyses, fruit quality, trunk diameter or cross-sectional area measurements, and general appearance including leaf color, fruit color, and overall size.

Smith et al. (1979) analyzed leaf samples using a macro Kjeldahl method. Yields of tart cherry, plum, peach, and apple were also evaluated, in order to examine whether nitrogen application by injection in trickle irrigation could reduce the total amount of nitrogen required to produce an equivalent plant response. All treatments were done in the field. Results indicated that the amount of nitrogen can be reduced to 50% of normal recommended rates

and still maintain the recommended percent leaf nitrogen and yield. Treatments of 25% of the recommended nitrogen rate did not significantly reduce leaf nitrogen in most cases. Accumulation of leaf nitrogen over time was also monitored. Results showed no significant differences between full,half,and quarter rates of trickle application and full rate fall ground application one week after the first injection. However , a control treatment was not included in the study.

Coston et al. (1978) reached similar conclusions for peach tree response to fertilizer application through a trickle irrigation system. A control treatment was included. Trees were planted in 189 L (50 gal) plastic barrels filled with calcined clay. Trunk diameter increases and leaf nitrogen were measured. The experiment was conducted for two years. In the first year, 113.5 g (0.25 lb) of nitrogen per tree was the maximum rate. Other rates applied were one half, one quarter, and one eighth this amount. Treatments were split into two or four trickle applications. Mean separation by Duncan's Multiple Range Test at the 5% level showed that fertilized trees had greater trunk diameter increases and leaf nitrogen than unfertilized trees. Trees receiving one quarter, one half and full amounts grew best.

In the second year, a full rate ground application treatment was added. Again, fertilized trees responded significantly better than non-fertilized trees. Treatments of one quarter, one half, full rate trickle applied, and

full rate surface applied were equivalent in terms of trunk diameter increases. Leaf nitrogen for the one quarter rate treatment was less than for the one half and full rates. Treatments of one eighth rate were lower for both criteria. These results were regarded as preliminary investigations for orchard work to be performed.

Chesness and Couvillon (1980) studied peach yield, leaf analyses and trunk diameter for four treatments carried out for four years. Treatments were 1) no irrigation with conventional nutrient application, 2) irrigation with conventional nutrient application, 3) irrigation plus full rate fertigation, and 4) irrigation plus one half rate fertigation. Trees receiving one half rate fertigation showed trunk diameter increases equal to those receiving the full amount applied conventionally. In fact, the method and amount of nutrient application had no influence on trunk diameter over the four year period. Trunk diameter increases on irrigated treatments were greater than on nonirrigated treatments for all four years. This suggests that trunk diameter may not be a good indicator of response to varying fertilization rates and methods of application.

Yield differences varied during the four year period. In the first year, the highest yields were obtained from the irrigated conventional and full rate trickle applied treatments. Yields for the one half rate trickle treatment were intermediate between full rate treatments and control. In the second and third years there were no differences

between any of the irrigated treatments. All irrigated treatments had higher yields than did nonirrigated treatments. In the fourth year there were no significant yield differences among any of the treatments, apparently due to adequate rainfall.

Leaf nitrogen analyses showed higher levels for trickle applied nitrogen treatments in all four seasons relative to conventional surface applications. Also, nitrogen levels for the one half rate trickle application were only slightly lower than for full rate for all four years. Again a control treatment without fertilizer nitrogen application was not included in the study.

C. NITROGEN AND NITRATE MOVEMENT

Nitrogen is the most important plant nutrient for many plants, and is more widely needed in Michigan fruit production than any other nutrient (Kenworthy et al., 1975). Furthermore, fertilizer and lime together represent the second highest source of variable cost next to chemical spraying incurred in tart cherry production in Western Michigan (Kelsey and Johnson, 1979). Nitrates in groundwater on the other hand, represent a lack of efficiency in fertilizer application. High nitrate levels in groundwater are hazardous, since they can be converted to nitrites which cause methemoglobinemia, a serious and sometimes fatal blood disorder in infants (Wolff and Wasserman, 1972). To better define the role of nitrogen fertilization in groundwater contamination problems, and to assess the potential impact of fertigation through trickle irrigation systems requires an understanding of 1) nitrogen interactions in the environment, and 2) soil processes and management practices affecting nitrate movement.

1. Nitrogen Interactions in the Environment

The following discussion follows that found in Tisdale and Nelson (1975). Nitrogen is found in many forms throughout the natural environment. It exists as both inorganic and organic compounds. In soils the bulk of nitrogen occurs as part of the soil organic matter complex, although significant levels of inorganic ammonium, nitrate and nitrite are present in many soils. The nitrogen cycle (Figure 5) illustrates the various forms and interactions of nitrogen in the environment.

The ultimate source for nitrogen in soils is the inert gas N_2, which makes up approximately 78 percent of the earth's atmosphere. This inert nitrogen is in dynamic equilibrium with various fixed forms, which include ammonia, NH_3, ammonium, NH_4+, nitrate, NO_3-, nitrite, NO_2-, nitrous oxide, N_2O, and nitric oxide NO. Higher plants are unable to utilize N_2 until it is first converted, or fixed into one of these compounds. Plants absorb the majority of their nitrogen in the ammonium and nitrate forms.

Fixation occurs through 1) the action of symbiotic bacteria, including Rhizobia which live on the roots of legumes, 2) free living soil microorganisms including blue-

green algae and bacteria, 3) electrical discharges of lightning in the atmosphere, and 4) industrial fixation by fertilizer manufacturers.

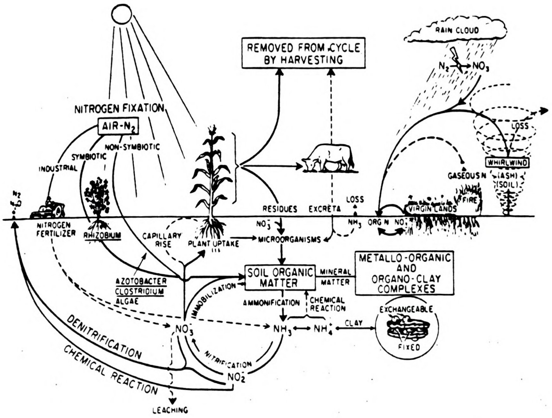


Figure 5. The Nitrogen Cycle (Nelson, 1975)

Nitrogen transformations in soils which affect the form and quantity of nitrogen present are a) mineralization, b) immobilization, c)denitrification, d) decomposition of nitrite, and e) volatilization of ammonia. Of these soil processes, mineralization and denitrification are most significant in terms of nitrate leaching, since they

directly affect abundance of nitrate in soils.

Mineralization is the conversion of organic nitrogen to a mineral form, either ammonium, nitrite or nitrate. It is a three step process consisting of aminization, ammonification and nitrification. Nitrification is especially important here, since it is the actual biological oxidation of ammonia to nitrate. Factors which affect nitrification are 1) supply of the ammonium ion, 2) population of nitrifying organisms, 3) soil aeration, 4) soil pH, 5) calcium, phosphorus and micronutrient balance, 6) soil moisture, and 7) temperature. These factors in turn are under direct or indirect control by soil management practices. Similarly, denitrification may be influenced by management strategies. Denitrification is the biochemical reduction of nitrates which results in gaseous loss of nitrogen from the soil.

Since management practices affect nitrate leaching indirectly through the processes of nitrification and denitrification, as well as directly such as in the case of irrigation water application which causes movement of accumulated soil nitrate, the overall affects of soil, water and fertilizer management practices on nitrate leaching will be discussed.

2. Management Practices Affecting Nitrate Movement

Laher and Avnimelech (1980) studied nitrification in light of application of ammoniacal fertilizer through trickle fertigation. They listed four distinguishing

characteristics of drip irrigation relevant to nitrogen transformation in the soil. They are 1) fluctuations of soil moisture with time are minimal due to high frequency of irrigation, 2) distribution of water in soil is not uniform since a zone of saturation exists below the emitter source, 3) immobile ammonium ions applied with the water are absorbed in the soil close to the emitter source, and 4) downward leaching is restricted to a small fraction of soil volume.

Bananas on a calcareous clay loam soil were trickle irrigated for eight hours daily and ammonium sulfate was delivered through the system once a month. Soil samples were collected below and around emitters. Samples equidistant radially from the emitter were grouped together and all were analyzed for nitrate, chloride and ammonium. Results showed an increase in ammonium concentration from fertilization only in the soil cylinder below the emitter. Very low levels of ammonium remained at the end of the fertilization cycle. Nitrate concentrations on the other hand, were low in the saturated zone below the emitter and higher farther away from the central core. Also, nitrate levels were higher at the end of the fertilizer cycle than immediately following fertilization.

It was concluded that an effective slow release fertilizer system is established when ammonium is applied through the trickle system. This is due to the fact that nitrification takes place mainly outside of the saturated

volume where downward water movement is minimal. Laher and Avnimelech also stated that the rate of nitrification could be controlled by manipulating 1) the volume through which ammonium is distributed and 2) soil aeration within this volume. Such manipulations could be enacted by varying a) fertilizer dilution rate and b) frequency of irrigation.

Application of nitrate nitrogen through trickle systems to both clay and sandy soils was studied by Bar-Yosef and Sheikholslami (1976) as discussed in the fertilizer injection section of this paper. Seven to 50% of the nitrate present in the clay soil could be expected to denitrify within 24 hours depending upon soil aeration. Nitrification and denitrification were negligibly small in the sandy soil.

Many researchers have investigated the affects of fertilizer and water management on nitrate leaching (Gerwing et al., 1979); Singh and Sekhon, 1976; Smika et al., 1977; Timmons and Dylla, 1981). In general, practices which maintain high levels of nitrate in proximity with the crop roots for the longest period of time are those which provide the minimal level of nitrate losses to leaching.

Gerwing et al. (1979) found that splitting the nitrogen application to corn substantially lowered the maximum nitrate concentrations in soil solution at the 1.5 m depth (4.9 ft). Evidence suggested that nitrate was distributed more uniformly throughout the soil profile when split applications were made. The same study showed increased

nitrogen levels in corn stover and grain under split applications.

Similarly, Singh and Sekhon (1976) found considerably more nitrate to be lost when all nitrogen was applied in a single application. Evaluation of soil samples collected at 0.15 m (0.49 ft) intervals up to 2.25 m (7.4 ft) led to the conclusion that as the number of splits are increased the likelihood of nitrate leaching diminishes. When all nitrogen was applied in a single treatment, considerably more nitrate was lost regardless of the irrigation schedule.

Singh and Sekhon as well as Smika et al. (1977) noted that amount and frequency of irrigation significantly affect nitrate leaching. Singh and Sekhon observed less movement of nitrate when irrigation amounts were less, even with frequent irrigations. Timmons and Dylla (1981) likewise observed greater nitrate leaching when supplemental irrigation was applied to corn on a sandy loam soil.

D. NITROGEN BALANCE TECHNIQUES

Nitrate movement may be evaluated by 1) soil sampling (Ellis and Hughes, 1982; Singh and Sekhon, 1976), 2) drain tile flow sampling, 3) lysimeter leachate collection (Timmons and Dylla, 1981), or 4) soil water vacuum extraction (Smika et al., 1977; Gerwing et al., 1979).

Collection of soil samples is destructive, and may be impossible at depths below fruit tree rooting depths where stones, gravel and hardpan layers are present. Lysimeters

of adequate size for fruit trees require costly and time consuming installation or disturbance of the soil profile. Vacuum extractors on the other hand, seem well suited to a comparative study in which replicated treatments to undisturbed soil profiles are required.

Gerwing et al. (1979), used porous ceramic vacuum extractors to obtain soil solution samples at 1.5 m (4.9 ft) and 2.4 m (7.9 ft) to determine if greater fertilizer use efficiency through multiple nitrogen applications to corn would reduce nitrate loss below the root zone and decrease the potential for nitrate movement to the aquifer. Smika et al. (1977) used vacuum extractors to collect water samples 1.50 m (4.9 ft) below the soil surface under center pivot irrigation in order to evaluate the effect of water management on nitrate leaching under corn.

Linden (1977) described development of a soil water sampling system, installation of samplers, and variations on methods and schedules for sample collection. Soil water is sampled when the applied vacuum within the sampler overcomes the matric suction holding water in the soil, and water moves into the sample chamber.

Two basic configurations of ceramic and subsequent flow pattern are possible: 1) a simple ceramic cup, and 2) a ceramic plate installed horizontally. Soil water flow into the cup is from all directions, while flow into the ceramic plate comes only from directly above the ceramic. The cup design has the advantages of low cost and simple

installation, and disruption of the soil profile is less than with plate installation. Its disadvantage is an ill-defined flow pattern. The plate configuration allows definition of direction of flow but costs more and is more difficult to install.

Vacuum may be applied continuously or intermittently. If converting sample solute concentrations to total solute mass is necessary, then vacuum must be continuous. Continuous vacuum requires a motor driven vacuum pump and greatly increases system cost and complexity. Hansen and Harris (1975) found that constant vacuum samplers sampled more uniformly through time and thus produced a narrower range of sample concentration than did samplers set with intermittently applied vacuum, but stated that the data did not necessarily have less bias.

Hansen and Harris suggested the following interim guides for reducing sampler data variability and thus aiding interpretation: 1) select samplers with similar intake rates, 2) use short sampling periods, 3) use a uniform sampler length, 4) use the same initial vacuum for all samplers, 5) avoid compositing samples so as not to obscure biases related to sampling technique, 6) check sampler bias for sampled soils, ions and ion concentrations where possible, and 7) minimize nitrogen transformations during collection.

III. METHODOLOGY

In the review of literature it was shown that problems associated with conventional cherry fertilization techniques might be overcome by means of fertilizer injection through trickle irrigation systems. Furthermore, the review of literature points up the lack of definitive evidence regarding the effects of nitrogen fertilizer application method, timing of application, and amount of fertilizer upon both the response of tart cherry trees and the nitrate content of soil water below the tree rooting depth over time. This suggests the need for a omparative study of nitrogen application practices.

This research will focus upon both tree response and nitrate leaching in order to achieve the overall goal of promoting optimal growth and vigor of tart cherry trees and minimal nitrate contamination of groundwater from nitrogen fertilizers under Northwest Michigan conditions.

A. RESEARCH APPROACH

Based upon the need to define the effects of nitrogen application practices on tree response and nitrate movement the following approaches are proposed for achieving the specific research objectives.

Objective 1. Determine the effect of nitrogen fertilizer application method, timing of application and amount of fertilizer upon the response of young tart cherry trees.

To achieve objective 1, various parameters of tree response will be evaluated under compartative nitrogen application practices. Nitrogen application "practices" here include 1)two different methods of application: a)surface applied and b) application through injection in the trickle irrigation system (referred to hereafter as surface applied and trickle applied), 2) four different timing schemes for surface applications: a) fall, b) spring, c) fall and spring split, and d) early spring and late spring split, and 3) four rates of nitrogen application: a) high, b) medium, c) low, and d) none. The purpose of evaluating tree response will be to establish relationships between the various application practices and subsequent tree growth and vigor at the research site.

Objective 2. To determine the effect of nitrogen fertilizer application method, timing of application, and amount of fertilizer upon the nitrate content of soil water below the tree rooting depth over time.

To achieve objective 2, four of the nitrogen application practices will be evaluated in terms of nitrate leaching by analysis of soil water samples collected from below the tree root zone. The four practices are control, medium rate fall surface applied, medium rate spring surface applied, and medium rate trickle applied. The purpose of monitoring nitrate content below the tree rooting depth will be to establish the relationship between timing and method of application, and nitrogen movement from the rooting volume.

B. EXPERIMENTAL DESIGN

The experimental design consists of two parts. Part one involves the nitrogen application treatments themselves, and part two involves the collection procedure for tree response data, water samples and soil moisture analysis data.

All field data for this research was collected from a block planted to 504 Montmorency tart cherry trees (Prunus cerasus L.) called the "500 Block" located at the Northwest Michigan Horticultural Experiment Station near Traverse City, Michigan.

The trees were planted in May of 1981 at a spacing of 5.5 x 4.3 m (18 x 14 ft). The orchard floor was maintained as a Kentucky bluegrass/perennial ryegrass sod with a 1.8 m (6 ft) weed free strip under the tree rows. Weeds were controlled with two sprays annually of Paraquat. Soil at the site is from the Emmet Series (Table 1).

1. Nitrogen Application Treatments

Nitrogen application treatments were initiated during

November, 1982. Fertilization records appear in the appendices.

Table 1. Emmet Series Soil Characteristics

Depth cm(in)	USDA Texture	AWC cm/cm(in/in)
0 - 56 (0 - 22)	sandy loam	.13 (.13)
56 - 81 (22 - 32)	sandy clay loam	.20 (.20)
81 - 152 (32 - 60)	sandy loam plus gravel	.10 (.10)

(Burgess et al., 1984)

The research plot was arranged in a randomized complete block design with four blocks (I,II,III, and IV), and eighteen treatments (1 - 18). See Figure 6 and Table 2. The blocking variable was slope, with Block I at the highest elevation and Block IV at the lowest. Slope was selected because differences in soil type tend to coincide with differences in elevation. Such differences could affect tree response. Also, the land slope affects runoff and infiltration and could therefore affect nitrogen movement.

The fertilizer used in this research was pelletized ammonium nitrate, 34% actual nitrogen. Treatments were carried out as shown in Table 2. Treatments 4 - 9 were made with a single application each year. Fall and spring split, and early and late spring split treatments (Treatments 10 - 15) were made in two equal applications. Treatments 16, 17, and 18, the trickle application treatments, were made in four equal applications.

N

BLOCK I			BLOCK II			BLOCK III			BLOCK IV		
6.	4.	1.	6.	8.	2.	10.	17.	14.	13.	12.	3.
5.	12.	9.	17.	3.	1.	15.	5.	13.	6.	11.	1.
11.	13.	8.	11.	10.	13.	3.	9.	1.	14.	16.	8.
15.	14.	10.	9.	12.	18.	6.	12.	4.	4.	18.	7.
17.	3.	7.	7.	16.	14.	7.	2.	16.	9.	17.	2.
16.	2.	18.	5.	4.	15.	8.	11.	18.	5.	10.	15.

Undulating Slope

--- 5 % down slope ----->

Figure 6. Treatment Plot Layout

Table 2. Nitrogen Fertilizer Treatments

Treatment	#	1983 Season kg (lb)	1984 Season kg (lb)
		Actual Nitrogen	
CONTROL	1	0.00 (0.00)	0.00 (0.00)
"	2	0.00 (0.00)	0.00 (0.00)
"	3	0.00 (0.00)	0.00 (0.00)
FALL APPLIED			
low N	4	0.07 (0.15)	0.14 (0.30)
medium N	5	0.14 (0.30)	0.27 (0.60)
high N	6	0.27 (0.60)	0.54 (1.20)
SPRING APPLIED			
low N	7	0.07 (0.15)	0.14 (0.30)
medium N	8	0.14 (0.30)	0.27 (0.60)
high N	9	0.27 (0.60)	0.54 (1.20)
FALL/SPRING SPLIT *			
low N	10	0.07 (0.15)	0.14 (0.30)
medium N	11	0.14 (0.30)	0.27 (0.60)
high N	12	0.27 (0.60)	0.54 (1.20)
SPRING SPLIT **			
low N	13	0.07 (0.15)	0.14 (0.30)
medium N	14	0.14 (0.30)	0.27 (0.60)
high N	15	0.27 (0.60)	0.54 (1.20)
TRICKLE APPLIED ***			
low N	16	0.07 (0.15)	0.14 (0.30)
medium N	17	0.14 (0.30)	0.27 (0.60)
high N	18	0.27 (0.60)	0.54 (1.20)

* One half applied in November, one half in March/April.
** One half applied in March, one half in June.
*** Applied in four equal treatments in May/June.

Plastic cups were calibrated to the nearest 14 g (0.5 ounce) and used in the orchard to measure the fertilizer for each tree in the surface application treatments. Fertilizer was banded under the drip line in a circular pattern with a radius of 0.46 m (1.5 ft). Fall surface applications were made in November. Spring surface treatments were applied in late March, and surface spring split treatments were applied in two equal amounts in late March and mid June.

A trickle irrigation system was set up on the 500 Block at the time of planting in Spring, 1981. The system is equipped with (1) 7.6 L/hr (2 gal/hr) vortex emitter per tree. Emitters are on extension tubes and are situated approximately 0.15 m (0.5 ft) from the trunk and 0.15 m (0.5 ft) above the soil surface. The lateral lines are buried 0.10 - 0.15 m (0.33 - 0.50 ft) below the surface. This system will be referred to hereafter as "the water system". The uniformity of water application was determined to be over 90% (Bralts 1983).

A second trickle irrigation system was set up and used for fertilizer injection to deliver nitrogen to the trickle application treatments. This system uses (1), (2) or (4) 3.8 L/hr (1 gal/hr) vortex emitter(s) per tree for treatments 16, 17 and 18 respectively. This system will hereafter be called "the fertilizer system". A valve on the water system submain was kept closed during fertilizer injection to insure that no fertilizer entered the water system network, and the two systems were never operated

simultaneously. By design the fertilizer system delivered two and four times the amount of fertilizer and water to treatments 17 and 18 respectively, than it did to treatment 16. Such differences could have caused tree response effects not attributable to the nitrogen application treatments.

To correct for these differences the water system was used to deliver water to treatments 1 - 17 in a timed procedure immediately following each fertilizer injection. Wooden clothespins were used to hold emitter extension tubes on the water system closed on treatments 16, 17 and 18. The system was then turned on and all treatments except 16, 17 and 18 were watered. At the appropriate times the pins were removed from treatments 16 and 17. To insure uniform water application during future irrigations, pins were removed from all treatments after all trees had received an equal amount of water (see appendices).

Refinements of fertilizer injection technique were made over the course of the first four injection sessions in 1983. These refinements mainly concerned problems with the injection procedure which arose due to the fact that by design, treatment 18 trees received such a large amount of water. To minimize the amount of water applied, the injection period had to be kept as short as possible. However, due to the low flow rate with the fertilizer system, and the need for strict time constraints on the injection procedure, several commonly used fertilizer injection techniques were not feasible.

In 1984, nitrogen injection was accomplished by mixing a stock solution of 20 kg (44.1 lb) of 34% ammonium nitrate per 114 L (30 gal) of water. Injection was done with a model 320 HT Hardi diaphram pump which delivers 49 L/min (13 gpm) at 2413 kilopascals (350 psi). Injection followed procedures outlined by Bralts et al. (1984). Twenty minutes was allowed for the irrigation system to come to equilibrium. Injection of nitrogen was accomplished in 20 minutes, and the lines were flushed for 20 minutes.

In order to check whether nitrogen delivery was uniform, the emitter discharge uniformity of the fertilizer system was evaluated on May 7, 1984, prior to the first trickle nitrogen application. The uniformity of the system was found to be excellent at 94%. The actual uniformity calculations appear in the appendices.

2. Data Collection Procedures

Timing of data collection was often influenced by the travel involved and samples were collected by personnel at the Northwest Michigan Horticultural Experiment Station. Data sheets and instructions for collection were developed, and appear in the appendices.

All trunk diameter measurements were taken with calipers at 0.30 m (1.0 ft) above the soil surface parallel to the row. In April and September of 1983, all seven trees per treatment plot were measured. In September of 1984 the first and seventh tree were not measured because of the possibility of nitrogen movement from adjacent treatment plots affecting these "buffer" trees. Data from five of the seven trees was analyzed.

For the purposes of this research, total terminal growth was not measured. Instead, 3 - 6 measurements were taken from each of the five inner trees per treatment plot. Both 1983 and 1984 growth was measured around September 20, 1984. The central leader of each of the 3 - 6 main scaffold branches was measured (Figure 7). The average growth was

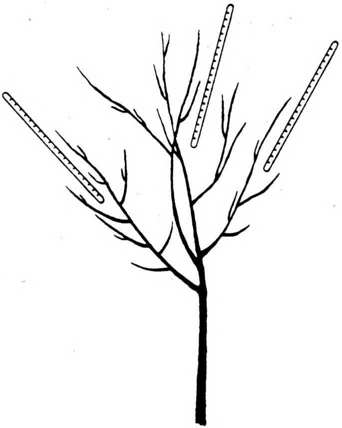


Figure 7. Average Terminal Growth Measurements

then calculated for each plot.

Leaf samples were collected on July 31 and August 2, 1984. About 100 leaves were collected from each treatment plot of seven trees, following procedures recommended by Kenworthy and Hull (1973). Samples were then air dried until September. Fruit was harvested from the 500 Block for the first time in July 1984. Total weight from each plot of seven trees was recorded.

Soil water vacuum extractors, or suction lysimeters as they are often referred to (Linden, 1977, were used to collect soil water samples from a depth of 1.8 m (6 ft). This depth was selected as being well below the active rooting zone of the trees. One vacuum extractor per treatment plot of seven trees was installed in treatments 1, 5, 14, and 17, for a total of 16 as shown in Figure 8. For purposes of organization, the sixteen lysimeter sites were assigned a letter, A through P, beginning with the lateral at highest elevation in Block I, and proceeding from south to north within a given row, and ending in Block IV.

During installation, an attempt was made to place each extractor 0.46 m (1.5 ft) directly East from the tree trunk (perpendicular to the row). Except on treatment 14, block IV, where there was a dead tree, the lysimeters were placed near the second tree from the north end of the treatment plot. Installation was made by using a soil slurry (Soil Moisture Equipment Corporation, 1983). A description of the soil profile at each site appears in the appendices.

BLOCK I			BLOCK II			BLOCK III			BLOCK IV		
6.	4.	1. D	6.	8.	2.	10.	17. J	14. L	13.	12.	3.
5. B	12.	9.	17. F	3.	1. H	15.	5. I	13.	6.	11.	1. P
11.	13.	8.	11.	10.	13.	3.	9.	1. K	14. N	16.	8.
15.	14. C	10.	9.	12.	18.	6.	12.	4.	4.	18.	7.
17. A	3.	7.	7.	16.	14. G	7.	2.	16.	9.	17. O	2.
16.	2.	18.	5. E	4.	15.	8.	11.	18.	5. M	10.	15.

N ↑

Undulating Slope

--- 5 % down slope ----->

Vaccum extractors are located at sites **A** through **P**.
Neutron probe access tubes are located at sites **D**,**H**,**K**,and**P**.

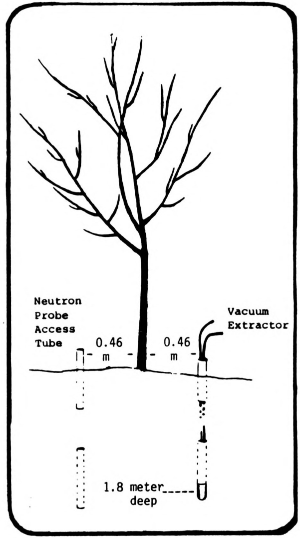


Figure 8. Vacuum Extractor and Neutron Probe Access Tube Placement

Collection of soil water samples began on September 9, 1983 and proceeded until October 4, 1984. The duration of applied vacuum varied throughout the year with relative ability to get into the orchard.

To evaluate soil nitrogen in the root zone, soil samples were collected on May 6, 1984, prior to the first fertilizer injection application. Each sample was a composite of four subsamples taken equidistant from the tree trunk. The samples were taken from the soil profile between 0.15 - 0.30 m (0.5 - 1.0 ft) in depth, at both 0.38 and 0.76 m (1.25 and 2.5 ft) from the trunk. Control, surface fall applied, surface spring split, and trickle applied nitrogen treatments were evaluated in this manner.

Soil moisture was evaluated in the research plot with a neutron probe. Four access tubes were installed near the vacuum extractor, one within the control (treatment 1) of each block (Figure 8). The site calibration curve appears in the appendices along with a field data sheet developed for neutron probe data. Neutron probe readings were taken at 0.15 m (0.5 ft) intervals within the profile to a depth of approximately 1.8 m (6 ft).

Since the research station is part of the NOAA National Weather Service network, daily records of precipitation were available. These appear along with records of irrigation in the appendices.

C. ANALYSIS TECHNIQUES

Analysis techniques include 1) laboratory procedures for extraction of raw data from field samples, and 2) statistical analysis and presentation of results. Raw data may be found in the appendices.

1. Laboratory procedures

Leaf samples collected in August were air dryed until October. Samples were then further dried in an oven at 105 degrees Celcius for 12 hours, ground in a mill and passed through a 40 mesh screen. Two seperate subsamples were weighed out from each sample.

The first subsample was dry-ashed, dissolved in nitric acid, filtered, and anlayzed spectrographically at the Michigan State University Soil Analysis Laboratory for Phosphorus, Potassium, Calcium, Magnesium, Manganese, Iron, Zinc, Copper and Boron. The second subsample was digested by the macro-Kjeldahl method and anlayzed colorimetrically for total nitrogen at the Michigan State University Soil Analysis Laboratory.

Soil water samples remained frozen until the day prior to laboratory analysis. Concentration of nitrate plus nitrite was determined colorimetrically on a Technicon auto-analyzer (Technicon 1973). Samples collected from September 10, 1983 to November 21, 1983 were analyzed on December 15, 1983. Samples collected from December, 1983 through May 6, 1984 were analyzed on May 9, 1984. The remaining samples were analyzed on November 16, 1984.

Soil samples were extracted with saturated calcium sulfate and the leachate analyzed for ammonium and nitrate concentration (Technicon 1973).

2. Statistical Analysis

Analysis of variance for a randomized complete block design was done for trunk diameter increases, terminal growth, and 10 different leaf nutrients to determine if there were significant differences among treatments. Duncan's multiple range test was then used to separate means at the 5 % level of significance. Appendix C gives the statistical model and a sample of the Duncan's test results.

IV. RESULTS, ANALYSIS AND DISCUSSION

A. TREE RESPONSE

1. Leaf Analyses

Leaf nutrient analysis was the most sensitive indicator of tree response. Leaf nutrients are shown in Table 3 with mean seperation by Duncan's multiple range test (Steel and Torrie, 1980 ;Little and Hills, 1978).

There were no significant differences in leaf nitrogen among method of application, timing or amount of nitrogen applied. However, leaf nitrogen increased as nitrogen fertilization rate increased (Figure 9a), and the highest leaf nitrogen occured for treatments in which multiple spring nitrogen applications were made (Figure 9b). The medium and high rate trickle treatments had more leaf nitrogen than any other treatment. They were not significantly different from most fertilized treatments, however.

There was a significant difference between all nitrogen fertilizer treatments and the control. Table 19 in Appendix A compares leaf nutrients in this study to the standards for cherries in Michigan as established by Kenworthy (1979).

The relatively high nitrogen levels found in the leaves at all nitrogen treatment rates (low, medium and high)

Table 3. Leaf Nutrients

	Major Elements in Percent					Minor Elements in ppm				
Tmt	N z	P	K	Ca	Mg	Mn	Fe	Cu	B	Zn
1	2.76 d	.21ab	1.51bc	1.31cd	.45abc	43e	61d	9b	32a	12ab
2	2.85d	.23a	1.77a	1.30d	.42c	41e	65cd	9b	32ab	11ab
3	2.69d	.22a	1.59abc	1.35bcd	.48abc	45de	63bcd	10ab	30abc	12ab
4	3.29abc	.20bcd	1.37c	1.57a	.52a	58cde	69abcd	11a	28abcd	12ab
5	3.21abc	.17d	1.37c	1.50ab	.47abc	86abc	63bcd	9b	24d	11b
6	3.26abc	.17cd	1.51bc	1.51ab	.47abc	103ab	70abcd	10ab	24d	11ab
7	3.26abc	.19bcd	1.68ab	1.48abcd	.48abc	64cde	69abcd	10ab	26bcd	12ab
8	3.16c	.18cd	1.44bc	1.43abcd	.47abc	81abc	72ab	10ab	25cd	12ab
9	3.34abc	.17cd	1.43bc	1.52ab	.50abc	105ab	70abcd	10ab	24d	13a
10	3.20bc	.18cd	1.51bc	1.44abcd	.46abc	86abc	74a	10ab	23d	12ab
11	3.21abc	.17d	1.35c	1.54ab	.50ab	78abcd	68abcd	9b	23d	11b
12	3.33abc	.17bcd	1.39c	1.50ab	.48abc	111a	67abcd	9ab	24d	12ab
13	3.28abc	.18cd	1.35c	1.55a	.50ab	89abc	69abcd	9ab	24d	12ab
14	3.29abc	.18cd	1.47bc	1.54ab	.50abc	91abc	69abcd	10ab	25cd	13ab
15	3.31abc	.17cd	1.57abc	1.38abcd	.44bc	102ab	66abcd	10ab	24d	12ab
16	3.29abc	.20abc	1.44bc	1.46abcd	.48abc	63cde	70abcd	10ab	29abcd	12ab
17	3.47a	.19bcd	1.42bc	1.49abc	.47abc	84abc	72abc	10ab	27abcd	13ab
18	3.45ab	.19bcd	1.39c	1.40abcd	.45abc	72bcde	73ab	10ab	26bcd	13ab

Treatments 1 - 3 CONTROL 10 - 12 FALL/SPRING SPLIT
Treatments 4 - 6 SURFACE FALL 13 - 15 SPRING SPLIT
Treatments 7 - 9 SURFACE SPRING 16 - 18 TRICKLE APPLIED

z Mean separation within columns by Duncan's Multiple Range Test, 5 % level. Values with the same letter are not significantly different.

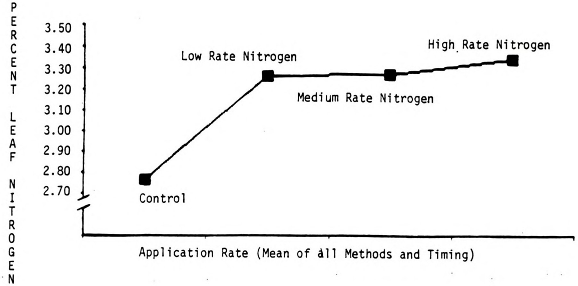


Figure 9a. Leaf Nitrogen for Control, Low, Medium, and High Rate Nitrogen Application Treatments

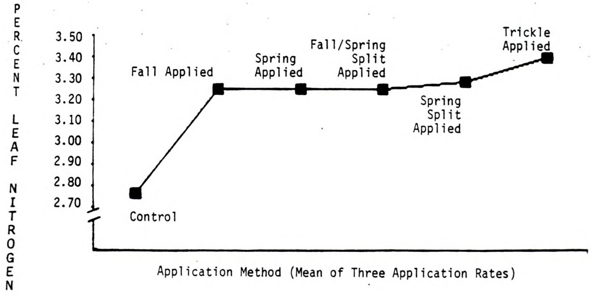


Figure 9b. Leaf Nitrogen for Each Application Method (Mean of Three Rates)

indicates the presence of residual nitrogen in the soil and in the tree during the course of this experiment, and suggests that the rate of nitrogen which is one half of the currently recommended rate may be higher than necessary for young trees without any crop load. Cropping will likely reduce these levels considerably in future years.

There were some significant differences in leaf phosphorus content among treatments. Leaves from control trees were significantly higher in phosphorus than in all nitrogen fertilizer treatments. Within nitrogen treatments, leaf phosphorus was greater under low nitrogen rates than in medium or high rate treatments, except in the spring split blocks. This is likely due to the larger leaf size on fertilized trees. Leaf size was not evaluated in this study.

There were also significant differences in leaf manganese between nitrogen fertilized trees and control trees, as well as among fertilizer treatments. Leaves from control trees had a significantly lower level of manganese than rate nitrogen treatments had higher leaf manganese than low or medium rates, except where nitrogen was applied through the trickle system. In this case, the effect of nitrogen rate on leaf manganese was not seen. This can probably be explained by the acidifying effect of the ammonium nitrate in the root zone, since availability of manganese is increased by reducing pH. One would expect the extent of the acidifying effect to be less for nitrogen

applied through the trickle system, since it is likely that less soil volume was acidified by trickle applied nitrogen than by that surface applied. This is one explanation for the apparent lack of effect under trickle applied nitrogen treatments.

Some significant differences were found among treatments in leaf potassium, calcium, magnesium, boron, iron, copper and zinc.

2. Terminal Growth and Trunk Diameter Growth

Terminal growth and trunk diameter growth measurements for 1983 and 1984 are shown in Table 4 with mean separation by Duncan's multiple range test. The data show that fertilized trees in general had more terminal growth and trunk growth, but that nitrogen application practice had no consistent effect. Significant differences in terminal growth measurement among the nitrogen treatments, and between nitrogen treatments and the control in 1983 and 1984 are not consistent. With the exception of control Treatment # 2, control trees had less terminal growth.

No significant differences existed in trunk diameter increases among any treatments in 1983. In 1984, nitrogen fertilized trees grew more, but growth was not always significantly greater than for control treatments. It appears that differences in trunk growth were suppressed by residual nitrogen in 1983. In 1984, trunk growth differences were just starting to be expressed.

Table 4. Terminal Growth and Trunk Growth in cm(in)

Trmt #	Terminal Growth 1983	Terminal Growth 1984	Trunk Diameter Growth 1983	Trunk Diameter Growth 1984
1	43.5(17.8)[z] c	46.9(19.4) c	1.5(.61)a	1.4(.62) c
2	48.1(18.9)abc	52.1(20.5)abc	1.6(.63)a	1.7(.67)abc
3	44.3(17.4) bc	49.0(19.3) bc	1.6(.61)a	1.5(.59) c
4	47.9(18.9)abc	54.0(21.3)abc	1.7(.67)a	1.8(.72)a
5	50.3(19.8)abc	53.1(20.9)abc	1.8(.71)a	1.7(.68)a
6	49.9(19.6)abc	51.0(20.1)abc	1.8(.69)a	1.8(.72)a
7	51.7(20.3)a	56.3(22.2)a	1.8(.72)a	1.9(.74)a
8	51.6(20.3)a	52.2(20.5)abc	1.8(.71)a	1.8(.71)ab
9	48.3(19.0)abc	50.5(19.9)abc	1.6(.65)a	1.7(.66)abc
10	48.4(19.1)abc	51.3(20.2)abc	1.7(.69)a	1.7(.67)abc
11	52.4(20.6)a	50.1(19.7)abc	1.8(.72)a	1.7(.66)abc
12	47.4(18.7)abc	48.5(19.1) bc	1.7(.68)a	1.9(.73)a
13	49.5(19.5)abc	49.4(19.4)abc	1.8(.70)a	1.7(.66)abc
14	48.2(19.0)abc	51.4(20.2)abc	1.7(.68)a	1.7(.65)abc
15	47.2(18.6)abc	53.0(20.9)abc	1.6(.65)a	1.7(.67)abc
16	49.6(19.5)abc	54.9(21.6)ab	1.8(.73)a	1.9(.74)a
17	48.0(18.9)abc	52.5(20.7)abc	1.6(.61)a	1.7(.67)abc
18	50.8(20.0)ab	54.4(21.4)ab	1.7(.69)a	1.8(.70)ab

Treatments 1 - 3 CONTROL; 10 - 12 FALL/SPRING SPLIT
Treatments 4 - 6 SURFACE FALL; 13 - 15 SPRING SPLIT
Treatments 7 - 9 SURFACE SPRING; 16 - 18 TRICKLE APPLIED

[z] Mean separation within columns by Duncan's multiple range test, 5% level. Values with the same letter are not significantly different.

3. Yield

No significant differences existed in yield among nitrogen treatments, or between nitrogen treatments and control. However, 1984 was the first year that any of the trees bore fruit. Some control trees appeared to fruit heavily, perhaps due to stress from lack of nitrogen. The

lack of yield differences is consistent with Tukey (1927). It is expected that yield effects will arise as the trees mature.

4. General Observations

One of the most notable differences among treatments was observed in leaf color. Leaves from control treatments were pale to yellow green. This condition, typical of nitrogen stressed trees, was more apparent in 1984 than in 1983, and seemed to become more apparent as the 1984 season progressed. No differences in leaf color were seen among fertilized treatments. No attempt was made to quantify this, or any other general observation, although photographs were taken to record some of the visible trends.

B. NITROGEN BALANCE

Qualitative evaluation of the nitrogen balance requires analysis of 1) soil water nitrate concentration below the root zone over time, 2) soil moisture, irrigation and precipitation, and 3) an appraisal of soil nitrate and ammonium within the root zone. The objective of this portion of the study was to evaluate soil water nitrate concentration below the root zone. The other parameters are used only to supplement discussion and aid in formulating conclusions.

The concentration of nitrate at 1.8 m (6 ft) over the course of the year for control, fall applied, spring applied, and trickle applied treatments is illustrated in

Figures 10a through 14a. It should be noted that plots for control, fall, and trickle applied treatments represent an average of three sites. The spring split plot represents an average of four sites. It should also be noted that the nitrate concentrations from Figures 10a - 14a do not imply specific values for nitrate concentration in groundwater. No attempt was made in this study to quantitatively measure or predict the nitrate concentration of groundwater under the nitrogen application treatments. However, a great deal of dilution would occur and the concentration of nitrate actually entering groundwater from these plots would be much less than the concentration found in soil water at 1.8 m (6 ft), which is illustrated in these plots.

Rainfall, irrigation and estimated snowmelt around the period of sampling appears in Figures 10b - 14b. Rainfall is illustrated as a semi-monthly total for the first and second half of each month. Estimated snowmelt is based upon 12.7 cm (5 in) of snowmelt being equivalent to 2.54 cm (1 in) of water applied for purposes of visual comparison. For freshly fallen snow this ratio was decreased to approximately ten to one. Liters of irrigation water was converted to centimeters using an area for the root zone of 2.6 m^2 (28 ft^2) (Kesner, 1981). The appendices contain a summary of rainfall, snowfall, irrigation, and fertilization records at the site, as well as results of soil sample nitrogen analysis.

Soil samples showed that very little nitrogen as

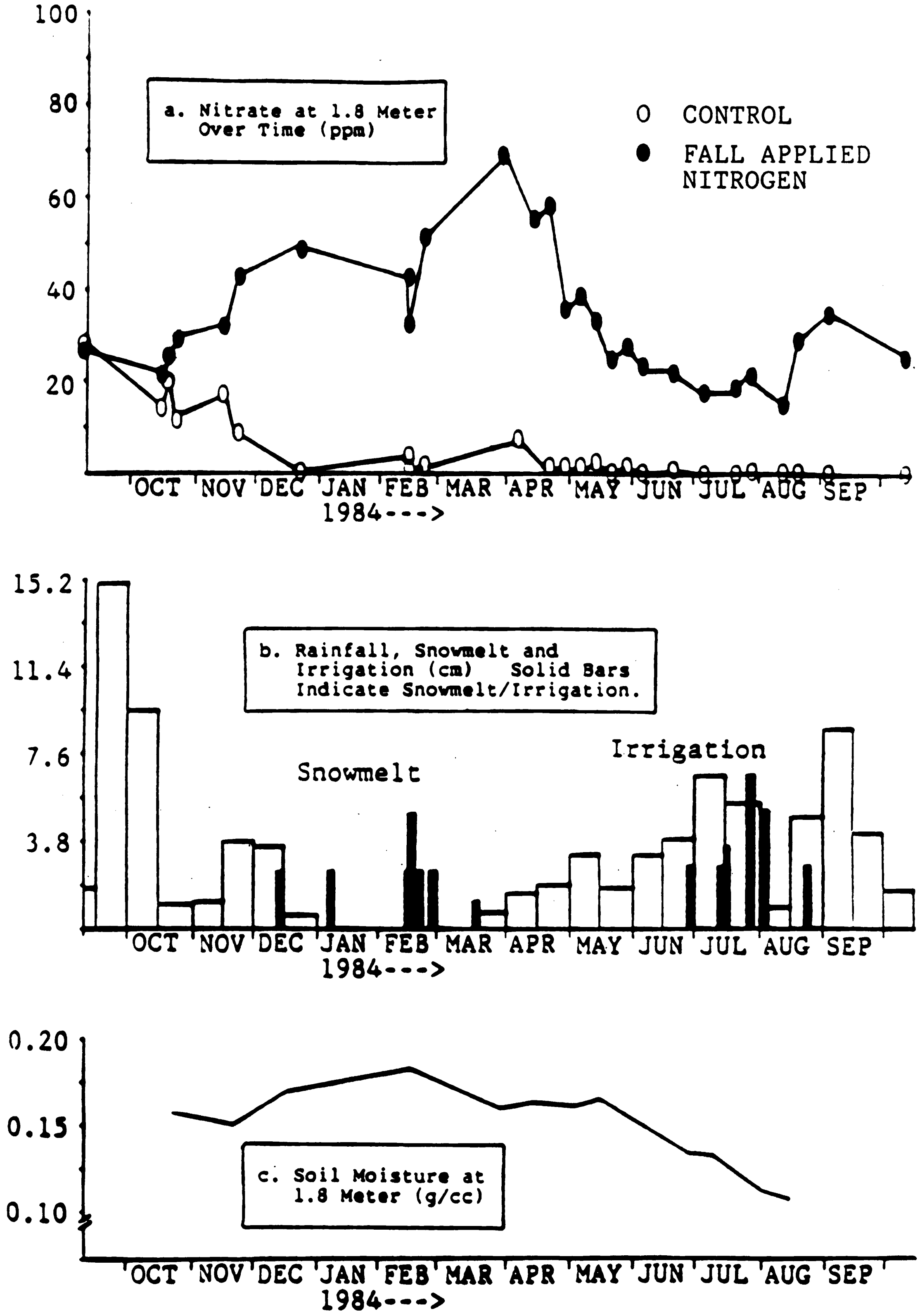


Figure 10. Nitrate Movement Under Control and Fall Applied Nitrogen Treatments

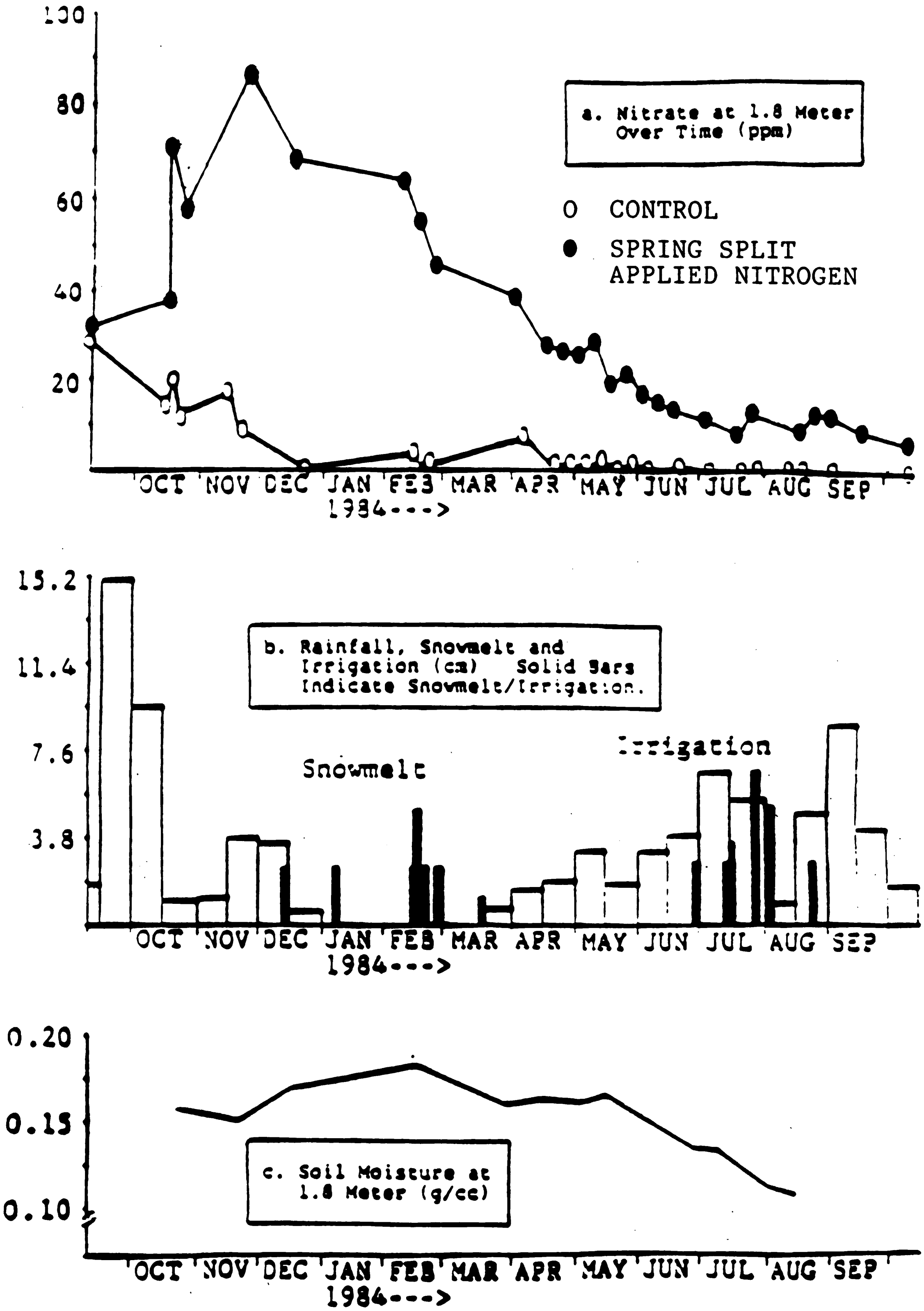


Figure 11. Nitrate Movement Under Control and Spring Split Applied Nitrogen Treatments

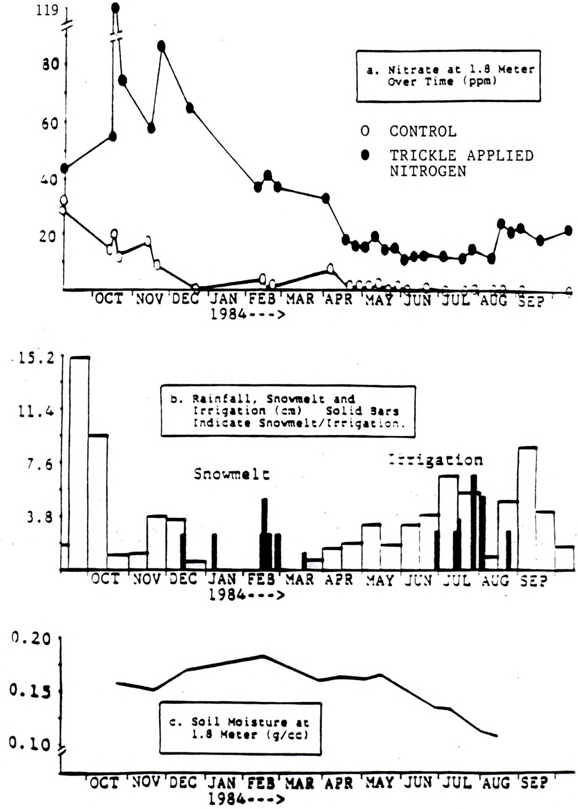


Figure 12. Nitrate Movement Under Control and Trickle Applied Nitrogen Treatments

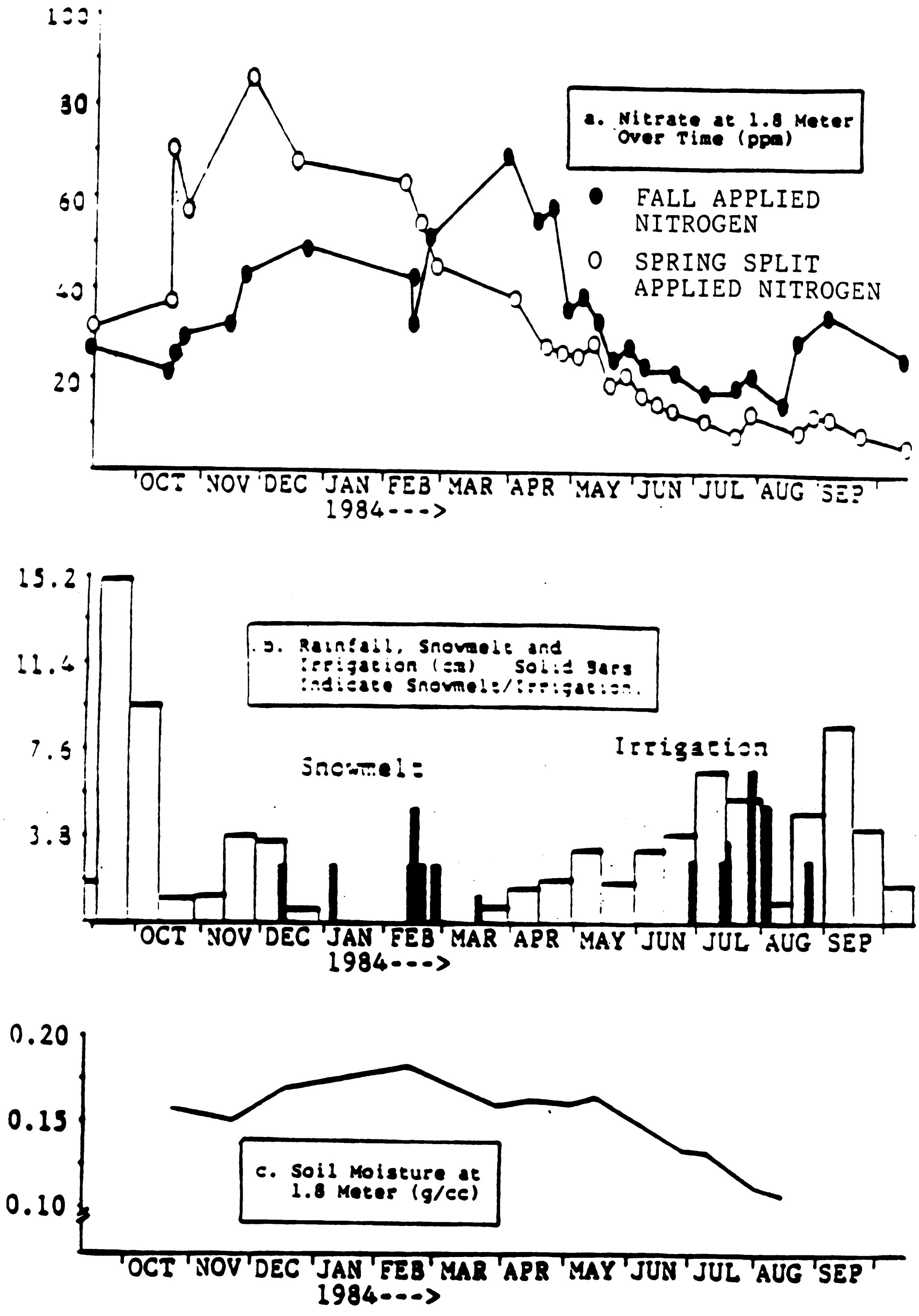


Figure 13. Nitrate Movement Under Fall Applied and Spring Split Applied Nitrogen Treatments

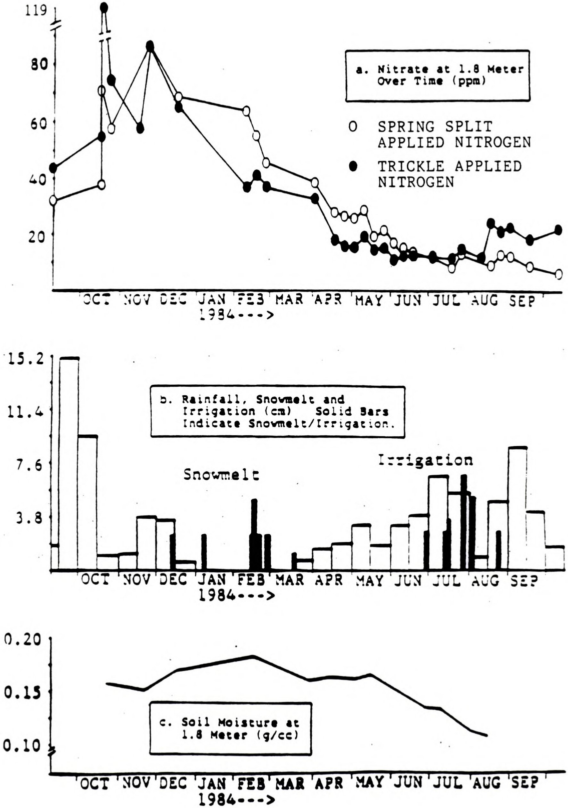


Figure 14. Nitrate Movement Under Spring Split Applied and Trickle Applied Nitrogen Treatments

nitrate or ammonium remained within the root zone after one year following injection under the trickle irrigation application treatments. Soil nitrogen within the root zone under trickle nitrogen application treatments was about the same as under control treatments when soil sampling was done on May 6. More nitrogen had remained within the root zone under surface applied treatments. The spring split applied treatment had more nitrogen within the root zone than did the fall applied because application had been made about one month previous to soil sampling.

Figures 10c - 14c show the soil moisture at 1.8 m (6 ft) as determined by neutron probe moisture analysis. Readings were taken through August 19, 1984. It is interesting to note that in all cases, as soil moisture at 1.8 m (6 ft) decreases, the nitrate concentration at 1.8 m (6 ft) also decreases. Water movement from the surface is apparently not sufficient during this time to carry nitrate beyond the root zone.

One concern in this research was that when soil moisture at 1.8 m (6 ft) dropped below field capacity, the water samples collected in the vacuum extractors would give artificially high nitrate concentrations. This apparently did not occur, previous to August 19, 1984, since moisture never went below approximately 11% on a dry weight basis. Field capacity for a sand is normally closer to 6% moisture on a dry weight basis. Nitrate concentrations did rise rapidly at one extractor site later in the summer (see appendices), but the volume of sample collected remained high and precipitation was significant throughout the same period. Therefore, the effect of low soil moisture upon the measured nitrate concentration is considered to be minimal. The effect is negligible when compared with the much greater effects brought on by fertilizer application and water movement through the profile. For reference, soil moisture profiles evaluated periodically to 1.8 m (6 ft) deep at the four sites studied appear in the appendices.

In all cases, more nitrate occurred below the root zone under the medium rate nitrogen treatments than under the control. The highest nitrate concentration under the fall applied nitrogen treatment occurred in March. For the spring applied treatments, the peak came in November. Fertilizer was applied to the fall treatments in November, 1982, and to the spring split treatments in March and June of 1983. Trickle applied nitrogen was applied in May - July of 1983.

Some portion of the surface fall applied nitrogen had already leached beyond the root zone by March, well ahead of active root growth under Michigan conditions. Tree roots had little opportunity to take up this nitrogen since there is almost no root activity from November to March. Spring surface applied nitrogen also leached to the 1.8 m (6 ft) level but the peak came in November. Active root growth had occurred during this leaching period.

In every case, the nitrate concentration at 1.8 m (6 ft) reached a low point in May and remained low throughout the summer. This was probably due to the fact that relatively little water moved beyond the root zone during this period. The highest concentrations of nitrate at 1.8 m (6 ft) under all fertilizer treatments occurred from late October to late April.

Nitrate concentration at 1.8 m (6 ft) appears to be very dependent upon water applied to the surface as rain, snowmelt and irrigation. This is best illustrated in Figures 13 and 14, as the nitrate concentration fluctuates after periods of heavy water application for fall, spring split and trickle applied treatments.

The spring split nitrogen treatment and the trickle treatment followed approximately the same pattern of nitrate concentration over time (Figure 14). The relatively high concentration of nitrates found under the trickle applied nitrogen treatments in October may be due to nitrogen that was applied at a single point rather than banded around the tree.

At one lysimeter site not included in these plots, a high level of nitrate was detected at 1.8 m (6 ft) in late summer of 1984 (see appendices). The soil profile at this site was a uniform sand, without the clay and gravel layers found at the other sites. This is an important finding, since it indicates that nitrogen application through trickle irrigation systems may result in significant leaching losses on very sandy soils. Further research is needed on the movement of these high nitrogen "spikes".

V. CONCLUSIONS AND RECOMMENDATIONS

The objectives of the proposed research have been addressed in full. Tree response and nitrate concentration of soil water below the tree root zone were evaluated for control, fall surface applied, spring split surface applied, and trickle applied nitrogen application treatments. To achieve the overall goal of promoting optimal growth and vigor of tart cherry trees and minimal nitrate contamination of groundwater from nitrogen fertilizers under Northwest Michigan conditions, the effects of nitrogen application practices on tart cherry tree response and nitrate movement under trickle irrigation have been shown.

The specific conclusions of the research are:

1. Nitrogen fertilizer application by injection through trickle irrigation systems is a viable alternative to surface application in terms of tart cherry tree response.

2. Nitrogen application at one half the medium recommended rate for four year old cherry trees provided yield, leaf analysis and growth response equivalent to that provided by the medium recommended rate and twice the medium recommended rate.

3. Nitrogen application rates to young tart cherry trees on sandy loam soil under herbicide strip orchard floor management can be reduced regardless of method and timing of application.

4. Movement of nitrogen beyond the tree root zone does occur under fall and spring split surface applied and trickle irrigation applied nitrogen fertilizer application practices, at the medium nitrogen application rate recommended for three and four year old cherry trees.

5. Surface applied nitrogen fertilizer applied in November moves beyond the root zone during the winter when uptake by the tree is minimal.

6. Nitrogen fertilizer applied in the spring does not move beyond the root zone until fall and is within the root zone when uptake is greatest.

7. The pattern of nitrate movement over time is similar for spring split surface applied and trickle irrigation applied nitrogen fertilizer.

Recommendations for further research are:

1. Continue the present treatments until the trees are in full fruit production.

2. Continue to investigate the extent to which nitrogen application rates to cherries can be reduced.

3. Quantitatively determine the nitrogen balance in the fruit tree environment under conventional and trickle applied nitrogen application practices.

4. Continue to study the movement and distribution of nitrogen emitted from a trickle source under orchard conditions, especially with emphasis on rate of application, and number, type, and location of emitters.

APPENDICES

APPENDIX A

Tree Response Data

Tree Response Data

Table 5. Percent Leaf Nitrogen (1984).

Treatment	#	Block I	Block II	Block III	Block IV	Trmt mean
CONTROL	1	2.65	2.65	2.70	3.05	2.76
"	2	3.00	2.84	2.55	3.00	2.85
"	3	2.80	2.75	2.30	2.90	2.69
FALL APPLIED						
low N	4	3.20	3.30	3.40	3.25	3.29
medium N	5	3.10	3.30	3.30	3.15	3.21
High N	6	3.35	3.25	3.05	3.40	3.26
SPRING APPLIED						
low N	7	3.25	3.15	3.25	3.40	3.26
medium N	8	3.10	3.00	3.25	3.30	3.16
High N	9	3.10	3.40	3.40	3.45	3.34
FALL/SPRING SPLIT						
low N	10	3.19	3.10	3.10	3.40	3.20
medium N	11	3.10	3.20	3.25	3.30	3.21
High N	12	2.95	3.60	3.35	3.40	3.33
SPRING SPLIT						
low N	13	3.20	3.35	3.25	3.30	3.28
medium N	14	3.20	3.55	3.35	3.05	3.29
High N	15	3.30	3.55	3.05	3.35	3.31
TRICKLE APPLIED						
low N	16	3.50	3.10	3.35	3.20	3.29
medium N	17	3.40	3.45	3.60	3.45	3.47
High N	18	3.45	3.40	3.40	3.55	3.45
Block Means		3.16	3.22	3.16	3.27	
Grand Mean		3.20				

Control mean	2.77	Low rate mean	3.26
Fall applied mean	3.25	Medium rate mean	3.27
Spring Applied mean	3.25	High rate mean	3.34
Fall/Spring Split mean	3.25		
Spring Split mean	3.29		
Trickle Applied mean	3.40		

Table 6. Percent Leaf Phosphorus (1984)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt mean
CONTROL	1	0.203	0.170	0.219	0.264	0.214
"	2	0.225	0.183	0.221	0.274	0.226
"	3	0.225	0.204	0.196	0.274	0.225
FALL APPLIED						
low N	4	0.202	0.209	0.180	0.194	0.196
medium N	5	0.155	0.179	0.171	0.172	0.169
High N	6	0.172	0.170	0.177	0.174	0.173
SPRING APPLIED						
low N	7	0.182	0.179	0.185	0.231	0.194
medium N	8	0.159	0.161	0.186	0.206	0.178
High N	9	0.151	0.174	0.166	0.199	0.172
FALL/SPRING SPLIT						
low N	10	0.182	0.177	0.166	0.209	0.183
medium N	11	0.148	0.167	0.157	0.210	0.170
High N	12	0.153	0.202	0.162	0.181	0.175
SPRING SPLIT						
low N	13	0.182	0.177	0.155	0.204	0.179
medium N	14	0.176	0.205	0.175	0.166	0.181
High N	15	0.155	0.192	0.160	0.184	0.173
TRICKLE APPLIED						
low N	16	0.199	0.222	0.178	0.210	0.202
medium N	17	0.164	0.190	0.190	0.208	0.188
High N	18	0.182	0.206	0.183	0.194	0.191
Block Means		0.179	0.187	0.179	0.209	
Grand mean		0.188				

Control mean	0.222	Low rate mean	0.191
Fall applied mean	0.180	Medium rate mean	0.177
Spring Applied mean	0.182	High rate mean	0.177
Fall/Spring Split mean	0.176		
Spring Split mean	0.178		
Trickle Applied mean	0.194		

Table 7. Percent Leaf Potassium (1984)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt mean
CONTROL	1	1.59	1.35	1.34	1.77	1.51
"	2	1.80	1.51	1.65	2.11	1.77
"	3	1.61	1.62	1.29	1.83	1.59
FALL APPLIED						
low N	4	1.40	1.55	1.18	1.34	1.37
medium N	5	1.46	1.61	1.14	1.29	1.37
High N	6	1.50	1.49	1.42	1.62	1.51
SPRING APPLIED						
low N	7	1.68	1.83	1.59	1.64	1.68
medium N	8	1.35	1.46	1.50	1.43	1.44
High N	9	1.47	1.50	1.50	1.23	1.43
FALL/SPRING SPLIT						
low N	10	1.61	1.40	1.40	1.62	1.51
medium N	11	1.32	1.33	1.42	1.35	1.35
High N	12	1.38	1.74	1.27	1.18	1.39
SPRING SPLIT						
low N	13	1.46	1.37	1.27	1.32	1.35
medium N	14	1.61	1.69	1.38	1.22	1.47
High N	15	1.25	1.71	1.54	1.78	1.57
TRICKLE APPLIED						
low N	16	1.48	1.77	1.26	1.26	1.44
medium N	17	1.34	1.47	1.28	1.60	1.42
High N	18	1.45	1.51	1.19	1.41	1.39
Block Means		1.49	1.55	1.37	1.50	
Grand Mean		1.48				

Control mean	1.62	Low rate mean	1.47
Fall applied mean	1.42	Medium rate mean	1.41
Spring Applied mean	1.52	High rate mean	1.46
Fall/Spring Split mean	1.42		
Spring Split mean	1.47		
Trickle Applied mean	1.42		

Table 8. Percent Leaf Calcium (1984)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt mean
CONTROL	1	1.34	1.28	1.40	1.23	1.31
"	2	1.47	1.35	1.38	1.01	1.30
"	3	1.44	1.42	1.29	1.25	1.35
FALL APPLIED						
low N	4	1.38	1.47	1.78	1.66	1.57
medium N	5	1.52	1.57	1.36	1.56	1.50
High N	6	1.61	1.63	1.38	1.43	1.51
SPRING APPLIED						
low N	7	1.46	1.56	1.61	1.28	1.48
medium N	8	1.50	1.59	1.48	1.15	1.43
High N	9	1.43	1.56	1.56	1.55	1.52
FALL/SPRING SPLIT						
low N	10	1.44	1.55	1.45	1.31	1.44
medium N	11	1.54	1.59	1.51	1.52	1.54
High N	12	1.47	1.40	1.54	1.57	1.50
SPRING SPLIT						
low N	13	1.45	1.60	1.63	1.53	1.55
medium N	14	1.44	1.47	1.62	1.63	1.54
High N	15	1.41	1.55	1.36	1.19	1.38
TRICKLE APPLIED						
low N	16	1.32	1.69	1.47	1.38	1.46
medium N	17	1.52	1.62	1.40	1.40	1.49
High N	18	1.43	1.45	1.28	1.45	1.40
Block Means		1.45	1.52	1.47	1.39	
Grand Mean		1.46				

Control mean	1.32	Low rate mean	1.50
Fall applied mean	1.53	Medium rate mean	1.50
Spring Applied mean	1.48	High rate mean	1.46
Fall/Spring Split mean	1.49		
Spring Split mean	1.49		
Trickle Applied mean	1.45		

Table 9. Percent Leaf Magnesium (1984)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
CONTROL	1	0.471	0.422	0.528	0.398	0.455
"	2	0.462	0.412	0.511	0.312	0.424
"	3	0.506	0.466	0.557	0.386	0.479
FALL APPLIED						
low N	4	0.557	0.475	0.530	0.515	0.519
medium N	5	0.500	0.468	0.483	0.439	0.473
High N	6	0.518	0.535	0.467	0.370	0.473
SPRING APPLIED						
low N	7	0.490	0.499	0.491	0.427	0.477
medium N	8	0.519	0.494	0.462	0.413	0.472
High N	9	0.490	0.534	0.468	0.500	0.498
FALL/SPRING SPLIT						
low N	10	0.468	0.532	0.444	0.399	0.461
medium N	11	0.520	0.552	0.415	0.517	0.501
High N	12	0.483	0.468	0.468	0.512	0.483
SPRING SPLIT						
low N	13	0.499	0.566	0.433	0.522	0.505
medium N	14	0.503	0.531	0.435	0.516	0.496
High N	15	0.519	0.482	0.401	0.364	0.442
TRICKLE APPLIED						
low N	16	0.493	0.522	0.450	0.457	0.480
medium N	17	0.507	0.503	0.444	0.429	0.471
High N	18	0.469	0.504	0.449	0.397	0.455
Block Means		0.499	0.498	0.469	0.437	
Grand Mean		0.476				

Control mean	0.453	Low rate mean	0.488
Fall applied mean	0.488	Medium rate mean	0.483
Spring Applied mean	0.482	High rate mean	0.470
Fall/Spring Split mean	0.482		
Spring Split mean	0.481		
Trickle Applied mean	0.469		

Table 10. Leaf Manganese in ppm (1984)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
CONTROL	1	48.80	46.00	47.70	28.50	42.75
"	2	52.50	42.10	32.90	35.50	40.75
"	3	56.20	45.60	46.00	32.00	44.95
FALL APPLIED						
low N	4	63.50	60.00	68.20	38.80	57.62
medium N	5	117.00	74.90	101.00	51.70	86.15
High N	6	94.90	134.00	88.80	92.50	102.55
SPRING APPLIED						
low N	7	71.90	79.80	65.00	37.60	63.57
medium N	8	96.50	123.00	53.50	50.20	80.80
High N	9	79.70	129.00	141.00	70.70	105.10
FALL/SPRING SPLIT						
low N	10	79.20	112.00	101.00	51.00	85.80
medium N	11	116.00	86.30	44.30	66.20	78.20
High N	12	124.00	138.00	85.60	97.10	111.18
SPRING SPLIT						
low N	13	99.10	103.00	76.30	78.70	89.27
medium N	14	102.00	72.10	132.00	59.70	91.45
High N	15	156.00	72.10	120.00	59.60	101.93
TRICKLE APPLIED						
low N	16	81.50	59.90	57.00	52.70	62.77
medium N	17	109.00	65.90	107.00	55.70	84.40
High N	18	66.20	111.00	58.70	50.80	71.67
Block Mean		89.67	86.37	79.22	56.06	
Grand Mean		77.83				

Control mean	42.82	Low rate mean	71.81
Fall applied mean	82.11	Medium rate mean	84.20
Spring Applied mean	83.16	High rate mean	98.49
Fall/Spring Split mean	91.73		
Spring Split mean	94.22		
Trickle Applied mean	72.95		

Table 11. Leaf Copper in ppm (1984)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
CONTROL	1	10.70	7.81	8.73	9.30	9.13
"	2	10.50	8.17	8.70	9.64	9.25
"	3	9.80	10.10	10.20	9.07	9.79
FALL APPLIED						
low N	4	11.00	14.90	9.32	9.18	11.10
medium N	5	9.07	10.70	8.78	8.56	9.28
High N	6	10.40	9.72	9.22	8.69	9.51
SPRING APPLIED						
low N	7	10.10	10.00	10.50	10.60	10.30
medium N	8	10.00	9.67	10.10	8.38	9.54
High N	9	9.78	9.69	9.51	9.93	9.73
FALL/SPRING SPLIT						
low N	10	10.60	9.39	8.70	10.70	9.85
medium N	11	9.58	9.15	9.07	9.28	9.27
High N	12	9.40	11.50	8.91	8.20	9.50
SPRING SPLIT						
low N	13	10.40	9.47	8.59	9.22	9.42
medium N	14	10.90	11.80	8.75	8.49	9.98
High N	15	8.23	11.60	8.75	9.63	9.55
TRICKLE APPLIED						
low N	16	10.50	10.50	8.30	8.91	9.55
medium N	17	10.10	10.00	9.36	9.56	9.76
High N	18	10.00	12.20	8.89	10.70	10.45
Block Mean		10.06	10.35	9.13	9.34	
Grand Mean		9.72				

Control mean	9.39	Low rate mean	10.04
Fall applied mean	9.96	Medium rate mean	9.57
Spring Applied mean	9.86	High rate mean	9.75
Fall/Spring Split mean	9.54		
Spring Split mean	9.65		
Trickle Applied mean	9.92		

Table 12. Leaf Boron in ppm (1984)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
CONTROL	1	31.70	24.70	42.30	31.20	32.48
"	2	30.90	27.70	34.30	33.40	31.58
"	3	31.70	30.90	26.00	33.10	30.43
FALL APPLIED						
low N	4	26.70	31.10	28.70	25.30	27.95
medium N	5	21.10	26.40	26.10	22.60	24.05
High N	6	24.60	26.20	23.80	22.80	24.35
SPRING APPLIED						
low N	7	24.70	27.00	25.50	26.20	25.85
medium N	8	25.30	22.70	28.30	22.20	24.62
High N	9	23.00	24.20	23.30	26.60	24.27
FALL/SPRING SPLIT						
low N	10	26.40	23.60	18.00	23.90	22.98
medium N	11	22.20	24.50	20.70	26.00	23.35
High N	12	21.80	29.00	21.60	23.70	24.02
SPRING SPLIT						
low N	13	25.60	24.20	21.90	24.70	24.10
medium N	14	25.00	28.60	24.50	22.90	25.25
High N	15	23.00	29.30	20.10	23.00	23.85
TRICKLE APPLIED						
low N	16	31.10	32.60	23.80	26.90	28.60
medium N	17	27.30	26.60	27.30	28.70	27.48
High N	18	24.50	32.20	26.70	22.00	26.35
Block Mean		25.92	27.31	25.72	25.84	
Grand mean		26.20				

Control mean	31.49	Low rate mean	25.90
Fall applied mean	25.45	Medium rate mean	24.95
Spring Applied mean	24.92	High rate mean	24.57
Fall/Spring Split mean	23.45		
Spring Split mean	24.40		
Trickle Applied mean	27.47		

Table 13. Leaf Iron in ppm (1984)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
CONTROL	1	64.40	58.80	61.70	57.60	60.62
"	2	68.80	55.30	59.20	63.90	61.80
"	3	69.50	61.20	65.60	56.40	63.17
FALL APPLIED						
low N	4	76.60	71.00	63.00	67.00	69.40
medium N	5	65.70	62.30	66.90	58.50	63.35
High N	6	74.70	77.00	69.20	60.90	70.45
SPRING APPLIED						
low N	7	70.30	64.00	72.40	67.80	68.62
medium N	8	62.20	76.20	77.40	73.40	72.30
High N	9	66.90	70.90	70.00	71.60	69.85
FALL/SPRING SPLIT						
low N	10	69.60	67.20	71.20	89.70	74.42
medium N	11	66.90	65.30	60.10	80.20	68.12
High N	12	62.80	70.40	62.40	71.00	66.65
SPRING SPLIT						
low N	13	71.60	63.60	57.90	83.90	69.25
medium N	14	68.10	76.40	64.10	66.70	68.83
High N	15	64.00	68.60	65.00	65.80	65.85
TRICKLE APPLIED						
low N	16	72.60	64.30	66.40	78.00	70.33
medium N	17	72.80	72.00	68.20	73.60	71.65
High N	18	71.00	75.40	67.10	78.40	72.97
Block Mean		68.81	67.77	65.99	70.24	
Grand mean		68.20				

Control mean	61.87	Low rate mean	70.41
Fall applied mean	67.73	Medium rate mean	68.85
Spring Applied mean	70.26	High rate mean	69.16
Fall/Spring Split mean	69.73		
Spring Split mean	67.98		
Trickle Applied mean	71.65		

Table 14. Leaf Zinc in ppm (1984)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
CONTROL	1	13.50	10.60	12.90	10.50	11.87
"	2	13.00	9.50	11.40	12.10	11.50
"	3	13.50	11.90	11.80	10.70	11.97
FALL APPLIED						
low N	4	12.30	13.10	11.40	11.30	12.02
medium N	5	10.90	12.40	11.20	9.50	11.00
High N	6	10.90	12.50	12.10	9.85	11.34
SPRING APPLIED						
low N	7	13.00	13.00	11.00	11.20	12.05
medium N	8	12.50	12.20	11.70	11.70	12.03
High N	9	11.40	13.10	14.50	15.00	13.50
FALL/SPRING SPLIT						
low N	10	11.90	13.50	11.40	12.80	12.40
medium N	11	10.80	10.10	9.79	12.30	10.75
High N	12	11.50	12.90	10.20	13.40	12.00
SPRING SPLIT						
low N	13	13.40	10.80	10.10	12.50	11.70
medium N	14	14.20	12.30	12.90	11.30	12.67
High N	15	11.60	12.80	10.70	12.00	11.78
TRICKLE APPLIED						
low N	16	12.90	11.70	10.10	12.80	11.87
medium N	17	13.50	11.00	15.20	11.80	12.87
High N	18	11.80	14.50	11.30		12.53
Block Mean		12.37	12.11	11.65	11.81	
Grand mean		11.99				

Control mean	11.78	Low rate mean	12.01
Fall applied mean	11.45	Medium rate mean	11.86
Spring Applied mean	12.53	High rate mean	12.23
Fall/Spring Split mean	11.72		
Spring Split mean	12.05		
Trickle Applied mean	12.43		

Terminal growth and trunk diameter was established by taking measurements on 5 of the 7 trees per treatment plot. The following tables contain values for a specific block and treatment number. Each value is an average of the measurements taken on five trees (10 - 15 actual measurements).

Table 15. Trunk Diameter Growth in 1983 (cm)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
CONTROL	1	1.48	1.44	1.52	1.70	1.53
"	2	1.80	1.36	1.58	1.66	1.60
"	3	1.56	1.64	1.38	1.62	1.55
FALL APPLIED						
low N	4	1.56	1.90	1.66	1.72	1.71
medium N	5	1.44	2.16	1.72	1.86	1.80
High N	6	1.62	1.80	1.98	1.65	1.76
SPRING APPLIED						
low N	7	1.66	1.74	1.88	2.10	1.84
medium N	8	1.60	1.78	1.88	2.00	1.81
High N	9	1.48	1.56	1.56	2.02	1.65
FALL/SPRING SPLIT						
low N	10	1.96	1.58	1.74	1.72	1.75
medium N	11	1.52	1.84	1.96	1.98	1.82
High N	12	1.56	1.82	1.78	1.78	1.73
SPRING SPLIT						
low N	13	1.68	1.68	1.92	1.88	1.79
medium N	14	1.78	1.74	1.58	1.80	1.72
High N	15	1.24	1.90	1.88	1.60	1.65
TRICKLE APPLIED						
low N	16	1.58	1.98	1.74	2.12	1.85
medium N	17	1.24	1.62	1.28	2.12	1.56
High N	18	2.10	1.40	1.54	1.96	1.75
Block Means		1.60	1.72	1.70	1.85	
Grand mean		1.72				

Control mean	1.56	Low rate mean	1.79
Fall applied mean	1.76	Medium rate mean	1.74
Spring Applied mean	1.77	High rate mean	1.71
Fall/Spring Split mean	1.77		
Spring Split mean	1.72		
Trickle Applied mean	1.72		

Table 16. Trunk Diameter Growth in 1984 (cm)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
Control	1	1.58	1.36	1.28	1.70	1.48
"	2	1.78	1.52	1.68	1.94	1.73
"	3	1.62	1.54	1.32	1.54	1.51
Fall Applied						
low N	4	1.56	2.08	1.80	1.88	1.83
medium N	5	1.54	1.96	1.68	1.70	1.72
High N	6	1.62	1.86	2.00	1.81	1.82
Spring Applied						
low N	7	1.70	1.68	1.96	2.16	1.87
medium N	8	1.60	1.80	1.80	2.02	1.80
High N	9	1.50	1.60	1.78	1.80	1.67
Fall/Spring Split						
low N	10	1.74	1.58	1.74	1.78	1.71
medium N	11	1.44	1.56	1.78	1.90	1.67
High N	12	1.54	1.84	2.18	1.88	1.86
Spring Split						
low N	13	1.68	1.64	1.64	1.70	1.67
medium N	14	1.60	1.76	1.46	1.80	1.66
High N	15	1.46	1.84	1.62	1.82	1.69
Trickle Applied						
low N	16	1.96	1.92	1.62	2.04	1.89
medium N	17	1.46	1.60	1.52	2.24	1.70
High N	18	2.14	1.56	1.40	2.08	1.79
Block Means		1.64	1.71	1.68	1.88	
Grand mean		1.73				

Control mean	1.57	Low rate mean	1.79
Fall applied mean	1.79	Medium rate mean	1.71
Spring Applied mean	1.78	High rate mean	1.77
Fall/Spring Split mean	1.75		
Spring Split mean	1.67		
Trickle Applied mean	1.79		

Table 17. 1983 Terminal Growth (cm)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
Control	1	42.17	42.40	38.97	50.47	43.50
"	2	51.94	45.62	47.00	47.72	48.07
"	3	48.39	46.43	37.64	44.58	44.26
Fall Applied						
low N	4	44.90	53.20	47.47	46.11	47.92
medium N	5	49.03	52.42	53.30	46.43	50.30
High N	6	45.73	50.29	53.23	50.33	49.89
Spring Applied						
low N	7	50.32	47.47	54.03	54.91	51.68
medium N	8	47.15	49.42	56.18	53.61	51.59
High N	9	46.70	45.14	47.62	53.62	48.27
Fall/Spring Split						
low N	10	49.76	43.77	47.74	52.34	48.40
medium N	11	49.53	50.26	56.67	53.07	52.38
High N	12	48.44	43.40	50.82	47.08	47.44
Spring Split						
low N	13	50.53	49.97	49.16	48.50	49.54
medium N	14	51.60	52.70	43.87	44.71	48.22
High N	15	40.17	53.27	46.87	48.35	47.16
Trickle Applied						
low N	16	46.46	52.13	49.97	49.97	49.64
medium N	17	37.81	51.03	42.83	60.50	48.04
High N	18	53.59	44.32	51.00	54.42	50.83
Block Means		47.46	48.51	48.58	50.37	
Grand mean		48.73				

Control mean	45.28	Low rate mean	49.44
Fall applied mean	49.37	Medium rate mean	50.11
Spring Applied mean	50.51	High rate mean	48.72
Fall/Spring Split mean	49.41		
Spring Split mean	48.31		
Trickle Applied mean	49.50		

Table 18. 1984 Terminal Growth (cm)

Treatment	#	Block I	Block II	Block III	Block IV	Trmt Mean
Control	1	46.03	44.73	45.24	51.72	46.93
"	2	52.97	48.06	50.29	57.25	52.14
"	3	52.61	48.46	43.17	51.64	48.97
Fall Applied						
low N	4	49.20	57.00	55.74	54.08	54.00
medium N	5	46.60	56.50	49.87	59.33	53.08
High N	6	49.15	50.36	54.32	50.17	51.00
Spring Applied						
low N	7	54.80	50.87	54.11	65.63	56.35
medium N	8	47.06	46.37	58.21	57.11	52.19
High N	9	46.87	48.89	49.69	56.50	50.49
Fall/Spring Split						
low N	10	55.06	48.17	47.76	54.41	51.35
medium N	11	44.16	50.29	52.43	53.57	50.11
High N	12	42.75	53.00	50.86	47.42	48.51
Spring Split						
low N	13	48.50	50.94	49.91	48.10	49.36
medium N	14	52.17	55.45	46.21	51.79	51.40
High N	15	45.67	57.40	48.00	61.09	53.04
Trickle Applied						
low N	16	55.14	54.70	53.41	56.34	54.90
medium N	17	46.25	52.28	49.67	61.76	52.49
High N	18	61.16	47.68	53.17	55.69	54.42
Block Means		49.79	51.18	50.67	55.20	
Grand mean		51.71				

Control Mean	49.35	Low rate mean	53.19
Fall Applied mean	52.69	Medium rate mean	51.85
Spring Applied mean	53.01	High rate mean	51.49
Fall/Spring mean	49.99		
Spring Split mean	51.27		
Trickle Applied mean	53.94		

Table 19. 1984 Measured Leaf Nutrients Compared With Kenworthy's Standard Values for Cherries

	N	P	K	Ca	Mg	Mn	Fe	Cu	B	Zn
Kenworthy Standard	2.95	.25	1.67	2.09	.68	150	203	47	50	30
Treatment										
1	2.76N	.21N	1.51N	1.31BN	.45BN	43BN	61S	9BN	32BN	12BN
2	2.85N	.23N	1.77N	1.30BN	.42BN	41BN	65S	9BN	32BN	11BN
3	2.69N	.22N	1.59N	1.35BN	.48BN	45BN	63S	10BN	30BN	12BN
4 low N	3.29N	.20BN	1.37N	1.57BN	.52BN	58BN	69BN	11BN	28BN	12BN
5 med N	3.21N	.17BN	1.37N	1.50BN	.47BN	86BN	63S	9BN	24BN	11BN
6 hi N	3.26N	.17BN	1.51N	1.51BN	.47BN	103BN	70BN	10BN	24BN	11BN
7 low N	3.26N	.19BN	1.68N	1.48BN	.48BN	64BN	69BN	10BN	26BN	12BN
8 med N	3.16N	.18BN	1.44N	1.43BN	.47BN	81BN	72BN	10BN	25BN	12BN
9 hi N	3.34N	.17BN	1.43N	1.52BN	.50BN	105BN	70BN	10BN	24BN	13BN
10 low N	3.20N	.18BN	1.51N	1.44BN	.46BN	86BN	74BN	10BN	23BN	12BN
11 med N	3.21N	.17BN	1.35N	1.54BN	.50BN	78BN	68BN	9BN	23BN	11BN
12 hi N	3.33N	.17BN	1.39N	1.50BN	.48BN	111N	67BN	9BN	24BN	12BN
13 low N	3.28N	.18BN	1.35N	1.55BN	.50BN	89BN	69BN	9BN	24BN	12BN
14 med N	3.29N	.18BN	1.47N	1.54BN	.50BN	91BN	69BN	10BN	25BN	13BN
15 hi N	3.31N	.17BN	1.57N	1.38BN	.44BN	102BN	66BN	10BN	24BN	12BN
16 low N	3.29N	.20N	1.44N	1.46BN	.48BN	63BN	70BN	10BN	29BN	12BN
17 med N	3.47N	.19BN	1.42N	1.49BN	.47BN	84BN	72BN	10BN	27BN	13BN
18 hi N	3.45N	.19BN	1.39N	1.40BN	.45BN	72BN	73BN	10BN	26BN	13BN

S = Shortage
BN = Below Normal
N = Normal
AB = Above Normal
E = Excess

Treatments 1 - 3 CONTROL
Treatments 4 - 6 SURFACE FALL APPLIED
Treatments 7 - 9 SURFACE SPRING APPLIED
Treatments 10 - 12 FALL/SPRING SPLIT
Treatments 13 - 15 SPRING SPLIT APPLIED
Treatments 16 - 18 TRICKLE APPLIED

APPENDIX B

Nitrate Movement Data

Table 20. Water Sample Nitrate Concentration for the Control Treatments (ppm)

BLOCK	1	2	3	4
TREATMENT	CONTROL	*	*	*
SITE	D	H	K	P
date				
09-10-83	27.90	38.90		
10-17-83	15.80	21.80	15.80	10.80
10-19-83	29.40	28.40	15.80	14.80
10-23-83	19.30	15.70	9.70	8.20
11-17-83	17.20	20.30		
11-21-83	21.30	19.80	2.20	2.20
12-19-83			1.23	1.21
02-11-84	8.95	19.35	0.97	0.94
02-14-84	3.47	32.27	1.03	1.10
02-22-84	2.52	22.01	1.24	1.30
03-31-84				
04-03-84	7.60	31.34		
04-16-84	1.54	27.61	0.62	0.24
04-21-84	1.83	26.68	0.34	0.10
04-30-84	1.56	24.68	0.31	0.27
05-06-84	1.16		0.40	0.06
05-11-84	2.03	24.70		
05-19-84	0.85	16.67	0.66	0.28
05-25-84	1.51	23.50	0.70	0.28
06-02-84	1.51		0.53	0.26
06-11-84	1.33	13.74	0.55	0.65
06-19-84	0.90	12.20	0.44	0.16
06-27-84	0.58	8.21		0.12
07-05-84	0.15	6.69		0.05
07-14-84		5.42		
07-18-84	0.03	2.52		
07-25-84		3.25		
08-01-84	0.03	3.79		
08-07-84	0.03	4.72		
08-15-84		5.58		
08-22-84				
08-29-84		5.42		
09-06-84		5.14		
09-18-84		5.55		
10-11-84		5.71		

Table 21. Water Sample Nitrate Concentration for the Fall Applied Nitrogen Treatments (ppm)

BLOCK	1	2	3	4
TREATMENT	FALL	*	*	*
SITE	B	E	I	M
date				
09-10-83	31.40	27.40	19.80	20.30
10-17-83	21.80	4.70		
10-19-83	19.30	23.80	32.90	4.70
10-23-83	34.30	18.80	35.30	
11-17-83	34.30	16.20	48.40	2.20
11-21-83	63.90	23.30	41.80	2.20
12-19-83	57.70		41.25	2.26
02-11-84	50.28		35.45	0.33
02-14-84	32.21		33.02	2.00
02-22-84	57.40		44.53	0.42
03-31-84	68.53			
04-03-84	85.42		50.56	0.35
04-16-84	76.44		34.48	0.34
04-21-84	77.11		38.63	0.32
04-30-84	54.45	22.41	33.54	0.35
05-06-84	74.03	22.01	14.77	0.34
05-11-84	55.31	20.90	27.96	2.44
05-19-84	37.73	14.71	22.85	1.55
05-25-84	44.01	17.37	21.55	1.66
06-02-84	32.94	14.79	22.53	1.98
06-11-84	27.73	12.85	26.76	2.59
06-19-84	24.80	11.23	30.30	3.37
06-27-84	20.93	7.68	30.94	3.82
07-05-84	16.40	9.62	28.36	4.32
07-14-84				
07-18-84	14.07	8.53	32.46	5.01
07-25-84		8.21	34.37	4.63
08-01-84		8.53	28.66	2.35
08-07-84		7.89	26.76	0.89
08-15-84		6.14	23.58	0.03
08-22-84			29.61	
08-29-84			31.83	
09-06-84			35.32	
09-18-84			31.83	
10-11-84			26.76	

Table 22. Water Sample Nitrate Concentration for the Spring Split Applied Nitrogen Treatments (ppm)

BLOCK	1	2	3	4
TREATMENT	SPRING	*	*	*
SITE	C	G	L	N
date				
09-10-83	17.80	42.00		33.40
10-17-83	11.80	39.90	55.50	39.40
10-19-83	13.80	66.60	125.50	76.20
10-23-83	15.70	76.50	76.00	58.90
11-17-83	25.30	92.50	144.30	76.00
11-21-83	30.30	95.10	145.80	75.50
12-19-83		79.84		55.56
02-11-84		72.00	52.44	62.93
02-14-84	55.14	85.76	39.96	34.68
02-22-84	63.06	61.74	23.34	30.59
03-31-84				
04-03-84	69.66	53.69	17.40	14.97
04-16-84	52.60	39.61	9.01	8.74
04-21-84	50.17	36.36	9.82	9.28
04-30-84	56.80	32.30	4.58	10.63
05-06-84	43.13	18.62	6.03	5.62
05-11-84	45.89	21.15		20.19
05-19-84	37.31	16.86	3.40	20.52
05-25-84	39.29	18.51	3.58	18.84
06-02-84	32.03	13.10	3.22	19.17
06-11-84	27.46	10.04	2.94	16.36
06-19-84	26.15	9.39	2.87	16.69
06-27-84	21.91	8.41	2.84	16.69
07-05-84	20.28	6.00	2.94	16.04
07-14-84				
07-18-84		4.10	3.42	15.71
07-25-84	19.30		4.49	16.36
08-01-84	19.30		4.42	15.38
08-07-84	19.07		4.39	13.30
08-15-84			4.60	13.30
08-22-84				12.00
08-29-84				12.65
09-06-84				12.00
09-18-84				10.04
10-11-84				6.10

Table 23. Water Sample Nitrate Concentration for the Trickle Applied Nitrogen Treatments (ppm)

BLOCK	1	2	3	4
TREATMENT	TRICKLE	*	*	*
SITE	A	F	J	O
date				
09-10-83	26.90	58.10	25.90	
10-17-83	39.40	56.50	18.80	70.10
10-19-83	30.90	89.80	30.90	238.30
10-23-83	32.80	91.50	37.30	93.00
11-17-83	24.80	89.50	36.30	
11-21-83	30.80	75.50	38.30	151.80
12-19-83	22.28	63.84	35.10	109.20
02-11-84	21.30	44.31	18.76	45.11
02-14-84	31.73	30.40	16.75	59.29
02-22-84	60.09	19.96	8.72	29.99
03-31-84	51.80	11.94	2.97	
04-03-84	49.30	10.36	4.50	28.09
04-16-84	34.65	1.94	2.83	16.50
04-21-84	38.14	3.11	2.63	13.02
04-30-84	35.35	2.52	1.94	7.43
05-06-84	40.51	2.52	0.77	2.83
05-11-84	36.10	3.48	3.22	
05-19-84	33.17	3.00	3.18	6.33
05-25-84	36.20	3.22	3.18	6.16
06-02-84	23.18	3.51	3.03	5.65
06-11-84	26.76	3.00	3.03	4.98
06-19-84	26.10	2.84	3.19	6.19
06-27-84	25.13	2.70	12.00	6.89
07-05-84	26.10	2.25	324.97	6.96
07-14-84				
07-18-84	25.15	1.56	451.41	6.63
07-25-84	23.87		175.24	6.30
08-01-84	24.19	0.67	238.46	7.29
08-07-84	23.87	0.27	288.37	7.62
08-15-84	23.23		171.91	
08-22-84			474.71	
08-29-84	21.05		587.84	
09-06-84	22.00			
09-18-84	18.19		704.30	
10-11-84	22.63		624.44	

Table 24. Average Sample Nitrate Over Four Blocks (ppm)

date	control	fall	spring	trickle
09-10-83	33.40	24.72	31.07	36.97
10-17-83	16.05	13.25	36.65	46.20
10-19-83	22.10	20.18	70.53	97.47
10-23-83	13.23	29.47	56.78	63.65
11-17-83	18.75	25.28	84.52	50.20
11-21-83	11.37	32.80	86.67	74.10
12-19-83	1.22	33.74	67.70	57.60
02-11-84	7.55	28.69	62.46	32.37
02-14-84	9.47	22.41	53.88	34.54
02-22-84	6.77	34.12	44.68	29.69
03-31-84		68.53		22.24
04-03-84	19.47	45.44	38.93	23.06
04-16-84	7.50	37.09	27.49	13.98
04-21-84	7.24	38.69	26.41	14.22
04-30-84	6.70	27.69	26.08	11.81
05-06-84	0.54	27.79	18.35	11.66
05-11-84	13.37	26.65	29.08	14.27
05-19-84	4.62	19.21	19.52	11.42
05-25-84	6.50	21.15	20.05	12.19
06-02-84	0.77	18.06	16.88	8.84
06-11-84	4.07	17.48	14.20	9.44
06-19-84	3.42	17.43	13.77	9.58
06-27-84	2.97	15.84	12.46	11.68
07-05-84	2.30	14.68	11.31	90.07
07-14-84	5.42			
07-18-84	1.27	15.02	7.74	121.19
07-25-84	3.25	15.74	13.38	68.47
08-01-84	1.91	13.18	13.03	67.65
08-07-84	2.37	11.85	12.25	80.03
08-15-84	5.58	9.92	8.95	97.57
08-22-84		29.61	12.00	474.71
08-29-84	5.42	31.83	12.65	304.44
09-06-84	5.14	35.32	12.00	22.00
09-18-84	5.55	31.83	10.04	361.25
10-11-84	5.71	26.76	6.10	323.53

Table 25. Water Sample Volume Collected for Control (mL)

BLOCK	1	2	3	4
TREATMENT	CONTROL	*	*	*
SITE	D	H	K	P
DATE				
09-10-83	52	62		
10-17-83	150	160	60	106
10-19-83	52	49	22	31
10-23-83	70	75	30	55
11-17-83	120	10		
11-21-83	45	50	20	30
12-19-83			20	35
02-11-84	410	510	300	330
02-14-84	140	210	15	190
02-22-84	70	60	15	40
03-31-84				
04-03-84	30	25		
04-16-84	140	170	70	80
04-21-84	60	75	30	25
04-30-84	90	100	50	50
05-06-84	70		20	50
05-11-84	40	25		
05-19-84	110	110	50	20
05-25-84	60	70	30	50
06-02-84	100		30	60
06-11-84	90	90	50	60
06-19-84	100	130	50	60
06-27-84	70	120	20	40
07-05-84	50	110		25
07-18-84	50	50		
07-25-84		85		
08-01-84	40	100		
08-07-84	5	80		
08-15-84		110		
08-22-84				
08-29-84		70		
09-06-84		110		
09-18-84		160		
10-11-84		220		

Table 26. Water Sample Volume Collected for Fall Applied Nitrogen Treatments (mL)

BLOCK	1	2	3	4
TREATMENT	FALL	*	*	*
SITE	B	E	I	M
DATE				
09-10-83	62	60	95	65
10-17-83			338	328
10-19-83	71	10	87	78
10-23-83	98	25	142	
11-17-83	170	100	55	45
11-21-83	70	115	110	80
12-19-83	120		110	140
02-11-84	440		570	515
02-14-84	110		95	130
02-22-84	125		145	135
03-31-84	20			
04-03-84	60		60	55
04-16-84	200		250	230
04-21-84	105		120	100
04-30-84	140	170	160	170
05-06-84	125	210	135	120
05-11-84	70	110	45	85
05-19-84	155	260	170	180
05-25-84	110	170	130	120
06-02-84	160	190	165	140
06-11-84	150	240	190	170
06-19-84	160	270	210	160
06-27-84	95	190	160	145
07-05-84	60	180	170	150
07-18-84	40	250	265	200
07-25-84		115	150	80
08-01-84		110	160	150
08-07-84		90	130	70
08-15-84		75	170	50
08-22-84			160	
08-29-84			160	
09-06-84			160	
09-18-84			240	
10-11-84			300	

Table 27. Water Sample Volume Collected for Spring Split Nitrogen Application Treatments (mL)

BLOCK	1	2	3	4
TREATMENT	SPRING	*	*	*
SITE	C	G	L	N
DATE				
09-10-83	110	62		60
10-17-83	180	132	254	220
10-19-83	82	44	62	62
10-23-83	114	70	102	105
11-17-83	30	30	15	45
11-21-83	40	45	60	85
12-19-83		45		90
02-11-84		450	480	535
02-14-84	400	40	280	260
02-22-84	140	65	185	90
03-31-84				
04-03-84	60	30	10	40
04-16-84	200	130	140	200
04-21-84	80	70	45	80
04-30-84	150	90	100	140
05-06-84	135	70	75	100
05-11-84	35	30		30
05-19-84	135	100	125	140
05-25-84	120	60	40	80
06-02-84	160	95	95	120
06-11-84	170	110	90	150
06-19-84	190	110	80	130
06-27-84	90	80	95	120
07-05-84	150	90	50	130
07-18-84		50	70	185
07-25-84	60		20	95
08-01-84	40		15	100
08-07-84	40		10	70
08-15-84				80
08-22-84				40
08-29-84				30
09-06-84				30
09-18-84				50
10-11-84				60

Table 28. Water Sample Volume Collected for Trickle Applied Nitrogen Treatments (mL)

BLOCK	1	2	3	4
TREATMENT	TRICKLE	*	*	*
SITE	A	F	J	O
DATE				
09-10-83	70	65	185	
10-17-83	230	240	700	161
10-19-83	88	79	265	50
10-23-83	165	120	348	96
11-17-83	60	50	145	
11-21-83	60	65	165	50
12-19-83	75	100	400	10
02-11-84	430	400	560	450
02-14-84	90	180	560	110
02-22-84	145	135	635	60
03-31-84	20	8	115	
04-03-84	60	50	500	25
04-16-84	230	210	620	190
04-21-84	100	95	260	60
04-30-84	140	130	320	120
05-06-84	135	105	200	90
05-11-84	70	50	560	
05-19-84	185	180	350	110
05-25-84	120	90	160	80
06-02-84	170	130	200	100
06-11-84	180	110	190	120
06-19-84	200	160	190	120
06-27-84	155	100	120	95
07-05-84	140	90	630	110
07-18-84	220	100	540	130
07-25-84	135		510	40
08-01-84	130		420	40
08-07-84	100	5	320	20
08-15-84	70		380	
08-22-84			310	
08-29-84	110		240	
09-06-84	120			
09-18-84	170		470	
10-11-84	280		620	

APPENDIX C

Statistical Analysis

Statistical Analysis

The statistical model for the randomized complete block design is $Y_{ij} = Y_{..} + T_i + B_j + e_{ij}$. In other words, each cell consists of the mean of all the variates, $Y_{..}$, the treatment effect, T_i, the block effect, B_j, and the residual or "experimental error" component, e_{ij}.

Table 29 illustrates the formulas used in this study for the analysis of variance in a randomized complete block design with t treatments and r blocks.

Table 29. Statistical Formulas for Randomized Complete Block Design

Source of Variation	Degrees of freedom	Sums of Squares: Definition	Sums of Squares: Working
Blocks	r - 1	$t\sum_j(\bar{Y}_{.j}-\bar{Y}_{..})^2$	$= \sum_j Y^2_{.j}/t - C$
Treatments	t - 1	$r\sum_i(\bar{Y}_{i.}-\bar{Y}_{..})^2$	$= \sum_i Y^2_{i.}/r - C$
Error	(r-1)(t-1)	$\sum_{i,j}(Y_{ij}-\bar{Y}_{.j}-\bar{Y}_{i.}+\bar{Y}_{..})^2$	$=$ SS(Total) - SS(Blocks) - SS(Treatments)
Total	rt - 1	$\sum_{i,j}(Y_{ij}-\bar{Y}_{..})^2$	$= \sum_{i,j} Y^2_{ij} - C$

C = Correction term = $Y^2_{..}/rt$

(Steel and Torrie, 1980)

Mean separation was accomplished using Duncan's Multiple-Range Test (Steel and Torrie, 1980). The spreadsheet package Perfect Calc was used to assist in the analysis. Table 30 is an example of the output.

Table 30. Duncan's Multiple Range Test Example Using 1984 Percent Leaf Nitrogen

MSE = 0.025509 (from analysis of variance)

Sy = 0.079858

p	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Qa'	2.84	2.99	3.09	3.15	3.21	3.25	3.29	3.32	3.34	3.36	3.38	3.39	3.41	3.42	3.43	3.44	3.45
Rp	0.23	0.24	0.25	0.25	0.26	0.26	0.26	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.28

Treatment #	17	18	9	12	15	16	14	4	13	7	6	11	5	10	8	2	1	3
	3.47	3.45	3.34	3.33	3.31	3.29	3.29	3.29	3.28	3.26	3.26	3.21	3.21	3.20	3.16	2.85	2.76	2.69
2.69	0.78	0.76	0.65	0.64	0.62	0.60	0.60	0.60	0.59	0.57	0.57	0.52	0.52	0.51	0.47	0.16	0.07	
2.76	0.71	0.69	0.58	0.57	0.55	0.53	0.53	0.53	0.52	0.50	0.50	0.45	0.45	0.44	0.40	0.09		
2.85	0.62	0.60	0.49	0.48	0.46	0.44	0.44	0.44	0.43	0.41	0.41	0.36	0.36	0.35	0.31			
3.16	0.31	0.29	0.18	0.17	0.15	0.13	0.13	0.13	0.12	0.10	0.10	0.05	0.05	0.04				
3.20	0.27	0.25	0.14	0.13	0.11	0.09	0.09	0.09	0.08	0.06	0.06	0.01	0.01					
3.21	0.26	0.24	0.13	0.12	0.10	0.08	0.08	0.08	0.07	0.05	0.05	0.00						
3.21	0.26	0.24	0.13	0.12	0.10	0.08	0.08	0.08	0.07	0.05	0.05							
3.26	0.21	0.19	0.08	0.07	0.05	0.03	0.03	0.03	0.02	0.00								
3.26	0.21	0.19	0.08	0.07	0.05	0.03	0.03	0.03	0.02									
3.28	0.19	0.17	0.06	0.05	0.03	0.01	0.01	0.01										
3.29	0.18	0.16	0.05	0.04	0.02	0.00	0.00											
3.29	0.18	0.16	0.05	0.04	0.02	0.00												
3.29	0.18	0.16	0.05	0.04	0.02													
3.31	0.16	0.14	0.03	0.02														
3.33	0.14	0.12	0.01															
3.34	0.13	0.11																
3.45	0.02																	
3.47																		

Treatment #	17	18	9	12	15	16	14	4	13	7	6	11	5	10	8	2	1	3
	3.47	3.45	3.34	3.33	3.31	3.29	3.29	3.29	3.28	3.26	3.26	3.21	3.21	3.20	3.16	2.85	2.76	2.69
	a	a	a	a	a	a	a	a	a	a	a	a	a					
		b	b	b	b	b	b	b	b	b	b	b	b	b				
				c	c	c	c	c	c	c	c	c	c	c	c			
																d	d	d

APPENDIX D

Supplemental Information

The following table gives the daily minimum and maximum temperatures, and the amount of rainfall, irrigation and depth of accumulated snow over the course of the soil water sample collection period. The date of fertilizer application is also provided by treatment number. Rainfall and snowfall values are in centimeters, and irrigation amount is in liters applied per tree. The minimum and maximum daily temperatures are given in degrees Celcius.

Table 31. Rainfall, Snowfall, Irrigation and Fertilizer Application Records

Date	Tmax	Tmin	Rain	Snow	Irrig	Fert Trmt #
9 1 82			0.3			
9 2 82			1.1			
9 6 82			2.1			
9 14 82			0.6			
9 15 82			1.0			
9 16 82			0.2			
9 17 82			0.2			
9 18 82			0.8			
9 20 82			1.9			
9 21 82			1.0			
9 24 82			0.2			
9 25 82			0.5			
10 1 82			0.4			
10 6 82			0.7			
10 7 82			0.2			
10 10 82			0.1			
10 12 82			0.2			
10 13 82			0.4			
10 14 82			0.6			
10 15 82			trace			
10 16 82			0.2			
10 17 82			0.7			
10 18 82			0.4			
10 19 82			0.1			
10 20 82			1.8			
10 21 82			0.3			
10 28 82			0.1			
10 29 82			trace			
11 1 82			0.1			
11 2 82			1.1			
11 18 82						4-6,10-12

Table 31. (Cont'd).

Date			Tmax	Tmin	Rain	Snow	Irrig	Fert Trmt #
12	9	82	-3	-10				
12	13	82	0	-9		3.8		
12	20	82	3	-10	0.2	2.5		
12	21	82	0	-3	0.3	12.7		
12	22	82	-2	-4		12.7		
12	27	82	13	-3	1.9			
12	28	82	12	-1	0.7			
12	29	82	11	-7	0.4	10.2		
1	3	83	1	-9		7.6		
1	4	83	-3	-8		7.6		
1	5	83	2	-7		2.5		
1	6	83	2	-2		2.5		
1	7	83	1	-2	0.5	12.7		
1	10	83	3	-5				
1	11	83	6	0	0.4	2.5		
1	12	83	0	-9	0.1	5.1		
1	13	83	-4	-9		5.1		
1	17	83	-1	-14	0.4	15.2		
1	18	83	10	-14		15.2		
1	19	83	-9	-14		15.2		
1	20	83	-7	-15		12.7		
1	21	83	-4	-13		12.7		
1	24	83	3	-9	0.4	15.2		
1	25	83	3	-6		15.2		
1	26	83	1	-10	0.1	15.2		
1	27	83	-8	-11		15.2		
1	28	83	-6	-10		15.2		
1	31	83	2	-6		10.2		
2	1	83	-3	-7		10.2		
2	2	83	-3	-8		10.2		
2	4	83	-1	-12	1.0	17.8		
2	7	83	-1	-11	1.1	22.9		
2	8	83	-4	-11		22.9		
2	9	83	-1	-7		22.9		
2	10	83	-4	-12		22.9		
2	11	83	-4	-11		22.9		
2	14	83	5	-11		15.2		
2	15	83	3	0		12.7		
2	16	83	3	0		12.7		
2	17	83	3	-1	0.6	10.2		
2	18	83	3	-3		10.2		
2	22	83	1	-2	0.1			
2	23	83	1	-3	1.1	2.5		
2	24	83	3	-4	trace			
2	25	83	-3	-10	0.1	7.6		
3	3	83	6	-2	0.1			
3	9	83	17	1	2.1			
3	10	83	1	-6	0.1			
3	21	83	4	-9		12.7		

Table 31. (Cont'd).

Date	Tmax	Tmin	Rain	Snow	Irrig	Fert Trmt #
3 22 83				20.3		
3 23 83				17.8		
2 24 83				17.8		
3 25 83				15.2		
3 28 83	2	-7		7.6		
3 29 83	2	-7		7.6		7-15
3 30 83	0	-6		5.1		
3 31 83	4	-4		2.5		
4 3 83	7	0		5.1		
4 7 83	4	3	0.2			
4 10 83			0.3			
4 11 83			trace			
4 12 83			trace			
4 13 83			0.2			
4 14 83			1.0			
4 15 83			0.5			
4 30 83			0.1			
5 2 83			0.2			
5 3 83			0.3			
5 6 83			0.2			
5 7 83			3.4			
5 8 83			2.3			
5 14 83			0.4			
5 15 83			0.2			
5 18 83					15.1	16-18
5 19 83			0.9			
5 20 83			2.8			
5 21 83			0.1			
5 23 83			0.8			
5 24 83			0.7			
5 25 83			1.6			
5 28 83					15.1	16-18
5 29 83			1.5			
5 30 83			0.6			
5 31 83			0.1			
6 1 83			0.1			
6 5 83			0.1			
6 9 83			0.3			
6 11 83					15.1	16-18
6 15 83						13-15
6 16 83			0.1			
6 17 83					30.2	
6 27 83			0.8			
6 20 83					37.9	
6 22 83					121.1	
6 28 83			2.0			
6 30 83			trace			
7 1 83			1.1			
7 4 83			0.5			

Table 31. (Cont'd).

Date	Tmax	Tmin	Rain	Snow	Irrig	Fert Trmt #
7 5 83					15.1	15-18
7 6 83					151.6	
7 13 83					60.4	
7 15 83					90.8	
7 25 83					60.4	
7 28 83			1.2			
7 29 83			1.2			
7 30 83			0.2			
8 2 83			0.3			
8 5 83					113.7	
8 9 83			0.2			
8 11 83			4.5			
8 12 83			trace			
8 18 83			0.1			
8 22 83			2.1			
8 26 83			0.2			
8 30 83			0.1			
8 31 83			0.1			
9 6 83			0.1			
9 7 83			1.0			
9 13 83			0.4			
9 14 83			0.4			
9 16 83			1.7			
9 17 83			0.9			
9 18 83			1.9			
9 19 83			trace			
9 20 83			3.7			
9 21 83			1.8			
9 22 83			1.8			
9 23 83			3.0			
9 24 83			0.3			
9 26 83			trace			
10 3 83			0.9			
10 4 83			2.0			
10 5 83			0.1			
10 6 83			0.3			
10 8 83			3.7			
10 12 83			0.2			
10 13 83			0.5			
10 14 83			1.1			
10 15 83			0.8			
10 17 83			0.1			
10 23 83			0.7			
10 25 83			0.3			
10 26 83			0.1			
11 3 83			0.1			
11 10 83			0.4			
11 11 83	11	3		1.5		
11 15 83			0.8			

Table 31. (Cont'd).

Date	Tmax	Tmin	Rain	Snow	Irrig	Fert Trmt #
11 21 83			2.1			4-6,10-12
11 28 83	1	-2	1.1			
11 29 83	3	-1	0.6	5.1		
12 1 83	-2	-4	0.6	10.2		
12 2 83	-4	-6	0.1	12.7		
12 5 83	3	-1	trace	12.7		
12 9 83	-5	-7	0.3	17.8		
12 10 83	-4	-8		27.9		
12 12 83	1	0	1.8	10.2		
12 13 83	1	-2		7.6		
12 14 83	0	-2		7.6		
12 15 83	0	-2	0.9	20.3		
12 16 83	-1	-9	0.1	25.4		
12 19 83	12	-18	0.6	33.0		
12 20 83	11	-19		33.0		
12 21 83	-8	-13		33.0		
12 28 83	-5			45.7		
1 3 84	-1	-3		50.8		
1 4 84	3	-2		45.7		
1 5 84	2	-4		40.6		
1 6 84	2	-4		na		
1 10 84	-6	-13		53.3		
1 11 84	11	-14		53.3		
1 12 84	-8	-13		53.3		
1 13 84	-7	-12		53.3		
1 18 84	-8	-11		58.4		
1 20 84	-7	-11		63.5		
1 23 84	-4	-8		66.0		
1 26 84	-2	-9		66.0		
1 27 84	-3	-7		66.0		
2 1 84	-4	-8		66.0		
2 2 84	-1	-5		66.0		
2 9 84	-2	-7		61.0		
2 10 84	3	-1		55.9		
2 11 84	8	2		45.7		
2 12 84	7	1		40.6		
2 13 84	11	6		25.4		
2 15 84	7	-1		12.7		
2 16 84	8	-1		10.2		
2 17 84	7	1		10.2		
2 20 84	4	-4		5.1		
2 21 84	2	-3		5.1		
2 22 84	3	-1		5.1		
2 23 84	12	4		2.5		
2 29 84	-4	-11				
3 5 84	2	-4		2.5		
3 6 84	-1	-11		5.1		
3 7 84	11	-18		5.1		
3 8 84	12	-18		5.1		

Table 31. (Cont'd).

Date	Tmax	Tmin	Rain	Snow	Irrig	Fert Trmt #
3 9 84	12	-21		5.1		
3 10 84	-6	-13		5.1		
3 11 84	-4	-16		5.1		
3 12 84	14	-19		5.1		
3 13 84	-8	-11		5.1		
3 15 84	7	-2	0.7			
3 16 84	4	-7		0.5		
3 20 84	0	-1	0.2			
3 21 84	2	1	1.4			
3 22 84	2	-1		2.5		
3 23 84	-2	-4		2.5		
3 30 84						7-15
4 6 84			0.7			
4 13 84			0.2			
4 14 84			0.6			
4 15 84			0.4			
4 16 84			0.7			
4 17 84	6	-2	0.1	0.5		
4 18 84			trace			
4 19 84			0.2			
4 23 84			0.6			
4 28 84			0.5			
4 30 84			1.2			
5 1 84			0.5			
5 4 84			0.1			
5 5 84					15.1	16-18
5 9 84			0.1			
5 13 84			0.5			
5 14 84			0.7			
5 18 84			0.3			
5 19 84					15.1	16-18
5 23 84			0.3			
5 26 84			2.3			
6 2 84					15.1	16-18
6 3 84			0.4			
6 6 84			0.1			
6 7 84			1.0			
6 10 84			2.2			
6 13 84			0.2			
6 14 84			0.2			
6 16 84					15.1	16-18
6 17 84			1.8			
6 18 84			3.2			
6 19 84			0.1			
6 25 84			0.1			
6 26 84					68.1	
6 27 84			1.4			
6 28 84			0.2			
7 4 84			0.8			

Table 31. (Cont'd).

Date	Tmax	Tmin	Rain	Snow	Irrig	Fert Trmt #
7 7 84			0.2			
7 10 84			0.4		68.1	
7 11 84			3.6			
7 13 84					90.6	
7 15 84			0.6			
7 17 84			0.3			
7 20 84			0.1			
7 24 84			0.1		166.5	
7 27 84			0.5			
7 31 84					128.7	
8 1 84			0.4			
8 2 84			0.4			
8 6 84			2.5			
8 8 84			0.5			
8 9 84			1.2			
8 16 84			0.3			
8 18 84			0.2			
8 21 84					128.7	
8 22 84			0.3			
8 83 84			0.2			
8 28 84			1.2			
8 30 84			0.8			
9 2 84			2.4			
9 3 84			3.4			
9 4 84			0.2			
9 5 84			0.1			
9 7 84			0.6			
9 9 84			0.3			
9 10 84			0.3			
9 11 84			0.1			
9 13 84			1.4			
9 15 84			0.1			
9 23 84			0.2			
9 24 85			trace			
9 25 84			2.2			
9 26 84			0.6			
9 29 84			1.2			
10 7 84			0.1			
10 8 84			1.1			
10 9 84			0.1			
10 13 84			0.3			
10 14 84			0.1			

The following set of directions and data sheet were developed to facilitate water sample collection.

Instructions for Water Sample Collection

1. Setting the vacuum:

This process will take approximately 1 hour.

A. Using the attached map, locate the 16 water samplers in the orchard.
B. Beginning with sampler A, attach the pressure-vacuum pump port marked vacuum to the access tube marked with orange paint.
C. Make sure the other access tube (no paint) is clamped closed.
D. Pump the pressure-vacuum pump about 2 full strokes to a reading of 20 " of Mercury.
E. If the vacuum does not hold, check for leaks - tube connections, clamps, etc.
F. Clamp the orange tube closed, remove the pump, close the top of the access tube cover (the PVC pipe) and move on to B, C, D, etc.
G. Record the required information on a data sheet.

2. Collecting the sample:

This should take approximately 1.5 hours.

A. After approximately 48 hours, return to the orchard with pressure-vacuum pump, 16 sample bottles, graduated cylinder, data sheet and extra cup or container.
B. Connect the pump port marked pressure to the access tube marked in orange.
C. Loosen both clamps, listening for a hiss of air which will signal whether or not the vacuum held. Record this on the data sheet where called for with a (+) or (-).
D. Being sure to avoid contamination from dirt, debris, etc., hold the sample bottle corresponding to the water sampler site (A, B, C, etc.) under the unmarked access tube and pump the pump gently. Fill the sample bottle first (60 ml) and then collect and measure the remainder of the sample using the extra container and graduated cylinder. This will prevent contamination from one sample to another.

The sample may arrive quickly - be careful.

E. Record the total volume collected.

3. Storing the samples:

A. When all 16 samples have been collected, place them together with a photocopy of the completed data sheet into a bag or box, label the bag or box with the date, and freeze the samples. They should remain frozen until just prior to analysis for nitrate concentration.

--- DATA SHEET ---

VACUUM (20" Mercury)

set by ____________ date ___________ time ____________

SAMPLE COLLECTION

collected by ____________ date ________ time ___________

SAMPLE	HELD VACUUM? (+ or -)	TOTAL VOLUME (ml)
A.		
B.		
C.		
D.		
E.		
F.		
G.		
H.		
I.		
J.		
K.		
L.		
M.		
N.		
O.		
P.		

Table 32. Fertilizer Injection System Uniformity Test

5/7/84	Time Collected 11:00 a.m.	Collected By Barry Hahn	
Sample #	Emitter Location	Pressure (kPa)	Time/fill 100 mL
1	B3 T17 Tr2	165	1 Min. 16.6 sec.
2	B3 T18 Tr6 E2	141	1 Min. 18.7 sec.
3	B3 T18 Tr3 E4	131	1 Min. 20.9 sec.
4	B2 T16 Tr4	128	1 Min. 29.8 sec.
5	B2 T18 Tr7	138	1 Min. 22.3 sec.
6	B2 T17 Tr4	159	1 Min. 13.7 sec.
7	B3 T17 Tr7	155	1 Min. 17.8 sec.
8	B2 T17 Tr2	159	1 Min. 31.1 sec.
9	B1 T17 Tr1	145	1 Min. 20.1 sec.
10	B1 T17 Tr7	145	1 Min. 23.1 sec.
11	B1 T16 Tr7	141	1 MIn. 21.0 sec.
12	B1 T17 Tr7	131	1 Min. 26.5 sec.
13	B1 T17 Tr4	128	1 Min. 22.8 sec.
14	B2 T16 Tr7	152	1 MIn. 28.5 sec.
15	B4 T18 Tr1	145	1 MIn. 26.5 sec.
16	B4 T17 Tr7	145	1 Min. 24.4 sec.
17	B4 T16 Tr7	138	1 Min. 29.5 sec.
18	B3 T17 Tr1	169	1 Min. 17.5 sec.

Key B = Block T = Treatment

E = Emitter Tr = Tree number

Table 32. (Cont'd.).

Emitter #	3 High Times	Emitter #	3 Low Times
8	1 Min. 31.1 sec.	6	1 Min. 13.7 sec.
4	1 Min. 29.8 sec.	1	1 Min. 16.6 sec.
17	1 Min. 29.5 sec.	18	1 Min. 17.5 sec.

3 Highs	3 Lows
91.1 sec.	73.7 sec.
89.8 sec.	76.6 sec.
89.5 sec.	77.5 sec.
270.4 sec. = (T max)	227.8 sec. = (T min)

Uniformity = 94%

Mean time to fill 100 mL = 82.8 seconds

100 mL/82.8 s = 4.3 L/hr (1.1 gal/hour)

Table 33. Irrigation Systems Coordination Procedure

WATER SYSTEM: GREEN EMITTERS = 7.6 L/hr (2 gal/hr)

FERTIGATION SYSTEM: BLACK EMITTERS = 3.8 L/hr (1 gal/hr)

		TREATMENTS		
Rate	Surface applied N and control (#1-15)	Low Rate (#16)	Medium Rate (#17)	High (#18)
EMITTERS	1 GREEN	1 GREEN + 1 BLACK	1 GREEN + 2 BLACK	1 GREEN +4 BLACK
HRS. OF OPERATION WATER SYSTEM	2 HOURS	1.5 HOURS	1 HOUR	0 HOUR
HRS. OF OPERATION FERTIGATION SYSTEM	0 HOUR	1 HOUR	1 HOUR	1 HOUR
WATER APPLIED BY WATER SYSTEM	15.1 Liter	11.3 Liter	7.6 Liter	0.0 Liter
WATER APPLIED BY FERTIGATION SYSTEM	0.0 L	3.8 L	7.6 L	15.1 L
TOTAL WATER APPLIED	15.1 L	15.1 L	15.1 L	15.1 L

Table 34. Soil Sample Nitrate and Ammonium Analysis

Values are ppm NO_3/ppm NH_4 in the soil sample extract.

Treatment	0.38 m from trunk	0.76 m from trunk
CONTROL		
Block 1	1.32/0.48	1.03/0.24
2	0.60/0.81	0.76/1.03
3	0.91/0.61	1.24/0.19
4	0.57/0.18	0.69/0.16
FALL APPLICATION		
Block 1	0.93/0.95	2.52/2.44
2	0.87/1.10	1.76/0.72
3	1.19/0.24	4.63/5.29
4	2.61/1.85	10.11/6.78
SPRING SPLIT APPLICATION		
Block 1	1.97/0.95	6.67/5.62
2	6.82/2.22	7.29/2.60
3	4.32/1.03	3.95/0.73
4	4.68/0.88	8.62/3.77
TRICKLE APPLICATION		
Block 1	1.13/1.07	1.32/1.36
2	1.03/0.89	0.77/0.43
3	0.81/0.24	1.24/0.19
4	0.80/0.55	0.76/0.21

The following soil characteristics were observed at vacuum extractor sites A - P.

SITE

A. Thin topsoil, sand/gravel w/some clay to 1.8 m

B. Topsoil, 15.2 cm sand, clay/sand stones, in rock at 1.8 m

C. Topsoil, sand to sand/clay, clay to clay/gravel, hard shale layer at 1.4 m

D. Topsoil, 15.2 cm sand, clay/gravel, sand/shale layers to 1.8 m

E. Topsoil, 0.3 m sand, sand/gravel with some clay/gravel to 1.8 m

F. Topsoil, some clay at 0.6 m, sand to sandy gravel to 1.8 m

G. Topsoil, 15.2 cm sand, clay and clay/gravel to 1.8 meter

H. Topsoil, clay to clay/gravel, large stones at 1.8 meter

I. Topsoil, 15.2 cm sand, clay/gravel to gravel to 1.8 m

J. Topsoil, sand to 1.8 m

K. Topsoil, sand, gravel/stones to 1.8 m with clay

L. Topsoil, sand to 1.8 m, light color for last 0.3 m

M. Gravel, thick clay layer from 1.2 m to 1.7 m, sand last 15.2 cm

N. Topsoil, 0.3 m sand, clay/clay gravel with stones, sand/gravel to clay/gravel to 1.8 m

O. Topsoil, gravel 0.3 m, gravel/clay to 1.8 m

P. Topsoil, gravel 0.6 m, clay/gravel to 1.8 m

High nitrate concentrations were detected at site J, where the soil profile consisted of sand to a depth of 1.8 meter (Figure 15). The site was under the medium rate trickle applied nitrogen treatment. It should be noted that the irrigation water applied through the fertilizer system at the time of fertilizer injection had a concentration of approximately 27000 ppm nitrogen. This water was applied through two 3.8 L/hr (1 gal/hr) emitters anchored next to one another. The concentration was determined as follows:

0.068 kg (0.15 lb) of nitrogen per tree over 20 minutes

2.5 L (0.67 gal) applied in 20 minutes

0.068 kg/2.5 L x 1000000 mg/kg = 27200 mg/L = ppm

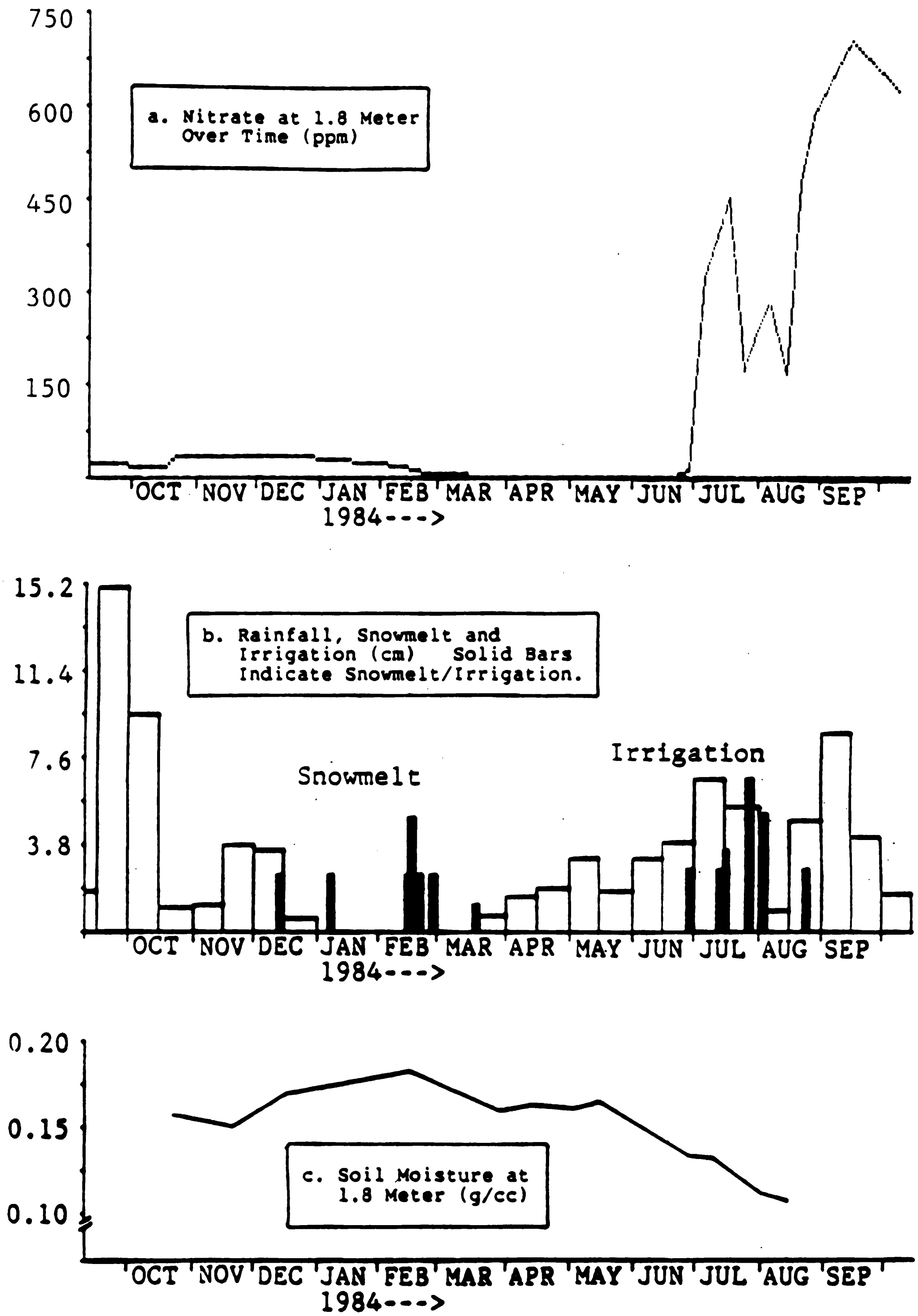


Figure 15. Sandy Site Nitrate Concentration Over Time (Trickle Applied Nitrogen)

The following data sheet was prepared for collection of soil moisture data with the neutron probe.

Neutron Probe Data Sheet

DATE ______________ TIME ________________ NAME ________________________

WEATHER ____

SITE P. background count: ____________________

depth	count
6"	
12"	
18"	
24"	
30"	
36"	
42"	
48"	
54"	
60"	
66"	
72"	
78"	

SITE K. background: ________________

depth	count
6"	
12"	
18"	
24"	
30"	
36"	
42"	
48"	
54"	
60"	
66"	
72"	
78"	

SITE H. background count: ____________________

depth	count
6"	
12"	
18"	
24"	
30"	
36"	
42"	
48"	
54"	
60"	
66"	
72"	
78"	

SITE O. background: ________________

depth	count
6"	
12"	
18"	
24"	
30"	
36"	
42"	
48"	
54"	
60"	
66"	
72"	
78"	

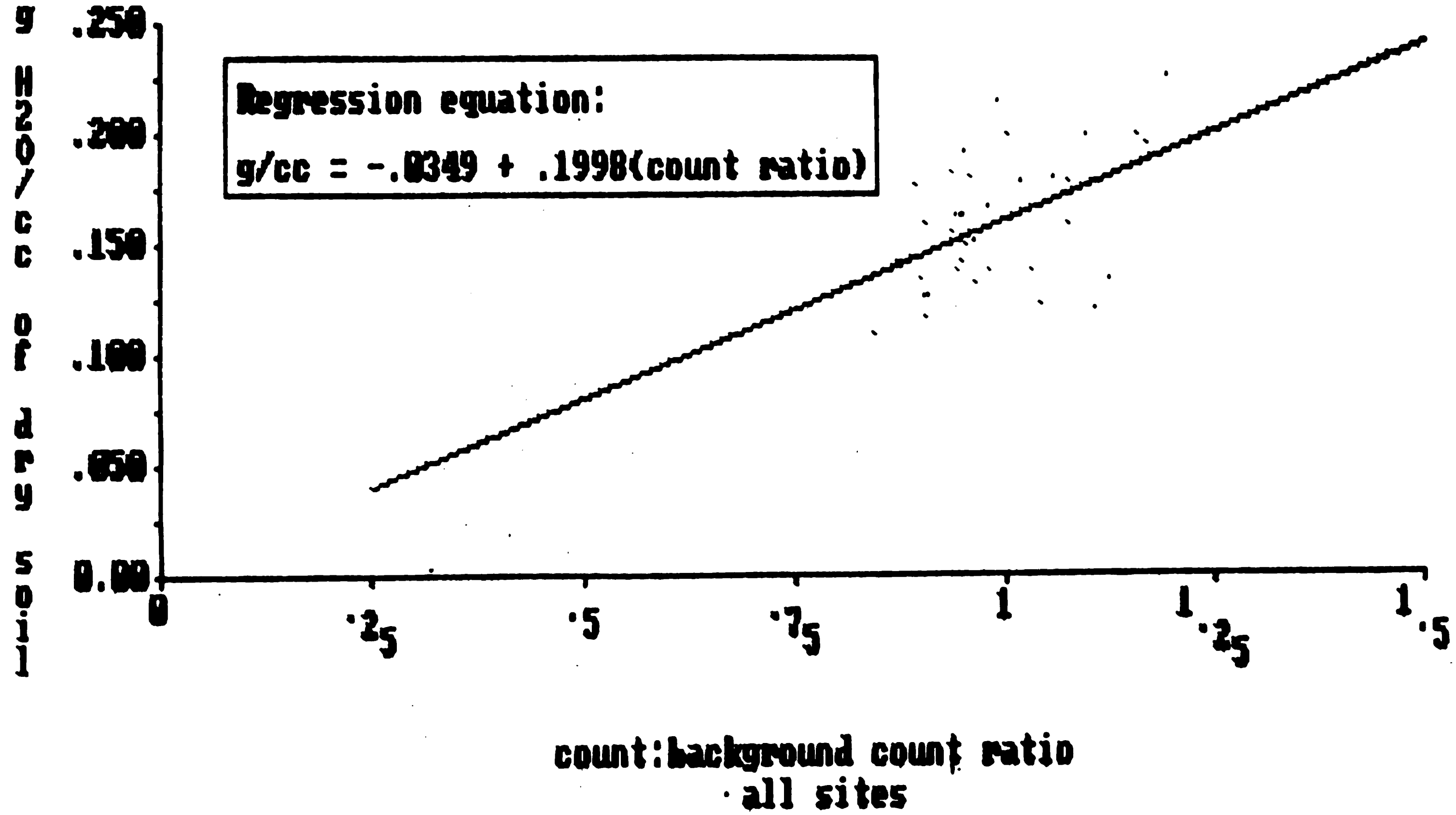
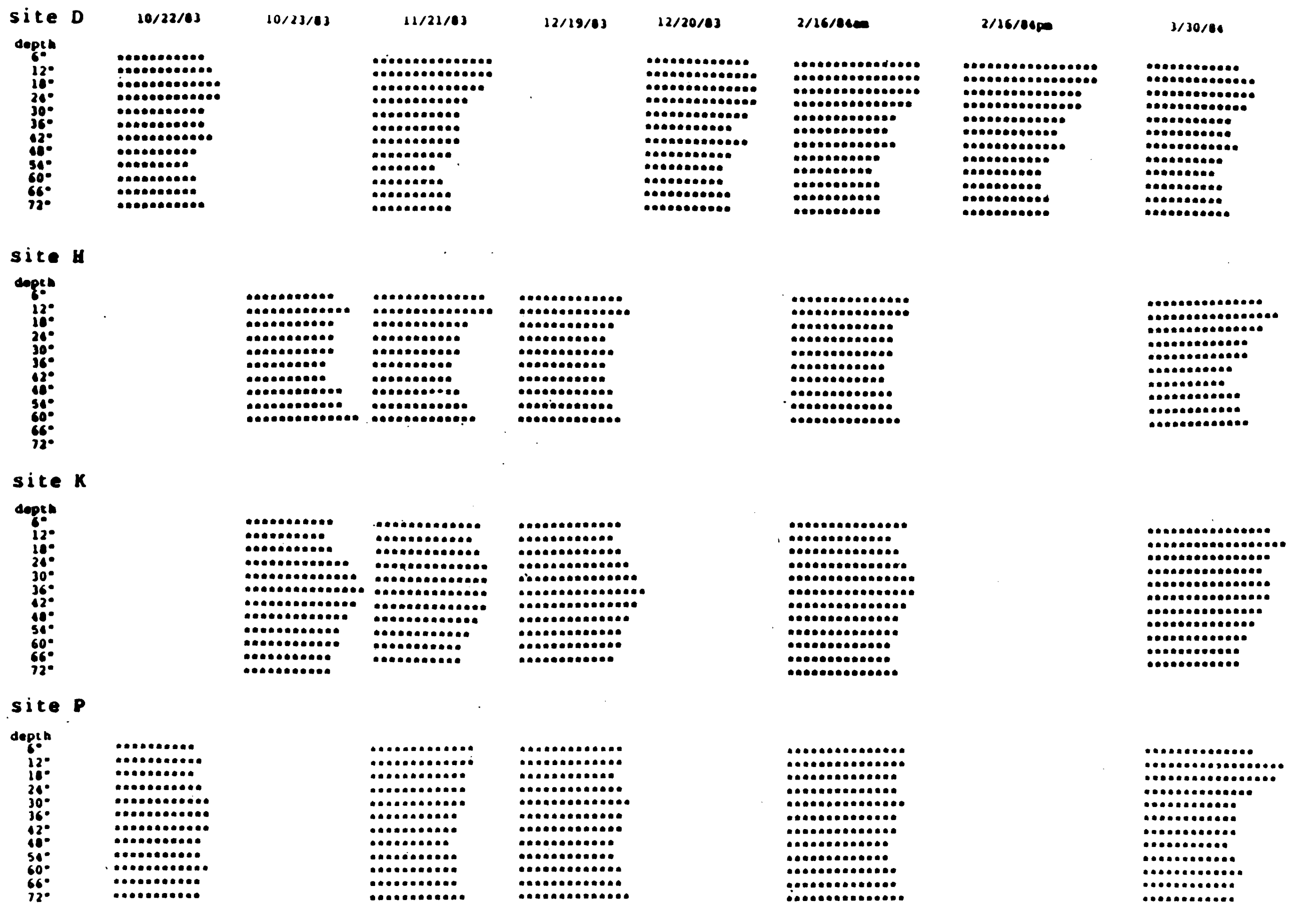
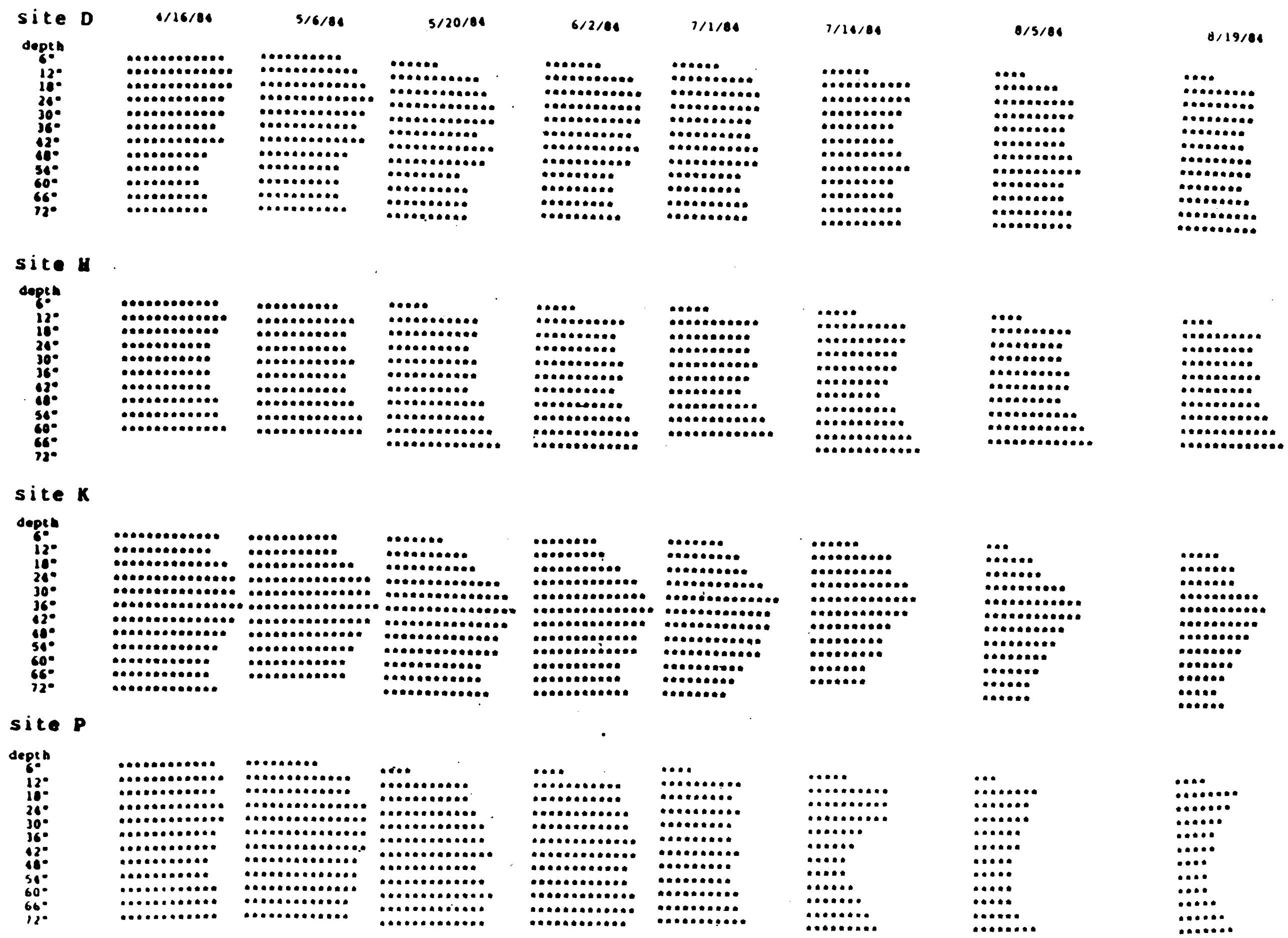


Figure 16. Neutron Probe Calibration Curve



Each * represents 0.01 g of water per cc of soil at the indicated depth.

Figure 17. Soil Moisture Profiles Measured With Neutron Probe



Each * represents 0.01 g of water per cc of soil at the indicated depth.

Figure 17. (Cont'd).

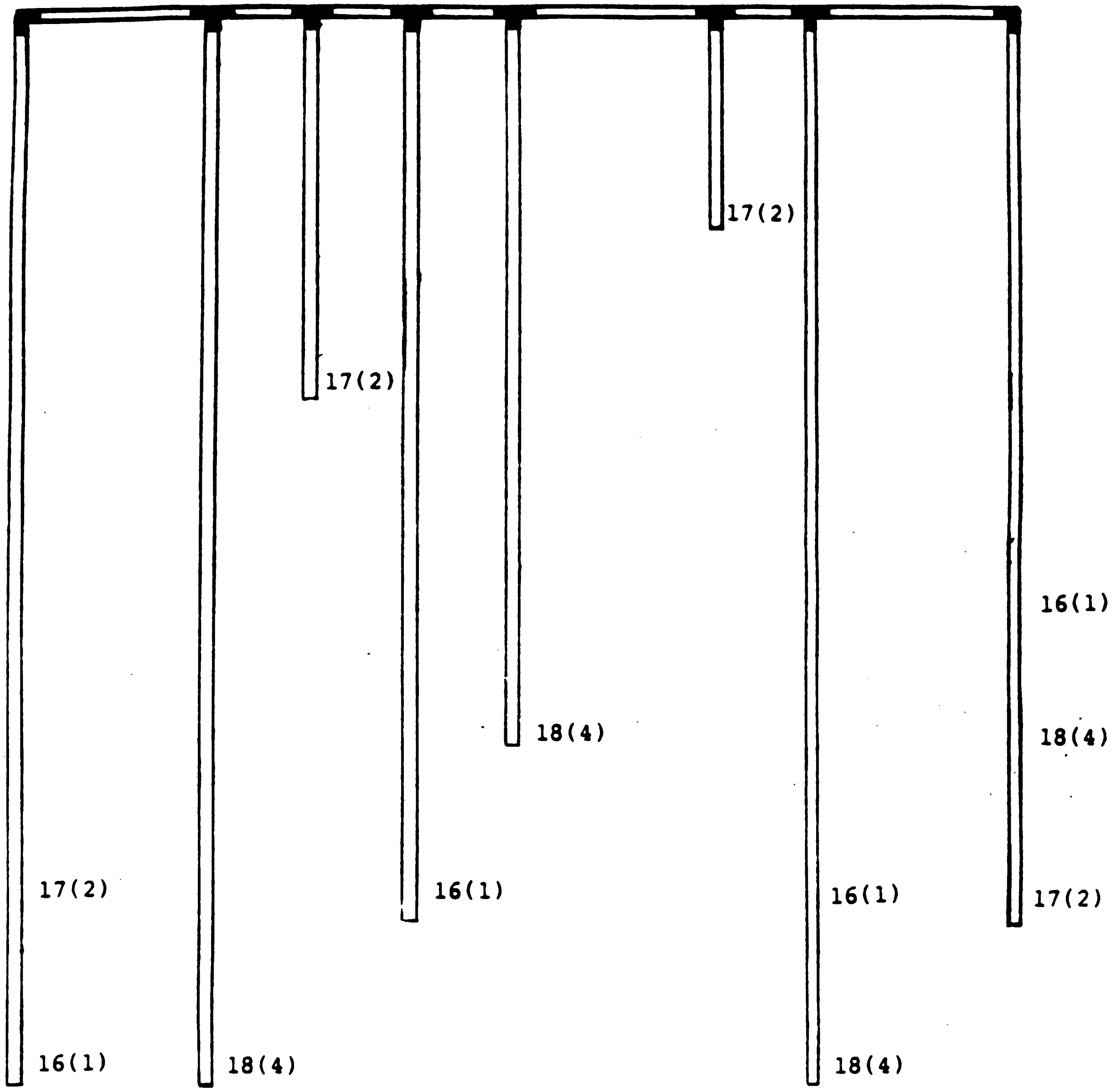


Figure 18. Fertilizer Injection System Layout with Treatment Number and (Number of Emitters per Tree)

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