THE EFFECTS OF THE LEVEL AND TIMING OF NITROGEN FERTILIZER APPLICATION ON RED PEPPER PRODUCTION IN QUÉBEC

by
Erica Fava

Department of Plant Science
Macdonald Campus of McGill University
Montréal, Québec

March 1998

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements of the degree of Master of Science.

0-612-44164-4

Suggested Short Title:

The Effects of Nitrogen Fertilization on Pepper Production

Abstract

The use of plastic mulches in producing red bell pepper (*Capsicum annuum* L.) is relatively new to Québec and management techniques need to be further developed in terms of nitrogen (N) fertilization as well as insect and disease control. A research project was undertaken in the 1995 and 1996 growing seasons to compare peppers grown on black and on silver mulches, and fertigated using either the conventional method (weekly N-fertigated) or N-fertigated using diagnostic chlorophyll meter readings. Both fertigation treatments resulted in similar yields, although those fertilized according to the chlorophyll meter received 28 to 42 kg N/ha less than the weekly fertilized treatments. The chlorophyll meter was able to detect N deficiencies. Alate aphid populations were significantly reduced by mulches, especially by the silver mulch in both years. However, apterous aphid populations were increased by mulches, most markedly by the black mulch. No significant effect of mulch or N was found on tarnished plant bug or European corn borer populations, or on the percentage of fruit with sunscald or viral symptoms.

Résumé

L'utilisation des paillis plastiques dans la production du poivron rouge (*Capsicum annuum* L.) est relativement nouvelle au Québec. Les techniques de sa gêrance par rapport à la fértilisation à l'azote (N) ainsi qu'au contrôle des ravageurs et des maladies ont besoin de développement. Un projet de recherche à été entrepris pendant les années de culture 1995 et 1996 pour comparer les poivrons cultivés sur des paillis noir et réfléchissants et subissant la fertigation dans une de deux façons différentes; soit une méthode traditionnelle (fertigation hebdomadaire à l'azote), soit une fertigation à l'azote basée sur des lectures d'un compteur de chlorophylle. Les deux traitements par fertigation ont donné des rendements comparables de poivrons malgré que les traitements fértilisés selon le compteur de chlorophylle aient reçu de 28 à 42 kg N/ha de moins que ceux qui ont subis des traitements hebdomadaires. Le compteur de chlorophylle pouvait détecter les déficiences en azote. Les populations de pucerons ailés étaient réduites significativement dans les deux années du projet par la présence des paillis, surtout les paillis réfléchissants. Par contre, les populations de pucerons aptères ont agrandi de façon plus marquée dans la présence du paillis noir. Ni les populations de punaise terne ni de pyrale du maïs, ni les pourcentages des fruits présentant des brûlures ou symptômes d'infection virale ont été affecté significativement par le taux d'azote ou l'utilisation des paillis.

Acknowledgements

This thesis is the final product of a lengthy and challenging project which I could not have completed without the help of those around me. Thanks are due to Dr. Katrine Stewart and Dr. Sylvie Jenni who not only came up with the idea, but also gave me guidance and advice. I wish to thank CORPAQ and FCAR for funding me as well as the project. Thanks to Roslyn James, who rescued me numerous times from administrative dilemmas. I was given expertise on the preparation of the land and on a host of other production details by the ever cheerful J.P. LaPlaine and Mike Blehoe of the Horticultural Centre. I am grateful to Dr. Jean Peterson for his help and humour in identifying pepper viruses, and to Dr. Don Smith for allowing me use of his laboratory. Dr. Georges Dodds generously provided assistance with tedious samplings and proof-reading, and was a constant wealth of amusing, if useless trivia. Thanks to my roommate, Josée Owen, who spent many late hours sampling and helped with so many little things. I am indebted to Madeleine Owen and Marie Senécal for their painstaking efforts in translating the abstract. I thank my family and close friends for listening to my tales of hardship when I encountered it, and for providing the diversions and entertainment that sustained me. Finally, I thank my dog, Keiko, who came with me to the field and reminded me of the important things.

Table of Contents

List of Tables

List of Figures

I. INTRODUCTION

Peppers are an important crop in Québec. In 1994, Québec produced approximately 6,000 T of peppers on 445 ha, with a farm value of 3.7 million dollars (Statistics Canada, 1995). Red pepper plants are stressed during the long ripening period in which green fruits turn red. Since the fruit stay on the plant longer, they continue to act as a nutrient sink and there is a greater potential for losses due to disease. For these reasons, red peppers have a higher market value than green peppers. This makes red peppers the ideal subject of pepper research in Québec.

The goal of this research was to improve yield and quality of red peppers by varying the following cultural methods: the level of nitrogen (N) applied, the colour of plastic mulch, and the type of irrigation.

The first objective of this research was to increase the efficiency of N application. Nitrogen is often applied at elevated rates in order to ensure high yields. However, excess N causes pepper plants to allocate more resources to vegetative rather than reproductive development (Miller et al., 1979; Roberts and Anderson, 1994). Excess N can also lead to plants becoming more succulent which may attract insects (Jansson and Smilowitz, 1986; Zhou and Carter, 1991) vectoring diseases or viruses (Brown et al., 1993; Jones, 1991). Finally, there are many environmental concerns about the application of excess N such as the contamination of ground water supplies through leaching losses.

Tissue tests may suggest when the N in the plant is suboptimal, and therefore proper timing for N application. By supplying N only when needed, excessive fertilization may be avoided. For this method to work, the tissue test must be quick, so that producers can apply the N before there is a reduction in yield. The Minolta SPAD-502 chlorophyll meter is a quick, in-field test which is not destructive to the plant (Hartz et al., 1993).

Plastic mulches may decrease the requirement for applied N. Plastic mulches decrease the number of N-consuming weeds present, therefore decreasing the level of N applied to a given area to meet the needs of the pepper plants. Plastic mulches also cause the soil to warm resulting in more favourable microbial action, which in turn increases the available N (Hankin et al., 1982).

Drip irrigation may decrease the requirement for applied N. Drip irrigation supplies water and fertilizer only to the root zone (Tindall et al., 1991), and therefore less water is used than other methods of irrigation. Leaching of fertilizer is thus reduced.

The second objective of this research was to determine the effects of silver and black plastic mulches on peppers. Since different colours of mulch have different effects on the plant microclimate (Splittstoesser and Brown, 1991), they may cause differences in growth and yield. The difference in microclimate, as well as the colour itself, may influence insect pest populations and disease incidence. It is important to evaluate which insects are attracted to or deterred from the plants since they may be beneficial or deleterious (Kring and Schuster, 1992; Zalom, 1981b).

II. LITERATURE REVIEW

2.1 HISTORICAL BACKGROUND

Peppers have been a staple of the Amerindians from northern Mexico to Columbia since prehistoric times. The oldest known records show that peppers were eaten as early as 7000 B.C. By the time Columbus arrived in 1492, the Amerindians had already domesticated four to five species which were used as spices or as insect and animal repellents. Columbus is thus thought to have been responsible for the dispersal of the pepper to the Old World. The plant obtained its name from its pungency which was reminiscent of black pepper, a desired commodity of that time (Andrews, 1984).

The migration of pepper is difficult to follow because of its rapid spread. However, it is known that it reached Spain by 1493, Italy by 1526, Germany by 1543, and the Balkans before 1569. It was most likely brought to Africa and the Far East by 1498, by Portuguese explorers and traders (Andrews, 1984). Within 100 years, it had spread throughout Europe and parts of Africa and Asia. Within 200 years, it had spread throughout the world (Somos, 1984). The spice was integrated into so many cultures that its New World origin was soon forgotten and it was long regarded as a native of Africa and India. It was reintroduced to the North American continent by the early English colonists (Andrews, 1984).

Some of the reasons for its rapid spread were that the seeds remained viable for several years, they were readily transportable, and the plants were suited to the climatic conditions of most countries in the world. Today, it is the most widely used condiment and spice in the entire world, having displaced black pepper (Andrews, 1984).

2.2 NUTRITION AND USE

Peppers are part of many processed foods either to flavour them and/or to give them colour. A pungent, hot flavour comes from the capsaicin compound found in hot peppers. This is what gives mixed spices such as curry powder and chili powder, as well as condiments such as pimento and salsa, their hot, spicy flavour. It also contributes in part to the flavour of ginger ales. It is this compound that is the active ingredient of some of the organic insect and animal deterrents, and the active component in the human deterrent 'Mace'. Both the sweet and the hot peppers are often used as a colouring agent in sausages and other meats, cheeses, salad dressings, and other prepared foods (Andrews, 1984).

Peppers are an excellent source of vitamins C and A. They have more than the usual recommended doses, especially green peppers which contain more vitamin C than red peppers. One mL of pepper juice contains 21-34 mg of vitamin C, exceeding lemon juice, which has 0.5 mg. Processed forms of pepper retain most of their vitamin C content, except for dried peppers. Vitamin C is known to prevent scurvy and has been shown to be an anti-carcinogen. Vitamin A is important for protecting skin, promoting growth, and ensuring the quick adaptability of the eye. Pepper is also a good source of the vitamin B complex (Andrews, 1984).

2.3 BOTANY

Peppers (as well as potatoes, eggplants, and tomatoes) belong to the Solanaceae family. The genus, *Capsicum*, contains twenty to thirty species native to America, and one doubtful species, *C. anomalum*, native to Japan. Of these, there are five domesticated species: *C. annuum*, *C. frutescens*, *C. pubescens*, *C. chinense*, and *C. baccatum*. In addition, there are three to five semi-domesticated species (Andrews, 1984).The most commonly grown species of pepper is the sweet pepper, *C. annuum*.

The pepper plant can be erect, prostrate, or compact in form, with dichotomous branching. The leaves grow from the stem in an alternate pattern. The young stem is green, then becomes streaked with grey, and finally turns brown. It has a fibrous root system in annual culture since the tap root is injured during transplanting, while, if direct seeded, it has a tap root (Somos, 1984).

After germination the plant grows vegetatively, becoming woody with age. The plant has a single stem until 9-11 leaves are formed and then it terminates with a flower cluster. This signals the two to three axillary buds closest to the apex to "break", thus forming two to three branches. Each of these branches will form approximately two leaves and then terminate in a flower cluster. This cycle of dichotomous branching repeats itself. Thus, the plant has a sigmoidal growth curve which results in the inverted conical shape of the plant (Andrews, 1984; Dorland and Went, 1947; Rylski and Halevy, 1972; Thomas and Watson, 1988).

Pepper flowers are borne either solitarily or in cymes in the branch axils. Each flower is produced on a single peduncle. The size of the flower can range from 1.2-3.5 cm. The calyx has five wholly or partly united sepals. The corolla is white and is made of five lobes. There are usually five stamens which are adnate to the base of the corolla and alternate to the corolla lobes. The anthers dehisce longitudinally and are blueish-purple in colour. The ovary can have two to five locules. In the case of *C. annuum*, four locules are desired in order to obtain a blocky-shaped fruit. The pistil is usually shorter than or equal in length to the stamens, but may be longer. Thus, the flowers are often self-pollinated, but are occasionally cross-pollinated. The stigma is club-shaped or dilated and becomes mucilaginous when receptive. It is only receptive the first day that the flower is open (Andrews, 1984; Cochran, 1938). Temperature and photoperiod have a great influence on anthesis (Cochran, 1938).

The fruit is called an inflated berry which describes the hollow interior (Somos, 1984). The base of the mature fruit is seated on the calyx. In the wild, the fruit separates easily from the calyx, but domesticated peppers have been selected for a persistent type, which remains attached. This type has better storage qualities since there is a reduced chance of secondary invasions through the wound. Some breeders are returning to the easily detached calyx for processing peppers, to facilitate machine harvesting (Andrews, 1984).

2.4 ENVIRONMENT

All solanaceous plants are warm season crops and are sensitive to low temperatures. However, of the main solanaceous vegetable crops, pepper and eggplant have higher temperature requirements than tomato and potato (Monteiro and Portas, 1986; Splittstoesser and Brown, 1991). Temperature has been found to be the most important factor affecting fruit set of pepper, with night temperature being the most critical. The optimum night temperature for bud development ranges from 15.5-20.5°C. Pepper flowers have the highest rate of fertilization when daytime temperatures are between 21-27°C and nighttime temperatures are between 18-27°C (Cochran, 1938). Fruit will not form at temperatures above 30°C due to excessive transpiration (Shelby et al., 1978). Highest germination of the pollen will occur at temperatures between 21-29°C when coupled with high humidity. The styles elongate when the temperatures are between 32-38°C and humidity is low (Cochran, 1938). This makes self-pollination an unlikely event because the stigma is then above the level of the anthers.

A deep sandy or sandy loam soil that is well drained with a pH between 7.1 and 8.3 is ideal for this crop (Andrews, 1984). Raised beds are commonly used in pepper production to improve soil drainage and decrease disease incidence (VanDerwerken and Wilcox-Lee, 1988). A well drained soil is important as the roots must remain well aerated. However, the plants do respond well to water. The peak moisture requirements occur during blooming and fruit setting (Andrews, 1984). Madramootoo et al. (1993) found that a minimum of 600 mm of irrigation (including rainfall) is required for peppers growing in Québec.

2.5 IRRIGATION

Drip irrigation may help control disease, improve fruit quality, and allow for fertilizer application in the irrigation water (Bhella, 1988; Locascio et al., 1989; Sweeney et al., 1987; Tan, 1995). The disadvantages of drip irrigation include the high cost of installation and removal of tubing, and the interference with field operations. The advantages to sprinkler irrigation are a lower plant canopy temperature, and frost protection in the early season (Tan, 1995). Tan (1995) found that, in general drip irrigation gave higher yields than sprinkler irrigation, but this was only significant in one out of the four years that the experiment was conducted.

High frequency trickle irrigation (15X) resulted in yields similar to those obtained using low frequency irrigation (5X) when peppers were mulched. The yields from plots which were mulched but not irrigated were similar to those which were sprinkler irrigated, but not mulched. The number of marketable fruit from plots which had no irrigation and no mulch was very low due to the high incidence of sunscald and blossom end rot (VanDerwerken and Wilcox-Lee, 1988).

2.6 NITROGEN

2.6.1 Nitrogen Requirements

The form of nitrogen (N) and the ratio of the forms available to peppers have a large influence on plant growth. Marti and Mills (1991) showed that fruit yield was not significantly reduced until the ratio of ammonium (NH_4^+) to nitrate (NO_3^-) was greater than 50%. Their results show that although the N content of the plant increases with NH_4^+, vegetative and reproductive yield do not. Hartman et al. (1986) had similar findings with tomato. Their explantation for this was that with more NH_4^+ in the fertilizer, more carbon (C) is used for the detoxification of the NH_4^+, instead of being allocated for vegetative or reproductive growth (Hartman et al., 1986). Therefore, the ratio of NH_4^+ to NO_3^- is an important consideration when choosing a fertilizer.

The optimum amounts of N for pepper production have been extensively evaluated (Batal and Smittle, 1981; Locascio et al., 1981; O'Sullivan, 1979; Payero et al., 1990; Stroehlein and Oebker, 1979). These sources reported maximum productivity at N fertilization rates ranging from 70 kg/ha (O'Sullivan, 1979) to >200 kg/ha (Locascio et al., 1981). This difference is the result of regional and seasonal differences in environment and cultural practices which affect the N availability and uptake efficiency. Therefore, it is difficult to compare optimum N rates since there are also differences in N application, and cultural practices which may influence N losses (Hartz et al., 1993).

Fletcher et al. (1993), Locascio and Fiskell (1977), and Riggs (1994) all showed that pepper yield had a quadratic response to N fertilization. In the study done by Riggs (1994), it was shown that over-fertilized plants had fewer fruit and more disease, but were bigger. The dense plant canopies were slower to dry, creating a more favourable environment for disease infection and spread.

Since N fertilizers are relatively inexpensive and N deficiencies can cause substantial yield decreases, producers tend to over-fertilize their crops. Thus it is possible that some producers are suffering yield losses from over-fertilization. Improving the efficiency of N fertilization would reduce the amount of N that may contaminate water resources while attempting to obtain optimal yields.

2.6.2 Increasing Nitrogen Efficiency

There have been efforts made in the past to develop methods of increasing N application efficiency. For example, drip irrigation has become a common method of irrigation in pepper production. This practice decreases the amount of irrigation and reduces fertilizer application due to a decrease in leaching losses. Drip fertigation applies the N close to the plant and avoids fertilizing the weeds. Plastic mulch also decreases leaching losses and increases the release of N from non-fertilizer sources by creating an ideal temperature and moisture environment in the surface layers where the organic matter is present. This ideal microenvironment favours rooting, which leads to greater uptake of N early in the season (Minotti, 1995). However, the information regarding optimal drip fertigation levels is limited.

Studies have attempted to increase the efficiency of N by applying it according to the stage of growth of the plant. Miller et al. (1979) found that the highest accumulation rate of N, phosphorus (P), potassium (K), Ca, and magnesium (Mg) occurred 28-42 days after transplanting. However, the highest nutrient uptake occurred 56-70 days after transplanting. This period of nutrient uptake corresponds with rapid fruit growth. Ninety-eight days after transplanting, the plants had absorbed 118 kg/ha N, 15 kg/ha P, 123 kg/ha K, 41 kg/ha Ca, and 32 kg/ha Mg. Riggs (1994) found that results did not differ if the N was applied weekly or if it was applied according to the stage of growth of the plant.

Soil tests have been useful in adjusting fertilization schemes, but they do not reveal whether or not the plant will be able to take up the N present in the soil. In addition, soil tests need to be analyzed in the laboratory which takes both time and money. Therefore, researchers have been analyzing the possibility of plant tissue tests in order to identify N deficiencies quickly and efficiently. The amount of whole leaf N (Tables 1 & 2) has been found to have fairly consistent results for the various stages of plant growth. The sufficiency concentrations in Table 1 refer to ranges of tissue N concentrations needed for normal growth at various stages of plant development. The lower values of the ranges are the minimum N percentages required in the plant in order to prevent N deficiencies. These values are also the critical leaf N concentrations listed in Table 2. The upper values of the ranges are the N percentages in the plant where luxury consumption begins (pers. comm., Dr. George Hochmuth, University of Florida).

Table 1: Pepper leaf N sufficiency concentrations

first flower buds	4.5-5.0%
first bloom	4.0-4.5%
fruit half grown	4.0-4.5%
first harvest	3.5-4.0%
second harvest	2.5-3.0%

Hochmuth (1994)

Table 2: Critical pepper leaf N concentrations

prior to blossom	4%
first bloom	3%
early fruit set	2.9%
early harvest	2.5%
final harvest	2.5%

Fletcher et al. (1993)

These known leaf N concentrations can help determine whether or not a plant tissue test is accurately identifying N deficiencies. A tissue test which is quick and accurate could be used in order to apply N only when necessary. Until recently, plant tissue analysis has been time consuming and expensive. However, now there are several meters which can be used in the field. There are portable nitrate selective electrodes, and a chlorophyll meter, which are useful for giving quick indications of the N status in the plant (Hartz et al., 1993).

2.6.3 The Soil Plant Analysis Development (SPAD) Meter

The SPAD-502 (Minolta-Canada Inc., Mississauga, ON) is an instrument which measures the relative amount of chlorophyll in the leaf. It does this by measuring the transmittance in two different regions of the light spectrum, at the 650 nm wavelength and at the 940 nm wavelength. The transmittance at 940 nm is used as a reference to compensate for factors such as leaf moisture content and thickness. The transmittance at 650 nm is sensitive to chlorophyll a and b, but not to varying levels of carotene. A ratio of these two values is calculated by the meter. The value given by the meter is a SPAD value which is proportional to the chlorophyll content. The SPAD value can range from 0-80 and is a dimensionless value because it is a ratio. The amount of chlorophyll is indicative of the nutritional status of the plant. As the amount of N in the leaf increases, the amount of chlorophyll increases as well. Thus the meter can be used to improve fertilizer efficiency. If the values are low then the plant is not obtaining the N it needs. Likely, the N is lacking in the soil, and fertilization is necessary. If the values are high, N application may not be required (Wood et al., 1992).

The SPAD tissue test is advantageous over other tissue tests because it is not affected by luxury consumption; a plant can not produce more chlorophyll if N is in excess because other factors required for chlorophyll may be limiting. As well, it is a quick procedure that the producer can easily do throughout the growing season in order to monitor the N status of the plant. Corrections can be made in the fertigation system, especially with a drip irrigation system since the fertilizers are applied directly into the root zone (Paterson et al., 1993). The method is also non-destructive to the plant. Blackmer and Schepers (1995) point out another advantage: this N management approach accounts for fluctuations in seasonal N availability.

Monitoring chlorophyll content in order to time N fertilization has been successfully done in Japan with rice, because there is a direct correlation between the SPAD reading and the N status of the rice plant. However, with other crops there is not such a clear relationship. In experiments done on corn with SPAD chlorophyll readings, it was found that there is a nearly linear relationship between the SPAD readings and the tissue N (Woods et al., 1992). There is a relationship between corn N status and chlorophyll content, but the correlation is not as high as it is in rice. This is due to the fact that the total N content in a plant varies during the various growth stages of the plant. In corn, only 50%-70% of the total leaf N is associated with the chloroplast, a large proportion of the remaining N is in the nitrate form which is not associated with the chlorophyll molecule (Dwyer et al., 1994). However, in rice there is a low amount of nitrate N found in the leaves at any stage of growth.

In corn, if there is an increase in the N level applied then there is also an increase in the amount of nitrate N. Since the SPAD values are not influenced by increases in nitrate levels, they are not affected by the plant's luxury consumption when high levels of N are applied. However, since the readings do fluctuate with the stage of plant development, the readings must be compared with reference plants which are slightly over-fertilized. This comparison or ratio of the crop average SPAD reading to the reference SPAD reading, is called the sufficiency index of the crop. In Nebraska, it has been recommended, in the case of corn production, that the entire field is given half to two-thirds the recommended rate of preplant N. They also recommend three to five reference strips in every field receiving a preplant N rate which is slightly higher than the recommended amount. The average reading of thirty plants in the field should be compared with the average of 30 plants in the reference strip. The leaf sampled is the most recently fully expanded leaf each week. It was also recommended that if the readings fall below the sufficiency index, then the plants should be checked again four to six days after additional N has been supplied, in order to ensure that the deficiency has been corrected (Paterson et al., 1993).

Blackmer and Schepers (1994; 1995) used a sufficiency index of 95% for a corn crop. If the values from the field were below this reference point for two consecutive weeks the plants were deemed N deficient. They demonstrated that if N deficiency was detected, a correction could be made without reducing yields.

Hartz et al. (1993) showed that relative chlorophyll concentration of pepper plants was poorly correlated with whole-leaf N concentration. In other words, much of the N in leaves may not be present in chlorophyll. However, the SPAD ratio of a field sample to a reference strip sample showed promise in detecting N deficiencies quickly, thus allowing for the application of N in time to avoid significant yield reductions.

Schepers et al. (1992) found that in corn, both grain yield and the chlorophyll meter readings reached a plateau at N rates over 225 kg N/ha. However, leaf disk N concentrations continued to increase until the rate of 300 kg N/ha even though the crop was unable to use the additional N. According to their results, leaf chlorophyll content or leaf greenness, as measured by the SPAD 502 chlorophyll meter may provide a better estimate of potential yield than leaf N concentration. Although environmental variations may limit the use of the meter as a method of determining leaf N concentration, the meter is a good yield indicator. Schepers et al. (1992) also found that the form of N may have an effect on the meter readings. Urea with the nitrification inhibitor form of fertilizer produced the highest yields. However, since neither the chlorophyll meter readings nor the leaf N concentrations showed any consistent difference between the N sources, it was concluded that the factors contributing to the higher yields were expressed before or after the time of tissue sampling.

2.6.4 Factors Influencing Chlorophyll Content

There are many factors which influence chlorophyll content. Water stress and genetic differences between cultivars have been shown to affect chlorophyll content (Schepers et al., 1992). In turfgrass, the amount of chlorophyll was a function of soil temperature, cover density, and N fertilization (Ledeboer et al., 1971). In wheatgrass, the greatest chlorophyll production occurred at 24/13°C day/night temperature regime (Bokhari, 1976). The developmental stage of the plant can influence chlorophyll concentration. The leaf chlorophyll content has been shown to decrease at flowering and fruiting in *Oenothera biennis* (Saulnier and Reekie, 1995). Within the plant, chlorophyll tends to be significantly higher in the younger leaves compared with the older leaves since N is translocated from older to younger leaves (Grunwald et al., 1971). Other nutrients also play a factor in the chlorophyll content of the leaves. Iron (Fe), manganese (Mn), and sulphur (S) deficiencies cause chlorosis in spinach and potassium (K) deficiency has been shown to significantly increase the dark green colour of the leaves. Originally, this dark green colour was thought to be the result of an increase in chlorophyll content in the chloroplasts. However, Bottrill and Possingham (1969) showed, in a series of tissue tests, that chloroplasts from S and K deficient plants contain lower amounts of both chlorophyll and N than plants grown on full medium. The size of K deficient cells was smaller than those grown on full nutrient medium. Consequently, there was an increase in chloroplast density which gives the leaves a darker green colour. Manganese deficient plants had chloroplasts with half as much chlorophyll, but the same amount of N as the plants grown on a full medium. Iron deficient plants had the same amount of N, but a smaller amount of chlorophyll than plants grown on full nutrient. Iron deficient plants exhibited the deficiency more on younger than older leaves (Bottrill and Possingham, 1969). Turner and Jund (1991) found that deficiencies of phosphorus, zinc, manganese, and iron may influence SPAD readings.

2.7 INSECTS

2.7.1 Problem Insects

There are approximately eight insects that cause problems in pepper production in Canada (Howard et al., 1994), three of which are of concern in Québec (pers. comm., Guillaine Mercier, PRISME: St-Hyacinthe, Qué). These are aphids, tarnished plant bug, and European corn borer.

2.7.1.i Aphids

The most common types of aphids on peppers are the green peach aphid, *M. persicae*, and the potato aphid, *M. euphorbiae*. Aphids are present throughout North America. The aphids colonize pepper plants on the abaxial leaf surfaces and in, or around, the flowers. Aphid populations can increase rapidly in hot, dry weather. Population explosions also occur after insecticidal treatment against the Colorado potato beetle, one of the aphid's predators. Aphids transmit the following viruses to solanaceous crops: cucumber mosaic virus, alfalfa mosaic virus, potato virus Y, and tobacco etch virus. Aphids do not cause significant losses in production, except during dry seasons, when they reduce growth and therefore lower yields. Leaves become twisted and cupped from the aphids feeding in clusters. Additional damage also results from the honeydew which supports the growth of mold reducing the economic value of the fruit (Howard et al., 1994).

All species of aphid have several generations each season. Of the species listed by Carr (1979), aphids range from having 10-20 generations per year (pea aphid, *Acyrthosiphon pisum*) to having innumerable generations per year (green peach aphid, *M. persicae*).

Aphids overwinter as eggs laid in the fall on host plants and hatch in the spring. This first generation consists solely of females which asexually give birth to females. As the aphids become overcrowded, a generation of winged females occurs. They fly to a new host plant and produce more wingless females. They can also be moved to a new plant by ants when food becomes scarce. Ants provide this service to the aphids and protect aphids from other predators in exchange for the honeydew that the aphids produce. Toward the end of the summer, a generation of males and true females (females requiring fertilization for reproduction) are produced, these mate and produce the eggs for the following year (Carr, 1979).

2.7.1.ii Tarnished Plant Bug

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), feeds on the flowers and stems of green beans (Stewart and Khattat, 1980), strawberry (Handley and Pollard, 1993), raspberry, apple (Mailloux et al., 1979), tomato, eggplant, and pepper (Howard et al., 1994). The bugs pierce the leaf and flower parts leaving small bleached areas as they draw out the sap. This often causes flower drop (Carr, 1979). Fruit of pepper may also be attacked leading to indentations in the surface of the fruit (Howard et al., 1994). Khattat and Stewart (1975) found that the damage was caused by either the fifth instars or the adults.

The optimal oviposition occurs between 21-27°C. In southern Québec, these temperatures usually occur towards the end of May. The first generation appears about mid June usually on strawberry plants. The adults from this generation will migrate towards other host plants such as raspberry, garden bean, potato, pepper, turnip, sugar beat, red clover etc.

In southern Québec, at least 2 generations will occur, sometimes 3. The eggs of the final generation overwinter in debris and can sustain low temperatures of 10°C for 15 days without adverse effects (Bostanian, 1994).

Lindquist and Sorensen (1970) found that tarnished plant bugs were more attracted to alfalfa plants which were heavily infested with aphids than alfalfa plants which were uninfested with aphids. A similar sort of attraction was also produced when the uninfested alfalfa plants were sprayed with a sugar solution. The tarnished plant bug seems to be attracted by sweet smells, such as those of flowers or of the honeydew that the aphids excrete. They also found that a tarnished plant bug ate on average 2.25 aphids per day.

2.7.1.iii European Corn Borer

Field pepper is an important host of the European corn borer, *Ostrinia nubilalis* (Hubner), but not as important as sweet corn. In Canada, the areas of highest pepper production, southwestern Ontario and Québec, are in corn producing areas and have the highest European corn borer populations (Howard et al., 1994; Royer and McNeil, 1993).

The larva of the European corn borer is a greyish pink caterpillar with a dark head and spots on the top of each segment. The caterpillar grows to be about 2.5 cm long. The adult is a yellowish brown moth with dark bands on the wings. (Carr, 1979). The larva enters the fruit usually near the calyx stem cap, often leaving saw-dust-like droppings around the hole. The possibility of the larvae being inside the fruit, given by the presence of the hole near the calyx, renders the fruit unmarketable. The fruit are damaged from mid-July to early August. If there are two generations, then damage may occur through September (Howard et al., 1994).

2.7.2 Use of Mulches in Insect/Disease Control

Aphids are the most important pests in agricultural systems in temperate climatic zones, according to Minks and Harrewijn (1987). This is mainly due to their ability to vector many diseases. Basky (1984) found that aphids were 70-80% effective in transmitting viruses. The green peach aphid is the most efficient vector of mosaic viruses (Toscano et. al., 1979). In the United States its potential as a disease vector results in up to eight applications of insecticides on peppers per year (Cartwright et al., 1990).

Some of the methods of aphid control are: the application of insecticides, the use of yellow sticky boards, mineral oil sprays, and mulch. The ineffectiveness of insecticides in controlling nonpersistent, insect-transmitted viruses has been well documented. The vectors are able to transmit the viruses in seconds. Consequently, the viruses are transmitted before the insecticide kills the vector (Brown et al., 1993; Kring and Schuster, 1992; Tachibana, 1981; Toscano et al., 1979; Wyman et al., 1979). Furthermore, Brown et al. (1993) found that insecticides used in combination with a silver mulch had no advantage over a silver mulch treatment alone. However, the use of systematic insecticides does reduce the number of aphids present, which decreases the population of the second generation, thereby reducing viral infection later in the season.

The number of yellow sticky traps necessary in order to reduce an aphid population can be as high as one board per plant. In addition, sticky boards have the negative effect of trapping the lady beetle, *Hippodamia convergens*, which is a predator of aphids (Corsoro et al., 1980).

Mineral oil concentrations which were not found to be phytotoxic, were much less effective than the two colours of mulch (white and aluminum) tested in controlling aphid populations and viral infections (Toscano et al., 1979).

In a study done by Brown et al. (1993) with summer squash, silver mulch and other coloured mulches (white, yellow, and black with yellow edges) were compared with a bare ground control. They found that silver mulch was superior in repelling winged aphids and that the other colours had effects intermediate between those of bare ground and silver mulch. Researchers have found similar results with a range of crops such as bell peppers (Cartwright et al., 1990), yellow squash (Conway et al., 1989), lupin (Jones, 1991), tomato (Kring and Schuster, 1992; Schalk and Robbins, 1987), faba bean (Tachibana, 1981), summer squash (Toscano et al., 1979), cucumber and southernpeas (Schalk et al., 1979).

In one study, the silver mulch delayed the onset of viral disease by 10-13 days compared with bare ground. Decreases in winged aphid populations, in disease infection, and in the delay in onset of disease, can each translate to an increase in yield (Brown et al., 1993). Although, there is a delay in winged aphid colonization of the pepper plants grown on mulches, there is a higher rate of multiplication resulting in an increase of non-winged aphids on the plants. This may be due to the improved microclimate for the plants grown on mulches which results in succulent plants which are conducive to aphid feeding and reproduction (Cartwright et al., 1990; Zalom, 1981a). In lupin production, reflective mulches were shown to decrease the spread of viruses by either decreasing the infection from external sources or by reducing the spread of infection within a row (Jones, 1991). The effectiveness of reflective mulches in this experiment, depended on the cloud cover during the peak period of winged aphid activity. One season had a two to three week cloudy and rainy period, during which the disease spread. The trials also revealed that reflective mulches are most effective if the ground is slightly sloping so that the soil particles on the surface of the mulch (which decrease the reflectivity) are washed away with precipitation.

Reflective mulches seem to have a greater effect when used for pepper rather than for tomato production, probably because the pepper plant is smaller and therefore does not cover as much of the reflective surface (Kring and Schuster, 1992). As well, aluminum mulch attracts certain tomato insect pests, but has not been found to attract any pepper insect pests. For example, Schalk and Robbins (1987) found that although reflective mulches decreased aphid populations, they increased tomato pin worm (*Keiferia lycopersicella*) and tomato fruit worm (*Heliothis zea*) in tomato production.

Thus it has been well documented that plastic mulches, particularly reflective mulches, are useful in controlling winged aphid populations and viral infections. Mulches are also more effective at reducing winged aphid populations than the above alternative methods. This effectiveness can be attributed to two main factors. First, plastic mulches inhibit weed growth and therefore there is a reduction in the number of host plants in the agricultural system. Secondly, plastic mulches reflect UV light which prevents the winged aphids from detecting plant colour and therefore averts landing on and infection of the host plants (Brown et al., 1993; Jones, 1991; Toscano et al., 1979; Zalom, 1981a). Reflective mulches also reflect the sky's colour, which confuses the aphids and causes them to change their flight direction away from the plants (Corsoro et al., 1980). Silver mulches have shown to increase pepper yield by 22% in comparison with black mulch (Heacox, 1995).

There are other insects which reflective mulches have also been shown to deter or attract. Several researchers have found that reflective mulches reduce the number of thrips, *Franklinielli* spp. (Kring and Schuster, 1992; Schalk et al., 1979; Scott et al., 1989). Studies have shown that populations of leafhopper, *Macrosteles fascifrons* (Zalom, 1981b), *Empoasca fabae* (Wells et al., 1984), whiteflies, *Trialeurodes* spp. (Kring and Schuster, 1992), banded cucumber beetle, *Diabrotica* spp. and leaf miner, *Liriomyza* sp. (Schalk et al., 1979) decreased on crops grown using reflective surfaces. However, aluminum and brown mulches seem to attract honey bees (*Apis mellifera* L.) and pickleworm (*Diaphania nitidalis*) (Schalk et al., 1979).

2.8 VIRUSES

There are eight known viruses that affect peppers in Canada. In Québec, most of the viral infections are cucumber mosaic virus or are complexes with cucumber mosaic virus. Cucumber mosaic virus can affect a wide variety of crops in Canada including clover, corn, cucumber, French bean, lettuce, melon, pepper, tomato, safflower, spinach, squash, and sugar beet. Infected pepper plants will exhibit large, necrotic rings on the older leaves. The fruit may be deformed, with yellow, concentric rings and/or spots on the immature fruit. In the field the virus is efficiently spread by the green peach aphid, *Myzus persicae* (Sulzer), but may also be spread by the potato aphid, *Macrosiphum euphorbiae* (Thomas), and melon aphids, *Aphis gossypii* (Howard et al., 1994; Sherf and MacNab, 1986). However, some viruses, such as PVY, can lose their ability to be transferred by aphids because of mutations in the genome region that encodes the helper component involved in aphid transmission (Thornbury et al., 1990).

2.9 SUNSCALD

Sunscald usually affects the fruit tissue, but may also affect leaves and stems. It causes a collapse of the mesophyll. The affected areas are sunken, light brown to white in colour, and may be wrinkled. These areas are also susceptible to invasion by secondary pathogens. Sunscald occurs if the fruit or young leaves are exposed to direct sunlight due to inadequate protection by the older leaves. The problem is aggravated by high humidity, high temperature, and wind whipping (Howard et al., 1994; Sherf and MacNab, 1986). Barber and Sharpe (1971) found that fruit which were exposed to full sun for 10 minutes with fruit surface temperatures of greater than 49°C were damaged by sunscald. In Australia, 50°C surface temperatures could be reached at an air temperature of 30.5°C on a clear day.

VanDerwerken and Wilcox-Lee (1988) showed that, because of high levels of sunscald and blossom-end rot on the non-mulched, non-irrigated plots, the percentage of marketable peppers increased with irrigation or mulch. Efforts have been made in Canada and in the northeastern United States to grow vegetable crops in the shade, to reduce the amount of sunscald. Shade increased foliar development, but retarded fruit and root development (Roberts and Anderson, 1994). Roberts and Anderson (1994) found that rowcovers in

Oklahoma helped shade the plants enough to reduce the amount of sunscald without significantly reducing the chlorophyll content of the leaves.

Once a green pepper turns red, it is much less likely to get sunscald. This has been reported to be due to the thermal stability of carotenoids and the increased osmotic pressure of mature fruits (Barber and Sharpe, 1971).

III MATERIALS AND METHODS

3.1 TRANSPLANTS

In 1995 and 1996, 'King Arthur' peppers (*Capsicum annuum* L.) were obtained from Petoseed Company (Saticoy, CA). This cultivar is a hybrid which is resistant/tolerant to bacterial spot race 2 (BSP-2), tomato (tobacco) mosaic virus (TMV), potato virus Y (PVY), and tobacco etch virus (TEV). In the 1997-1998 Norseco Co. (Laval, Qué) seed catalogue, 'King Arthur' is characterized as having early to mid-season maturity and high yields. It produces a medium green fruit which ripens to a brilliant red. It is a reliable cultivar, which sets fruit well under high temperatures, has a large size, and has a blocky-shaped fruit.

The seeds, which were treated with Thiram (tetramethylthiuram disulphide) were sown in trays containing moistened ProMix BX (75-85% Canadian sphagnum peat moss, perlite, vermiculite, dolomitic and calcitic limestone, wetting agent) in the greenhouse at Macdonald Campus of McGill University in mid-April. In 1995, the trays were kept under natural daylight conditions. The trays received 13-14 hours of daylight. Day temperatures varied between 20°C-26°C (depending on cloud cover and outside temperature) and night temperatures were approximately 20°C. In 1996, the trays received 15 hours of light. Light was supplemented by high pressure sodium (HPS) lamps when necessary. Day and night temperatures were maintained at 23°C and 18°C, respectively. The seedlings were irrigated as required. When the seedlings had four true leaves, they were transplanted into 6 cm X 6 cm X 6 cm cells containing moistened ProMix BX and the plants were fertilized weekly at a rate of 200 ppm of 20-20-20 (N, P_2O_5, K_2O). When the plants were six weeks old, they were moved to the cold frames for acclimatization for approximately one week.

In 1995, the seedlings were infested with thrips, fungus gnats, and aphids while in the greenhouse. Initially, an insecticidal soap was used to control these pests. Biological controls were used as well. The lady beetle (*Hippodamia convergens*) was used to control the aphids. Parasitic wasps (*Hypoastis* spp. and *Cucumeris* spp.) were used to control the fungus gnats and thrips. In 1996, there was no pest infestation in the greenhouse.

3.2 STUDY SITE

The experiment was conducted in 1995 and 1996 at the Horticulture Research Centre of Macdonald Campus of McGill University in Ste. Anne-de-Bellevue, Québec (45°24.5'N, 74°56'W). The soil was classified as a St. Bernard sandy loam with a Ph of 6.9.

3.3 EXPERIMENTAL LAYOUT

A randomized complete block design with three blocks and eight treatments was used. The treatments are listed in Table 3. Four treatments received fertilization above a preplant application and four treatments did not. The additional fertilizer that the four fertilized treatments received was a 7 g/L stock solution of 24-10-20 (N, P_2O_5, K_2O). The four fertilized treatments were drip irrigated and consisted of two fertilization regimes, each of which was evaluated in combination with a silver and a black mulch. Treatments 1 and 2 [**B**lack mulch, **D**rip irrigated, **W**eekly Fertilized (**BDW**) and **S**ilver mulch, **D**rip irrigated, Weekly Fertilized (SDW)] received an additional 40 kg N/ha and 60 kg N/ha applied over 10 weeks at a rate of 4 kg N/ha and 6 kg N/ha each week in 1995 and 1996, respectively. Treatments 3 and 4 [Black mulch, Drip irrigated, SPAD Fertilized (BDS) and Silver mulch, Drip irrigated, SPAD Fertilized (SDS)] were fertilized according to tissue analysis using the Minolta SPAD 502 chlorophyll meter. Readings were taken from five plants in each plot and were compared with readings from five plants in over-fertilized reference plots. The over-fertilized reference plots were fertilized on a weekly basis, receiving a total of 150 kg N/ha. If the ratio of these two plots fell below 95% (Hartz et al., 1993) then the SPAD treatments (BDS and SDS) were fertilized at the weekly-fertilized rate of that year. The other four treatments did not receive any additional fertilization and were as follows: 5) black mulch with drip irrigation (BDN), 6) bare soil with microjet irrigation in 1995 (NMN), silver mulch with drip irrigation in 1996 (SDN), 7) bare soil with drip irrigation (NDN), 8) bare soil without any applied irrigation (NNN).

Table 3: Mulch, irrigation, and N fertilized treatments in 1995 and 1996

Treatments			
Mulch	Irrigation	Fertilization	Code
1: **Black,**	Drip,	Weekly	**BDW**
2: Silver,	Drip,	Weekly	**SDW**
3: **Black,**	Drip,	SPAD	**BDS**
4: Silver,	Drip,	SPAD	**SDS**
5: **Black,**	Drip,	None	**BDN**
6: None,	Microjet,	None-1995	**NMN**
6: Silver,	Drip,	None-1996	**SDN**
7: None,	Drip,	None	**NDN**
8: None,	None,	None	**NNN**

Table 4 presents the amount of water supplied to each treatment in 1995 and 1996. With the exception of NMN, all of the irrigated treatments received approximately the same amount of water in 1995 and also in 1996. The NMN treatment received more water than the other irrigated treatments because twice the volume of water was required to cause the microjets to spin.

Table 4: Amount of water supplied (mm/plot) to each mulched, irrigated, and N fertilized treatment

Treatment	1995	1996
Black, Drip, Weekly (BDW)	399.5	211.3
Silver, Drip, Weekly (SDW)	399.5	211.3
Black, Drip, SPAD (BDS)	421.2	194.8
Silver, Drip, SPAD (SDS)	421.2	194.8
Black, Drip, None (BDN)	388.1	224.9
None, Microjet, None (NMN-1995)	523.3	
Silver, Drip, None (SDN-1996)		204.8
None, Drip, None (NDN)	381.8	175.2
None, None, None (NNN)	0	0

The plots were irrigated when the tensiometer readings at a depth of 30 cm had a pressure above 50 centibars (cb). The tensiometer readings at 60 cm were used, in the same manner, to schedule the duration of the irrigation. The 30-60 cm soil depth is used since nearly all vegetables grown with irrigation extract water from the top 60 cm of the soil and 75-95% of the roots are in the top 30 cm. It has been determined, that if the soil tension of a sandy loam soil is between 40-60 cb, then 50% of the available water has been depleted and irrigation is necessary to maintain soil moisture (Storlie, 1992). This practice has been recommended by extension services and producers find it a reliable, inexpensive method for scheduling irrigation (Fletcher et al., 1993; Storlie, 1992).

The fertilization treatments were chosen to evaluate whether or not the plants fertilized according to the SPAD tissue test (BDS, SDS) would require less fertilizer without reducing yields in comparison to the more conventional, weekly fertilized system (BDW, SDW). The silver mulch treatments (SDW, SDS, SDN-1996) were evaluated for their effects on insect and disease incidence, as well as the growth and yield of the plants in comparison to the black mulch treatments (BDW, BDS, BDN). The non-fertilized treatments on black (BDN) or silver mulch (SDN-1996) were evaluated in contrast to the other black mulch-fertilized treatments (BDW, BDS) or silver mulch-fertilized treatments (SDW, SDS), respectively in order to evaluate the differences in yield, insect and disease incidence due to fertilizers. The microjet irrigation treatment (NMN-1995) was added as a comparison to the drip irrigated treatment (NDN) in order to evaluate the differences in the spread of diseases. The treatment without additional fertilization, irrigation, or mulch (NNN) was the true control of the experiment.

Figure 1 is a diagram of an experimental plot. Each plot contained 31 plants. Nine of these plants were used for recording the yields. On either side of these nine plants were four guard plants, which were not used for collecting data. The remaining 14 plants were used for destructive sampling. On either side of each block, there was a guard plot. The purpose of the guard plots and guard plants were to avoid border effects. Data have been analyzed using the Statistical Analysis System (SAS) (SAS Institute Inc., Cary, NC) with the Student-Newman-Keuls (SNK) test at the α=0.05 level.

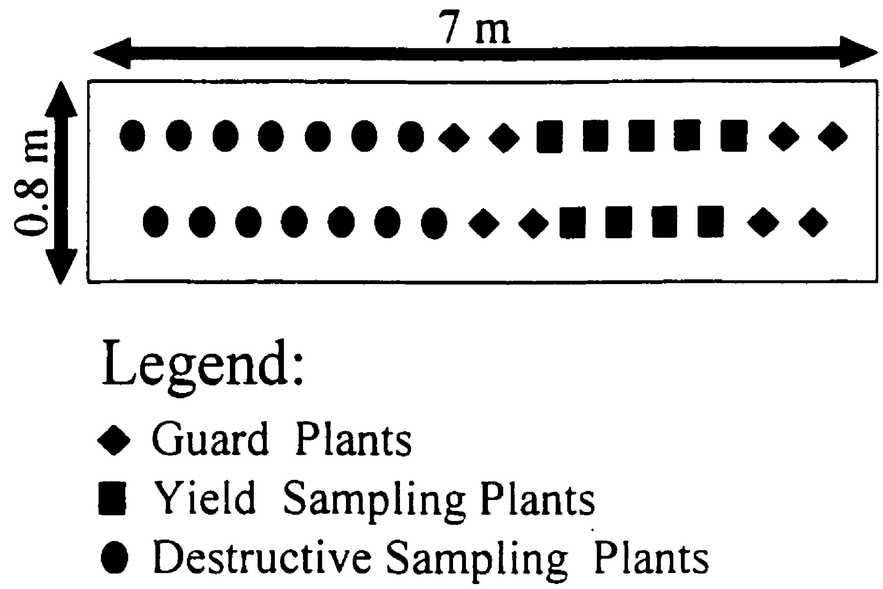


Figure 1. A typical experimental plot layout

D. FIELD PREPARATION

The field had been ploughed the previous autumn to a minimum depth of 20 cm with a mouldboard plow. In the spring, the field was disced with a Triple K cultivator and rototilled. Two weeks before transplanting, a preplant fertilizer 27-0-0 (N, P_2O_5, K_2O) was banded in the centre of each plot at the rate of 60 kg N/ha and 40 kg N/ha in 1995 and 1996, respectively. The total amount of fertilizer applied to each treatment is given in Tables 5 and 6, for 1995 and 1996, respectively. All the treatment levels are below the 140 kg/ha level recommended by the Conseil des Productions Végétales du Québec (C.P.V.Q.; 1982). The fertilizer levels were chosen according to a study which demonstrated that fertilization of peppers through a drip irrigation system required lower levels of fertilization to maintain economic yields (Rigby et al., 1988).

Table 5: Total amount of N applied (kg/ha) in 1995 to each mulched, irrigated, and N fertilized treatment

Treatment	Preplant	Fertigation	Total
Black, Drip, Weekly (BDW)	60	40	100
Silver, Drip, Weekly (SDW)	60	40	100
Black, Drip, SPAD (BDS)	60	12	72
Silver, Drip, SPAD (SDS)	60	12	72
Black, Drip, None (BDN)	60	0	60
None, Microjet, None (NMN)	60	0	60
None, Drip, None (NDN)	60	0	60
None, None, None (NNN)	60	0	60

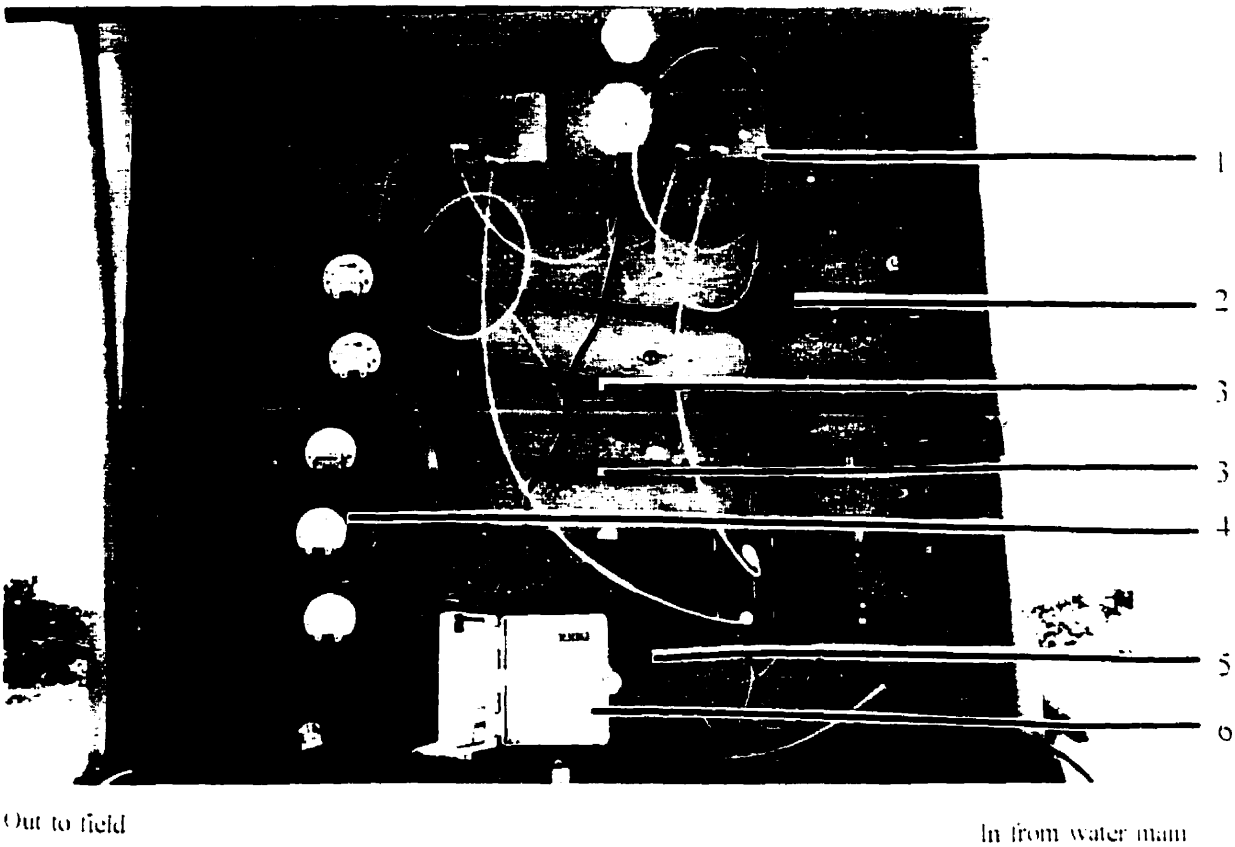
Table 6: Total amount of N applied (kg/ha) in 1996 to each mulched, irrigated, and N fertilized treatment

Treatment	Preplant	Fertigation	Total
Black, Drip, Weekly (BDW)	40	60	100
Silver, Drip, Weekly (SDW)	40	60	100
Black, Drip, SPAD (BDS)	40	18	58
Silver, Drip, SPAD (SDS)	40	18	58
Black, Drip, None (BDN)	40	0	40
Silver, Drip, None (SDN)	40	0	40
None, Drip, None (NDN)	40	0	40
None, None, None (NNN)	40	0	40

After banding the preplant fertilizer, the 0.0275 mm thick plastic mulch (Plastitec, St. Remi, Qué.) was laid with a mulch layer (Dubois et fils, St. Remi, Qué.) which was attached to a Massey Ferguson 245 tractor. The beds were 7 m long, 0.8 m wide, and 0.25 m high. The plots were spaced 1.2 m apart and the blocks were spaced 2 m apart to allow weeding machinery to pass between the beds.

The 9 mm thick drip tape (Vanden-Bussche Irrigation, Delhi, ON), located under the mulch on the surface of the bed, had drip holes spaced 30 cm apart. The drip lines were installed with the plastic mulch. The drip lines were connected to Netafin tubing (Vanden-Bussche Irrigation, Delhi, ON) which had a 1.5 cm (inside diameter) and 1.8 cm (outside diameter). The tubing was also used in the microjet plots. Six microjets were spaced evenly within a plot and connected directly to the tubing.

From each plot, the tubing was connected to an irrigation control box (Figure 2). In the control box, the tubing was connected to water meters in order to monitor the amount of water applied to each plot. The tubing then connected the water meters to a solenoid valve (Vanden-Bussche Irrigation, Delhi, ON) which allowed the water to flow out of the system. This valve was controlled by a 'Rainbird' irrigation controller (Vanden-Bussche Irrigation, Delhi, ON). The irrigation controller could also be programmed to supply water to specific treatments for a given time on a given day. A Mecomatic injection pump (MacDonald et Fils Inc., Montréal, Qué.) supplied fertilizer stock solution into the tubing of the plots which required additional fertilizer (BDW, SDW, BDS, SDS). The pump was calibrated to supply 1.5 L of stock solution every 30 minutes. Finally the tubing was connected to a water main which was kept at the same pressure in order to ensure that the concentrated fertilizer would



Legend:

1 Injection pump
2 Solenoid valve
3 Netafin tubing
4 Water meter
5 Filter
6 Rainbird controler

Figure 2: Diagram of irrigation box

be appropriately diluted during the fertigation process. The plots were irrigated for 15 minutes before and after fertigation in order to fill the irrigation systems with water and to ensure that all the fertilizer had been given to the plants.

The day of transplantation, 6 cm diameter holes were cut into the plastic mulch with a tulip bulb planter. The holes were staggered in a double row with 45 cm between the rows and 45 cm within the row. In each hole, a single seven week-old pepper transplant was planted, giving a plant density of 22,500 plants/ha. Each seedling was given 250 mL of a starter solution of 10-52-10 (N, P_2O_5, K_2O) at a concentration of 7 g/L.

3.5 MAINTENANCE

The plots without mulch were weeded on a regular basis. In 1995, the area around the plots was hand weeded in order to limit the number of alternate hosts for insects and disease. In 1996, a preplant herbicide, Treflan (trifluralin), was used at a rate of 0.6 kg ai/ha and the area around the plots was kept weed-free. Due to an unusually high population of aphids in the field in 1995, the plants were sprayed with an insecticide three times during the season. On June 13, 1995, Malathion (malathion) was used at a rate of 4 g/L. On July 5 and 8, 1995, Thiodan (endosulfan) was used at a rate of 4 g/L since it is also recommended against tarnished plant bug which also appeared at this time.

3.6 MEASUREMENTS

3.6.1 Growth Stage

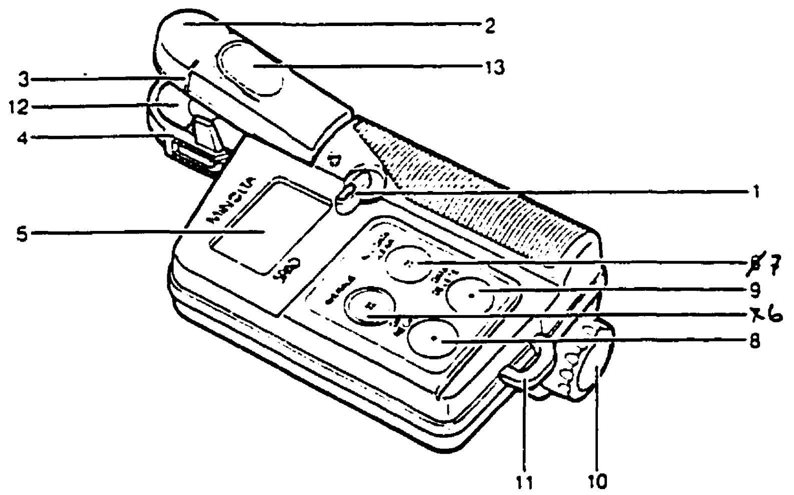
The date of flowering, early fruit set, and the date of first harvest were recorded for each treatment since N requirements vary with the growth stage of the plant (Fletcher et al., 1993; Hochmuth, 1994).

3.6.2 SPAD Chlorophyll Meter

SPAD measurements were taken once a week from five plants in the fertilized plots and five plants in the guard plots in order to create a sufficiency index (ratio of plot chlorophyll reading: over-fertilized plot chlorophyll reading). The purpose of this was to be able to identify when the SPAD fertilized treatments required fertilization and to know if the fertilized weekly plots were at any point considered N deficient according to the sufficiency index calculated.

Two leaves per plant were sampled. The leaves taken were the most recently expanded leaves (Blackmer and Schepers, 1995; Hochmuth, 1994; Turner and Jund, 1991; Wood et al., 1992). These are the leaves which are completely unfolded, have few wrinkles, and are approximately the same colour as the older leaves of the plant.

Figure 3 shows a diagram of the SPAD meter. Prior to taking a reading, the SPAD meter was calibrated. Calibration was done by turning the SPAD meter on and then clamping down the measuring head with no leaf sample inside. The actual readings can then be continuously taken as long as the meter is not turned off. The leaf sample is inserted into the sample slot (6 mm^2) of the measuring head which is clamped down around the sample. The



1. Power switch: Switches power on and off.
2. Measuring head: When closed, measurement is performed.
3. Center line: Indicates the center of the measuring area.
4. Sliding depth stop: Can be set to ensure that measurements of all samples are taken at the same distance from the sample edge. Can be removed if desired.
5. LCD panel: Displays data and other information.
6. **AVERAGE**: Calculates the average value of all data in memory.
7. **ALL DATA CLEAR**: Deletes all data in memory.
8. **DATA RECALL**: Recalls data stored in the previous data number to the display.
9. **1 DATA DELETE**: Deletes the displayed data.
10. Battery chamber cover
11. Strap eyelet
12. Sample slot: Samples are inserted here for measurement.
13. Finger rest: Press here to close measuring head.

Figure 3. Diagram of the Minolta 502 SPAD Meter (source: Minolta 502 SPAD Meter instruction manual)

measuring head must be kept closed until a value appears on the light-emitting diode (LED) screen. From each leaf three readings were taken on each side of the mid-vein. The average of the two leaves (12 readings) was then calculated by the meter. On a given plant, values which were inconsistent (values more than 10 SPADs above or below the average reading) were erased and taken again. The average of the two leaves was recorded for each plant. Sampling the entire field generally took 90 minutes between 9:00 am and 11:00 am.

3.6.3 Destructive Sampling

Every 15 days, SPAD readings were taken (in the manner described above) from two plants from each plot. These plants were then cut at the soil level. Leaf area was measured with the 'Paton Electronic Planimeter' (Paton Industries Ltd., Stepney, South Australia) and stem, leaf, and fruit fresh weights and dry weights were taken from the harvested plant. The dried leaf samples were then digested, distilled, and titrated using the Kjeldahl system (Tecator, Kjeltec System 20, Box 70, S-26301 Höganäs, Sweden) to determine the level of foliar N present. The foliar N was determined in order to evaluate the accuracy of the sufficiency index (as determined by calculations using values from the SPAD chlorophyll meter) in determining N deficiency.

3.6.4 Insects

The populations of aphids and tarnished plant bug (*Lygus lineolaris*) were monitored weekly in the plots.

Winged aphids were counted from 22.5 cm X 22.5 cm pan traps which were placed in the centre of each plot. The pan traps were painted a bright yellow (Toscano et al., 1979). Dr. Jacques Cartier (pers. comm., Ottawa, ON) recommended using an enamel paint made by the Flecto Company called Varathane yellow #1 and filling the traps half full with a saturated salt solution in order to preserve the insects. Initially, a saturated salt solution was put in the pan traps 24 hours prior to the insect counts. However, on windy days the salt solution blew out of the traps and caused some damage to the leaves of nearby plants. Accordingly, tap water was used in the traps.

Non-winged aphids were counted on three plants per plot. The abaxial side of the four lowest and largest leaves which were 90° apart on the stem were used for the counts. The number of single, colony I, colony II, and colony III aphids, groups of aphids containing 1-2, 3-5, 6-10, and > 10 aphids, respectively, were recorded. This method of indexing the aphids has been developed by PRISME (Production et Regie Integrée du Sud-ouest de Montréal Env.) as part of a scouting program to schedule spraying applications. In June 1995, the recommendation was to spray the plants with Pyrimicarbe (primor) or Thiodan (thiodan) if an average of two aphids per plant prior to the budding stage; an average of four aphids per plant from budding to fruit set; or an average of six colony III colonies per plant were observed during harvest (pers. comm., Guillaine Mercier, PRISME: St-Hyacinthe, Qué).

Tarnished plant bug (*L. lineolaris*) populations were counted on nine plants per plot. It is believed that tarnished plant bug is attracted by the sweet smell of flowers (Lindquist and Sorensen, 1970). Therefore, when counting tarnished plant bugs, the area around the flower clusters of each plant was observed and a total number of insects recorded for each plot.

3.6.5 Yield

The plants were harvested twice a week and graded according to commercial standards. The requirements for each of these grades of fruit is listed in Table 7. The number and weight of each of the marketable fruit grades (grade 1 and grade 2 fruit) as well as the culls were recorded. Harvested fruit were also evaluated for damage caused by viruses, sunscald, and European corn borer (*Ostrinia nubilalis*).

Table 7: Criteria for the grades of harvested fruit in 1995 and 1996*

Grade	Criteria
No. 1	-fruit weight > 100 grams -faint imperfections -three to four lobes
No. 2	-fruit weight > 100 grams -small imperfections -one to four lobes
Culls	-fruit weight < 100 grams -fruit weight > 100 grams and has large defects (blossom end rot, sunscald, rotting, etc.)

*The scheme used in the above table was modified from the classification schemes of Aziz (1994), Rigby (1988), Teolis (1994).

IV RESULTS AND DISCUSSION

4.1 METEOROLOGICAL DATA

Mean temperature data for the two years of the study are presented in Table 8. Mean temperatures for June and July were approximately 1.5°C cooler in 1996 than in 1995, with mean maximum temperatures approximately 2.5°C cooler. Mean August temperatures were nearly identical in both years (~20.3°C). Although September's temperatures were approximately 3°C cooler in 1995, 1995 was generally a warmer year than 1996.

Total monthly rainfall data for the 1995 and 1996 seasons are also presented in Table 8. Total rainfall in June was approximately 10 mm lower in 1995 than in 1996. The 1995 season was wetter, with a total of 366 mm compared with the 1996 season which had a total of 309 mm.

Table 8: Mean monthly temperatures and total monthly rainfall for the Montréal area during the 1995 and 1996 growing seasons

Month	Temperature (°C)						Rainfall (mm)	
	Maximum		Minimum		Average			
	1995	1996	1995	1996	1995	1996	1995	1996
June	26.3	23.6	14.0	13.6	20.2	18.6	56.6	65.5
July	27.4	24.9	16.9	15.4	22.2	20.2	122.1	106.0
Aug.	26.0	26.1	14.4	14.5	20.2	20.4	127.4	22.5
Sept.	19.3	21.1	7.4	11.5	13.4	16.3	59.6	115.1

Environment Canada (Montréal International Airport) (1995 & 1996)

4.2 NITROGEN

4.2.1 Foliar Nitrogen

The minimum N percentage on a dry leaf matter basis which is necessary for pepper plants to avoid N deficiencies has been established by several researchers for various stages of plant growth (Fletcher et al., 1993; Hochmuth, 1994; Miller et al., 1979). Dr. George Hochmuth (pers. comm.) believes the values from Fletcher et al. (1993) are the best defined in terms of being the absolute minimum percentage of N required by the plants. These "critical leaf N concentrations" are presented in Table 9 along with the dates in the 1995 and 1996 seasons when the growth stage occurred.

Table 9: Critical N values for different growth stages* of pepper and date when these growth stages occurred during the 1995 and 1996 growing seasons

Period	Date (1995)	Date (1996)	Critical % Nitrogen*
Prior to Blossom:	before June 28	before July 3	4
First Bloom:	June 28	July 3	3
Early Fruit Set:	July 16	July 17	2.9
Early Harvest (Green):	August 15	August 19	2.5
Final Harvest:	September 13	October 2	2.5

*Fletcher et al. (1993)

The foliar N levels were determined by digesting leaf samples using the Kjeldahl system (Tecator, Kjeltec System 20, Box 70, S-26301 Höganäs, Sweden) in 1995 and 1996 (Tables 10 and 11, respectively). The values in these tables which are enlarged and in bold are those values where the plant is judged to be N deficient using the Fletcher et al. (1993) criteria presented in Table 9.

Table 10: The effects of mulch, irrigation, and N on the mean foliar N content (% dry weight) in 1995 as determined by the Kjeldahl method of N analysis (means based on 2 plants per plot)

Treatment	June 15	July 1	July 16	July 31	Aug. 15	Aug. 30	Sept. 14
Black, Drip, Weekly (BDW)	4.19^{a*}	4.15^{a}	3.61^{ab}	3.26^{a}	3.06^{a}	2.98^{a}	3.04^{a}
Silver, Drip, Weekly (SDW)	**3.60**^{ab}	3.80^{a}	**2.88**^{b}	3.16^{a}	2.79^{a}	2.51^{a}	2.62^{a}
Black, Drip, SPAD (BDS)	4.06^{a}	4.12^{a}	3.02^{ab}	3.11^{a}	2.77^{a}	2.83^{a}	2.97^{a}
Silver, Drip, SPAD (SDS)	**3.96**^{a}	3.93^{a}	3.14^{ab}	3.16^{a}	2.72^{a}	2.84^{a}	3.07^{a}
Black, Drip, None (BDN)	4.02^{a}	3.86^{a}	3.08^{ab}	**2.52**^{a}	3.00^{a}	2.92^{a}	2.96^{a}
None, Microjet, None (NMN)	**3.47**^{ab}	4.04^{a}	3.69^{a}	**2.46**^{a}	2.92^{a}	3.06^{a}	2.91^{a}
None, Drip, None (NDN)	**2.95**^{b}	4.23^{a}	3.44^{ab}	3.28^{a}	2.57^{a}	2.84^{a}	2.83^{a}
None, None, None (NNN)	**3.01**^{b}	3.81^{a}	3.80^{a}	3.59^{a}	3.07^{a}	3.10^{a}	3.18^{a}
Over-fertilized Reference Plot	4.03		3.76	3.93	3.55	2.69	2.77

* -Values in the same column with the same letter are not significantly different using SNK at α=0.05.

-Values which are in bold and enlarged are deficient in N according to Fletcher et al. (1993).

Table 11: The effects of mulch, irrigation, and N on the mean foliar N content (% dry weight) in 1996 as determined by the Kjeldahl method of N analysis (means based on 2 plants per plot)

Treatment	June 20	July 5	July 20	Aug. 4	Aug. 19	Sept. 3	Sept. 18
Black, Drip, Weekly (BDW)	**3.82^{a*}**	3.58^{a}	3.40^{a}	3.02^{a}	2.54^{ab}	**2.39^{a}**	**2.47^{a}**
Silver, Drip, Weekly (SDW)	**3.23^{ab}**	**2.86^{a}**	3.13^{a}	**2.82^{a}**	**2.46^{ab}**	**2.27^{a}**	**2.41^{a}**
Black, Drip, SPAD (BDS)	**3.63^{a}**	3.59^{a}	3.13^{a}	**2.83^{a}**	2.53^{ab}	**2.23^{a}**	**2.48^{a}**
Silver, Drip, SPAD (SDS)	**3.71^{a}**	3.64^{a}	3.32^{a}	3.09^{a}	2.86^{a}	**2.38^{a}**	2.57^{a}
Black, Drip, None (BDN)	**3.62^{a}**	3.25^{a}	3.38^{a}	2.93^{a}	2.55^{ab}	**2.47^{a}**	**2.47^{a}**
Silver, Drip, None (SDN)	**2.94^{b}**	3.62^{a}	3.18^{a}	**2.64^{a}**	**2.29^{b}**	**2.27^{a}**	**2.46^{a}**
None, Drip, None (NDN)	**3.39^{ab}**	**2.94^{a}**	3.10^{a}	**2.83^{a}**	**2.29^{b}**	**2.27^{a}**	**2.32^{a}**
None, None, None (NNN)	**3.59^{a}**	3.01^{a}	3.51^{a}	3.02^{a}	2.83^{a}	2.62^{a}	**2.44^{a}**
Over-fertilized Reference Plot	3.84	4.53	4.14	3.63	3.05	2.66	2.71

* -Values in the same column with the same letter are not significantly different using SNK at $\alpha=0.05$.
-Values which are in bold and enlarged are deficient in N according to Fletcher et al. (1993).

In the 1995 season, generally, the plants were not N deficient. The average monthly June temperature was 20°C and 19°C in 1995 and 1996, respectively. In the beginning of the 1995 season (June 15), the plants not grown on black plastic were N deficient. Hankin et al. (1982) reported that higher temperatures, constant moisture, and increased aeration under mulched treatments favour microbial populations which ensure more nitrification and thus more soluble minerals. It is possible that with the warmer temperatures in 1995, the black mulch was able to heat the soil sufficiently in order to provide the proper environment for increased nutrient availability.

On July 16, 1995, the SDW treatment was found to be deficient in N. This may be the result of the high N demand on the plant because of its heavy fruit load. This treatment had the highest early marketable yields (11.3 T/ha). The BDN and NMN treatments were deficient on July 31, 1995. The deficiency in the BDN treatment may be due to increased growth caused by mulching treatment without additional N fertilization to support that growth. Locascio et al. (1985) showed that plants grown on mulch had more growth, but less foliar N than plants grown without mulch with the same fertilization rates.

In the 1996 season, more plants showed N deficiency symptoms than in 1995. This may be the result of the use of less preplant fertilizer in 1996 (40 kg N/ha) than in 1995 (60 kg N/ha). The preplant fertilizer was lowered in 1996 in order to unmask any potential differences caused by the various treatments.

The lower amount of preplant fertilizer in 1996 may have caused more deficiencies early in the season. All treatments on the June 20, 1996 sampling date were deficient. Towards the early harvest stage of the plants, on August 4 and 19, 1996, some deficiencies occurred in treatments which were irrigated, but not fertilized (SDN, NDN). This may be due to the increased growth of mulched and/or irrigated plants as shown by Bhella (1988) and VanDerwerken and Wilcox-Lee (1988). The SDW and BDS treatments were also deficient on August 4 and the SDW treatment was deficient on August 19, 1996. However, these were minor deficiencies in which foliar N levels fell just below the critical values of 2.9% and 2.5% on August 4 and 19, 1996, respectively (Table 9).

On the final two sampling dates in 1996 (September 3 and September 18), almost all of the treatments were deficient. This may be because the fertilization for the additionally fertilized treatments had been stopped. The additionally fertilized treatments received supplemental fertilization from June 12 to August 21 in the 1995 season and from June 17 to August 26 in the 1996 season.

4.2.2 The SPAD Chlorophyll Meter and Foliar N

The plants which were used for the foliar N analysis were used for SPAD sampling as well. SPAD readings were also taken from plants which were not destructively sampled in order to determine whether or not the BDS and SDS treatments should be given additional fertilizer. The plants required additional fertilization when the plants in the treatment plots had a SPAD value which was less than 95% of the value obtained in over-fertilized plots. These over-fertilized plots were assumed to be N sufficient. (The over-fertilized plots are used in order to account for seasonal and regional environmental differences which may have an effect on chlorophyll content.) In both years, the over-fertilized reference plots used to calculate the SPAD sufficiency index never fell below the critical N values for the given growth stage (Tables 10 and 11). This implies that these plants were never N deficient, according to the Fletcher et al. (1993) criteria, and the assumption had been correct.

The treatments which were fertilized according to the SPAD sufficiency index were fertilized on the following dates: August 7, 14, and 21, 1995; July 22 and 29, 1996 and August 5, 1996. Each year, the SPAD sufficiency index method was unable to identify deficiencies (according to the foliar N values) at the beginning of the season, June 15, 1995 and June 20, 1996, (Tables 10 and 11, respectively). At the beginning of the season the critical percentage of N is the highest at 4%. It is possible that at these high levels, the SPAD meter is less accurate in detecting N deficiencies. Dwyer et al. (1994) and Wood et al. (1992) reported that at higher leaf N levels, a larger proportion of N is in the nitrate-N form and is not associated with the chlorophyll molecule.

There were no other deficiencies in the SPAD fertilized treatments (BDS, SDS) in 1995 (Table 10). In 1996 (Table 11), the BDS treatment was found to be deficient on August 4, 1996. The SPAD fertilization dates (noted above) surround this date. Thus it seems as though sometime after the July 20, 1996 destructive sampling date, the plants in the BDS treatment became N deficient. On July 22, 29, and August 5, 1996 the SPAD meter sufficiency index method found them to be deficient and additional fertilizer was given. On the August 19, 1996 destructive sampling date the plants in the BDS treatment were no longer deficient. This period corresponds to the early fruit set to early harvest stages of the plant. From this information, it appears that the SPAD meter sufficiency index method was useful in identifying N deficiencies during these stages. Turner and Jund (1991) showed that the SPAD meter was well correlated with N fertilizer needs at the pre-panicle initiation and panicle differentiation stages of semidwarf rice, but poorly correlated in the tillering and heading growth stages. Blackmer and Schepers (1995) reported that the SPAD meter was best correlated with yield at the R4 and R5 stages in corn. Therefore the meter may only be useful in detecting N deficiencies when the plant is in the reproductive stages or close to reproduction.

Pearson's and Spearman's correlation tests were preformed in order to determine whether or not the SPAD meter values had a direct correlation with foliar N levels. Pearson's correlation test evaluates only linear correlations whereas Spearman's correlation test evaluates a broad range of correlations. Therefore, Pearson's test is more powerful than Spearman's correlation test since it is more specific. The correlation coefficients and the probability values were similar for both tests. However, since graphs plotting the foliar N and SPAD meter values did not demonstrate a clear linear relationship, the values that are reported are those of Spearman's test since it evaluates a broad range of correlations.

Table 12: Correlation between foliar N levels and SPAD chlorophyll meter values in pepper plants in 1995 using Spearman's correlation coefficients and probability values

	June 15	July 1	July 16	July 31	Aug. 15	Aug. 30	Sept. 14
correlation coefficient (r)	**0.54***	-0.10	**0.56**	0.05	**0.34**	0.22	0.24
probability value (p)	0.0084	0.6289	0.0001	0.7296	0.0164	0.1385	0.1021

* Correlation coefficients which are significant at the $\alpha=0.05$ level are in bold and enlarged.

Table 13: Correlation between foliar N levels and SPAD chlorophyll meter values in pepper plants in 1996 using Spearman's correlation coefficients and probability values

	June 20	July 5	July 20	Aug. 4	Aug. 19	Sept. 3	Sept. 18
correlation coefficient (r)	**0.50**[*]	-0.12	**0.35**	0.27	**0.52**	**0.36**	0.18
probability value (p)	0.0003	0.4218	0.0138	0.0641	0.0002	0.0119	0.2165

[*] Correlation coefficients which are significant at the $\alpha=0.05$ level are in bold and enlarged.

Tables 12 and 13 give the Spearman's correlation coefficients and the associated probability values for the 1995 and 1996 seasons, respectively. These tables show that SPAD meter values and foliar N levels are not always significantly correlated. However, in both years there was a significantly positive correlation at the $\alpha=0.05$ level on the first, third, and fifth sampling dates which correspond to the prior to bloom, early fruit set, and early harvest stages, respectively. In 1996, the September 3 sampling date was also significantly correlated. These results indicate that there is a significant correlation at certain growth stages. Therefore, these results signify that if this relationship does truly exist, the use of the meter may be most accurate only at these growth stages.

The results of the foliar N levels which were superimposed with the Fletcher et al. (1993) critical percentage N values showed that at the prior to bloom stage, there were N deficiencies which had not been detected by the SPAD sufficiency index method. This data shows that at the prior to bloom stage, the N is significantly correlated to the SPAD values. This contradiction may indicate that the sufficiency index value of 95%

may need to be adjusted in order to detect deficiencies at this stage. It is also possible that if the SPAD sampling techniques were improved in order to obtain higher r^2 values then the present sufficiency index (95%) would be able to detect deficiencies.

Presently, even when the correlation is highly significant ($p < 0.0003$), the correlation coefficients are low (ranging from 0.50 to 0.56) and consequently the r^2 values are also low (ranging from 0.25 to 0.31). The low r^2 values may be due to plant variation in relative chlorophyll and therefore N content. The leaves which were sampled were the most recently fully expanded leaves. On a pepper plant, there are many of these leaves occurring at the same time, particularly at the latter stages of plant development. Therefore it is possible that there was a large variability in the SPAD sampling. There have been reports which have sampled the leaf closest to the reproductive structure of the plant once the plant has reached the reproductive stages in crops such as rice (Johnkutty and Palaniappan, 1996), tall fescue (Kantety et al., 1996) and corn (Dwyer et al., 1994; Jemison and Lytle, 1996; Wood et al., 1992).

Another possible explanation for the low r^2 is that the SPAD sampling was done on only two leaves per plant. However, the foliar N levels were determined from a sample of all the dried leaves of the plant since two leaves do not provide enough dried sample with which to do the Kjeldahl foliar N analysis. Wood et al. (1992) had similar findings with corn, the correlation between SPAD and tissue N was higher at the midsilk stage where they had just used the earleaf for N analysis than at the V10 stage where they had used the whole plant. They believe that this may be due to the difference in the tissue used for sampling and/or due to a higher correlation at the midsilk stage.

Other possible explanations for the low r^2 values, are that there were treatment effects due to the different mulch types which created different environments for the plants, or possibly a block effect. Therefore, Spearman's correlation tests were also performed within a block for each sampling date or within a mulched treatment for each sampling date in 1995 and 1996 (Tables 14 and 15, respectively).

Table 14: Correlation between foliar N levels and SPAD chlorophyll meter values in pepper plants within blocks or within mulched treatment in 1995 using Spearman's correlation coefficients (r) and probability values (p)

		June 15	July 1	July 16	July 31	Aug. 15	Aug. 30	Sept. 14
Block 1	r*	**0.71**	0.64	**0.55**	0.22	**0.57**	0.16	0.12
	p	0.0465	0.0856	0.0428	0.4049	0.0218	0.5421	0.6643
Block 2	r	**0.82**	-0.63	**0.68**	-0.25	-0.10	-0.05	0.01
	p	0.0234	0.0909	0.0036	0.3919	0.7044	0.8541	0.9569
Block 3	r	0.02	-0.17	**0.55**	0.12	0.41	0.36	**0.62**
	p	0.9554	0.6932	0.0263	0.6643	0.1130	0.1682	0.0108
Black	r	-0.17	-0.33	**0.55**	0.20	0.40	0.30	-0.10
	p	0.6682	0.3807	0.0186	0.4180	0.1045	0.2226	0.6986
Silver	r	-0.30	0.26	0.24	0.45	0.38	-0.11	0.54
	p	0.6238	0.6228	0.4433	0.1869	0.2170	0.7292	0.0709
None	r	**0.70**	-0.03	**0.67**	-0.28	0.31	0.40	0.41
	p	0.0358	0.9322	0.0045	0.2671	0.2033	0.1045	0.0878

* Correlation coefficients which are significant at the α=0.05 level are in bold and enlarged.

Table 15: Correlation between foliar N levels and SPAD chlorophyll meter values in pepper plants within blocks or within mulched treatment in 1996 using Spearman's correlation coefficients (r) and probability values (p)

		June 20	July 5	July 20	Aug. 4	Aug. 19	Sept. 3	Sept. 18
Block 1	r*	0.45	-0.33	**0.58**	0.41	0.39	0.35	-0.18
	p	0.0812	0.2172	0.0193	0.1130	0.1402	0.1796	0.5133
Block 2	r	**0.54**	-0.16	-0.15	0.44	**0.50**	0.22	0.43
	p	0.0315	0.6026	0.5825	0.0920	0.0471	0.4117	0.0929
Block 3	r	**0.58**	0.28	**0.57**	0.39	**0.61**	**0.51**	0.09
	p	0.0177	0.3023	0.0213	0.1341	0.0122	0.0432	0.7492
Black	r	**0.52**	-0.21	0.38	0.23	0.42	**0.60**	-0.09
	p	0.0280	0.4039	0.1166	0.3627	0.0805	0.0088	0.7293
Silver	r	**0.63**	-0.03	0.37	0.45	**0.59**	0.08	0.29
	p	0.0051	0.9034	0.1325	0.0582	0.0104	0.7632	0.2361
None	r	0.54	-0.58	0.39	0.27	0.55	**0.67**	0.27
	p	0.0709	0.0765	0.2153	0.3911	0.0625	0.0168	0.3966

* Correlation coefficients which are significant at the $\alpha=0.05$ level are in bold and enlarged.

In both years, significant within block and within mulch correlations (Tables 14 and 15) occurred on the same dates as the overall significant correlations (Tables 12 and 13) with the exception of September 14, 1995 when there was a significant correlation in block 3 but no overall correlation. The significant correlation coefficients from within a block or within a mulched treatment are higher than the overall significant coefficients from the same date. However, they are still low and consequently have low r^2 values. The significant correlations within the block or mulch type result in an overall significant correlation.

In 1995 and 1996 there is not a mulch type which consistently had significant correlations between foliar N level and SPAD values. There is not an overall mulch treatment effect on the correlation between SPAD values and foliar N level. However, in 1995 and 1996 Block 1 and Block 3, respectively, had significant correlations on each date that also showed an overall significant correlation. There may be an overall block effect on the correlation between SPAD values and foliar N level.

The SPAD values in this experiment are significantly correlated with N values. However, more work needs to be done in order to determine the correct leaf and the correct stage(s) for sampling which will improve the correlation coefficients and therefore this method of detecting N deficiencies.

4.3 APHIDS

4.3.1 Apterous Aphids

Apterous aphids are the non-winged aphids which are usually found on the abaxial side of the leaves of infested plants.

In 1995, the apterous aphids were counted according to the indexing method described by PRISME (see materials and methods). However, the indexing method proved to be difficult to analyze statistically. Therefore, the average number of aphids found in each index colony in 1996 was used in analyzing the 1995 data. The average number of aphids in colony I, colony II, and colony III is 3.61, 7.07, and 14.24, respectively. As 1995 had a greater infestation of aphids than 1996, the average number of aphids used for each colony index is thought to be conservative.

Tables 16 and 17 give the mean apterous aphid population in each treatment on each sampling date. The average number of apterous aphids for the 1995 season per plot (3 plants) was 669.9 compared with 571.0 in 1996. This indicates that there was a much higher infestation of aphids in the 1995 than in the 1996 season. If the aphid populations in each mulch, irrigation, fertilization treatment (combination treatment) on a given date are compared with each other, there are only two dates in 1995 (Table 16) and in 1996 (Table 17) that have significant differences. All the combination treatments have statistically similar populations on a given date. However, if specific combination treatments are contrasted then the effects of certain treatments are seen.

Table 16: The Effects of mulch, irrigation, and N on the mean apterous aphid population in 1995 (means based on 3 plants per plot)

Treatment	June 12	June 21	June 27	July 4	July 11	July 18	July 25	Aug. 1	Aug. 8	Aug. 15	Aug. 21	Aug. 29	Sept. 5	Sept. 12	Sept. 19	Season Total
Black, Drip, Weekly	82.3^{ab*}	19.6^{a}	34.2^{a}	71.5^{a}	44.5^{a}	101.8^{a}	8.7^{a}	2.9^{a}	7.7^{a}	7.6^{a}	2.2^{a}	8.6^{a}	11.8^{a}	42.2^{a}	83.7^{b}	529.2^{a}
Silver, Drip, Weekly	6.7^{b}	12.6^{a}	14.8^{a}	71.4^{a}	54.4^{a}	112.4^{a}	26.2^{a}	2.3^{a}	6.4^{a}	0.3^{a}	8.6^{a}	15.2^{a}	70.0^{a}	86.3^{a}	170.8^{b}	658.3^{a}
Black, Drip, SPAD	42.9^{b}	12.8^{a}	52.0^{a}	51.2^{a}	62.9^{a}	134.6^{a}	20.6^{a}	1.7^{a}	2.7^{a}	6.2^{a}	4.7^{a}	13.0^{a}	108.2^{a}	130.1^{a}	369.9^{a}	1013.5^{a}
Silver, Drip, SPAD	26.0^{b}	23.8^{a}	27.2^{a}	232.4^{a}	72.8^{a}	95.2^{a}	23.7^{a}	4.9^{a}	0.7^{a}	8.4^{a}	13.7^{a}	8.7^{a}	33.7^{a}	72.7^{a}	62.5^{b}	706.4^{a}
Black, Drip, None	87.9^{ab}	78.1^{a}	62.2^{a}	162.4^{a}	52.1^{a}	23.6^{a}	7.0^{a}	1.0^{a}	3.9^{a}	3.3^{a}	7.9^{a}	15.0^{a}	10.3^{a}	15.0^{a}	71.7^{b}	601.4^{a}
None, Microjet, None	143.8^{a}	86.1^{a}	39.7^{a}	108.3^{a}	59.8^{a}	40.6^{a}	12.0^{a}	4.9^{a}	4.3^{a}	16.2^{a}	3.3^{a}	7.6^{a}	22.5^{a}	10.6^{a}	35.0^{b}	594.7^{a}
None, Drip, None	76.1^{ab}	85.8^{a}	33.1^{a}	41.9^{a}	181.2^{a}	78.3^{a}	13.0^{a}	0.7^{a}	5.7^{a}	12.4^{a}	10.9^{a}	17.2^{a}	50.0^{a}	71.5^{a}	128.4^{b}	806.1^{a}
None, None, None	43.4^{b}	0.3^{a}	17.8^{a}	24.1^{a}	64.0^{a}	44.5^{a}	14.9^{a}	6.4^{a}	10.2^{a}	9.2^{a}	14.8^{a}	6.7^{a}	17.5^{a}	73.1^{a}	102.8b	449.7^{a}

* Values in the same column with the same letter are not significantly different using SNK at $\alpha = 0.05$ level.

Table 17: The effects of mulch, irrigation, and N on the mean apterous aphid population in 1996 (means based on 3 plants per plot)

Treatment	June 19	June 26	July 3	July 10	July 17	July 24	July 31	Aug. 7	Aug. 14	Aug. 21	Aug. 28	Sept. 4	Sept. 11	Sept. 18	Season Total
Black, Drip, Weekly	73.3a*	121.3a	122.3a	391.3a	107.0a	45.7a	21.0a	3.3a	3.3a	0.0a	0.0a	0.0a	0.3a	1.3a	890.3a
Silver, Drip, Weekly	24.3a	24.7a	43.7a	83.0a	63.7a	75.3a	53.3a	7.7a	0.0a	0.0a	1.7a	1.3a	1.7a	2.0a	382.3a
Black, Drip, SPAD	70.7a	154.3a	141.7a	326.7a	115.0a	32.7a	30.0a	5.0a	1.3a	0.3a	0.3a	0.0a	0.3a	0.3a	878.7a
Silver, Drip, SPAD	28.3a	77.3a	57.0a	118.7a	78.3a	31.7a	22.0a	6.7a	0.7a	1.0a	3.7a	1.3a	5.3a	4.7a	436.7a
Black, Drip, None	110.7a	135.0a	110.7a	190.0a	123.3a	57.0a	42.7a	5.3a	4.0a	0.0a	0.0a	0.7a	0.0a	3.7a	783.0a
Silver, Drip, None	18.7a	49.7a	80.0a	154.7a	96.0a	30.0a	25.7a	3.0a	1.7a	0.0a	3.0a	0.0a	2.3a	0.0a	464.7a
None, Drip, None	51.0a	87.0a	42.0a	91.3a	59.3a	40.7a	32.0a	6.3a	0.3a	0.0a	0.7a	2.3a	1.0a	2.0a	416.0a
None, None, None	42.7a	61.0a	38.3a	102.7a	26.7a	18.7a	12.7a	5.7a	1.0a	0.3a	0.0a	3.7a	1.3a	1.3a	316.0a

* Values in the same column with the same letter are not significantly different using SNK at $\alpha = 0.05$ level.

Tables 18 and 19 show the results of planned contrasts. The experiment examined the effects of specific mulch, irrigation, and fertilization treatments on the apterous aphid populations. However, due to a lack of space and time, these treatments were not factorially combined. Examining the effects of a particular mulch, irrigation, or fertilization treatment is done by specific contrasts which create a small factorial design. For example, to compare the effects of black to silver mulch in 1996 the BDW, BDS, BDN combination treatments are compared with the same irrigation and fertilization treatments in combination with a silver mulch (ie. SDW, SDS, SDN).

In 1995, the results of the planned contrasts show that there are only two dates where there are significant results. On June 12, black is significantly different from silver, microjet irrigation is significantly different from drip irrigation, and irrigation is significantly different from no irrigation on the populations of apterous aphids. The population numbers in Table 16 indicate which treatment is significantly higher than the other. Since the populations on the BDW and BDS treatments on June 12, 1995 are higher than the populations of SDW and SDS, it is clear that Table 18 is revealing the significantly higher populations of apterous aphids on black mulch in comparison to silver mulch treatments on that date. Similarly, the microjet treatment (NMN) has significantly higher populations of aphids than the drip irrigated treatment (NDN) and the irrigated treatments (NMN and NDN) have significantly higher populations than the non-irrigated treatment (NNN). Archer et al. (1995) also found there to be significantly ($p<0.05$) more apterous aphids on irrigated wheat than on non-irrigated wheat.

Table 18: Summary table of F values for effects of planned contrasts on apterous aphid population in 1995

Contrast[Note]	June 12	June 21	June 27	July 4	July 11	July 18	July 25	Aug. 1	Aug. 8	Aug. 15	Aug. 21	Aug. 29	Sept. 5	Sept. 12	Sept. 19	Season Total
fert. vs. no fert.	0.96	1.84	0.84	1.58	0.00	6.62*	0.50	0.45	0.09	0.26	0.74	0.17	1.66	1.77	4.11	0.44
weekly vs. SPAD	0.23	0.00	0.79	1.15	0.25	0.07	0.28	0.18	2.15	0.35	0.80	0.02	0.91	0.72	2.03	1.63
black vs. silver	4.81*	0.00	1.69	1.91	0.07	0.23	1.32	0.74	0.20	0.19	3.34	0.02	0.07	0.02	3.11	0.18
micro. vs. drip	5.16*	0.00	0.08	0.51	5.41*	0.79	0.01	3.80	0.07	0.22	1.62	0.64	0.38	0.97	1.12	0.51
irrig. vs. no irrig.	6.64*	3.53	0.80	0.40	1.56	0.17	0.05	3.64	1.32	0.54	2.21	0.30	0.24	0.36	0.08	0.96

Note: -fertilization vs. no fertilization = BDW, BDS vs. BDN
-weekly vs. SPAD = BDW, SDW vs. BDS, SDS
-black vs. silver = BDW, BDS vs. SDW, SDS
-microjet vs. drip = NMN vs. NDN
-irrigation vs. no irrigation = NMN, NDN vs. NNN

* probability value < 0.05

Table 19: Summary table of F values for effects of planned contrasts on apterous aphid population in 1996

Contrast[Note]	June 19	June 26	July 3	July 10	July 17	July 24	July 31	Aug. 7	Aug. 14	Aug. 21	Aug. 28	Sept. 4	Sept. 11	Sept. 18	Season Total
fert. vs. no fert.	0.84	0.01	0.03	0.74	0.50	0.03	0.11	0.31	4.10	1.91	0.00	0.27	0.49	0.03	0.05
weekly vs. SPAD	0.00	2.52	0.37	0.04	0.14	2.23	1.59	0.01	0.61	5.74*	0.71	0.00	2.19	0.24	0.03
black vs. silver	14.76**	15.35**	8.80*	8.49*	2.07	0.00	0.11	0.23	9.13*	0.96	5.53*	1.23	8.16*	0.10	17.47**
mulch vs. no mulch	0.33	0.03	2.66	0.73	1.82	0.01	0.04	0.32	5.69*	0.00	0.24	4.92*	0.01	0.01	1.88
drip vs. no irrig.	0.09	0.46	0.01	0.01	0.58	0.67	2.38	0.02	0.30	0.72	0.12	1.64	0.04	0.08	0.33

Note: -fertilization vs. no fertilization = BDW, SDW, BDS, SDS vs. BDN, SDN
-weekly vs. SPAD = BDW, SDW vs. BDS, SDS
-black vs. silver = BDW, BDS, BDN vs. SDW, SDS, SDN
-mulch vs. no mulch = BDN, SDN vs. NDN
-drip vs. no irrigation = NDN vs. NNN

* probability value < 0.05
** probability value < 0.005

July 11, 1995 is the other date that shows significant differences. On this date it is only the microjet vs. drip contrast that is significantly different. Table 16 reveals that the drip irrigated treatment has higher populations than the microjet irrigated treatment. This is contradictory to the June 12, 1995 date. It is possible that the 1995 season had such a high population of aphids that their distribution in the field was fairly uniform and therefore differences caused by the treatments were not evident. This can be seen in the season totals in Tables 16 and 18 which do not show any significant differences.

In the 1996 season, there are no significant differences in the apterous aphid populations among the 8 treatments (Table 17). However, the populations of aphids on the sampling dates from June 19 to July 17 on the black mulch are usually higher than the silver mulch treatments. The results of the planned contrasts in Table 19 confirm that black mulch has significantly higher populations of apterous aphids than silver mulch on the sampling dates from June 19 to July 10. However, there is no significant difference between mulched treatments and non-mulched treatments on these dates. Other dates which show a significant difference between black and silver are August 14, 28, and September 11. On August 14, black mulch has significantly higher populations than silver mulch. On August 28 and September 11, silver has significantly higher populations than black mulch. However, these last three dates had very low populations of aphids. Therefore it is difficult to draw any conclusions from these results. Csizinszky et al. (1995) proposed that mulches should be selected for their effects on insect population only under high insect stress. The season total of aphids also shows that overall black mulch has a significantly higher population than silver mulch (Tables 17 and 19).

Cartwright et al. (1990) and Zalom (1981a) also found higher apterous populations on mulched treatments.

On August 14 and September 4, there is also a significant difference between mulched and non-mulched treatments. Mulched treatments are significantly higher, and significantly lower than non-mulched treatments on August 14 and September 4, respectively (Tables 17 and 19). There is also a significantly higher population of apterous aphids on SPAD fertilized treatments compared with weekly fertilized treatments on August 21 (Tables 17 and 19). Once again, all of the significant contrasts which occur after August 7 have very low populations of aphids and therefore do not affect the season totals.

The main effect on aphid populations seems to be that black mulch has significantly higher populations than silver mulch. Silver mulch has been reported to have lower aphid populations (Brown et al., 1993; Kring and Schuster 1992) than other colours of mulch and non-mulched treatments. However, it has also been shown that apterous aphids usually multiply more rapidly on mulched treatments than on non-mulched treatments due to the better microenvironment and also the more succulent plants (Cartwright et al., 1990; Zalom, 1981a). This may be the reason that there was no significant difference between mulched and non-mulched treatments.

Although there was not a significant difference in the planned contrasts between mulched and non-mulched treatments, there generally were low populations of apterous aphids on non-mulched treatments from June 19 to July 17 when the populations of aphids were high for the 1996 season. It would have been interesting to see the results of planned contrasts between black mulched treatments and non-mulched treatments, as the silver mulched treatments seem to have similar values to non-mulched treatments which caused no significant difference between mulched and non-mulched treatments. There may be higher populations on the black mulch because in the beginning of the season the temperatures on the black mulch may have been higher and aphid populations increase rapidly at higher temperatures (Howard et al., 1994).

4.2.2 Alate Aphids

The 1995 season had a much higher alate aphid population than 1996 (Tables 20 and 21). In 1995, the period of highest infestation was from June 27 to July 18. During this period, the silver mulch had the lowest populations of aphids. The period of lowest infestation was from the July 25 to August 29. During this period, there were no significant differences in population among the treatments. Thus it appears that mulch type only has an effect on alate aphid population during periods of high infestation. Csizinszky et al. (1995) reported that the effects of mulch on insects should be evaluated during periods of high insect stress. The 1995 season totals of alate aphid population are given in Table 20 and illustrated in Figure 4. Figure 4 clearly demonstrates that the significantly lowest populations of alate aphids occurs on the silver mulches. Black mulch also significantly reduced alate aphid populations. Brown et al. (1993) also found silver mulch superior to black mulch which preformed better than no mulch. From Figure 4, it appears as though fertigation level has no effect on the aphid populations. This has been confirmed by Archer et al. (1995) on wheat and by Jansson and Smilowitz (1986)

Table 20: The effects of mulch, irrigation, and N on the mean alate aphid population in 1995 (means based on 1 pan trap per plot))

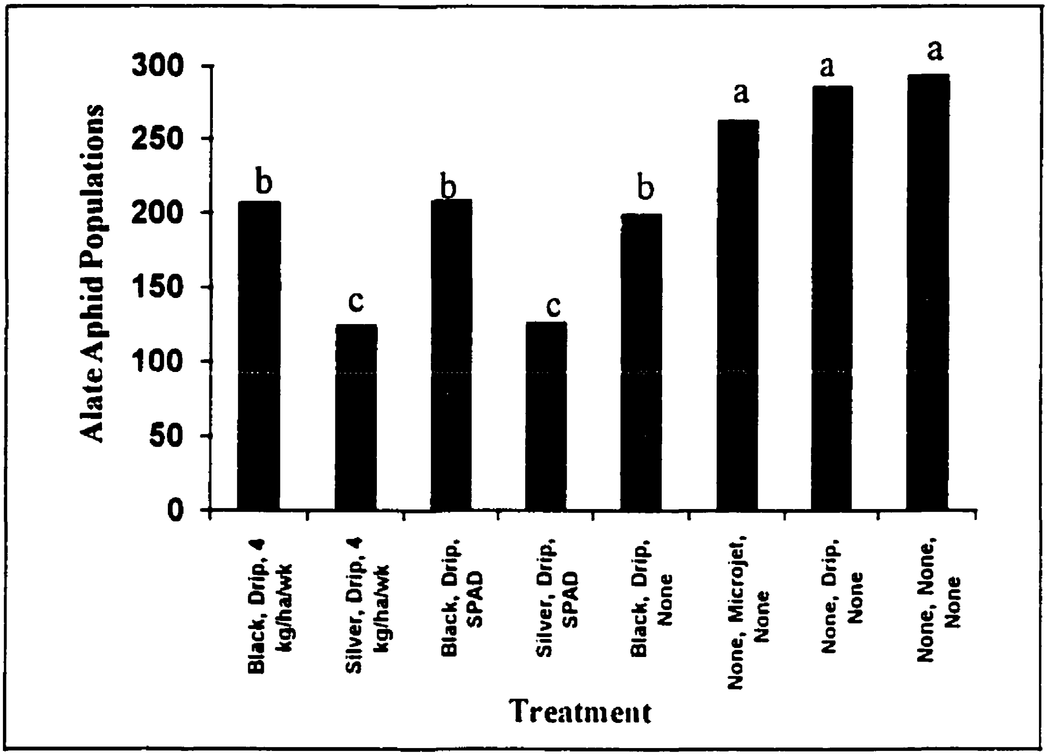
Treatment	June 27	July 4	July 11	July 18	July 25	Aug. 8	Aug. 15	Aug. 29	Sept. 12	Sept. 19	Season Total
Black, Drip, Weekly	54.3[abc]	56.7[bc]	24.0[abc]	27.3[ab]	2.3[a]	5.0[a]	0.3[a]	6.3[a]	9.0[a]	21.3[a]	206.7[b]
Silver, Drip, Weekly	34.0[c]	34.3[c]	13.3[c]	11.7[bc]	1.7[a]	3.0[a]	1.7[a]	4.0[a]	8.7[a]	11.7[a]	124.0[c]
Black, Drip, SPAD	61.7[ab]	62.7[b]	22.7[abc]	17.7[abc]	1.7[a]	5.0[a]	1.0[a]	4.7[a]	14.3[a]	16.7[a]	208.0[b]
Silver, Drip, SPAD	30.3[c]	36.3[c]	15.3[bc]	10.7[c]	1.7[a]	2.7[a]	1.3[a]	7.0[a]	10.7[a]	9.7[a]	125.7[c]
Black, Drip, None	46.7[bc]	64.7[b]	20.7[abc]	20.3[abc]	1.7[a]	7.0[a]	1.7[a]	8.5[a]	12.0[a]	18.7[a]	199.0[b]
None, Microjet, None	76.0[a]	97.3[a]	30.3[abc]	22.0[abc]	2.3[a]	3.7[a]	1.3[a]	11.0[a]	11.7[a]	10.0[a]	262.0[a]
None, Drip, None	80.7[a]	105.7[a]	34.7[ab]	18.3[abc]	1.7[a]	5.0[a]	3.0[a]	9.0[a]	11.0[a]	16.3[a]	285.3[a]
None, None, None	81.0[a]	105.0[a]	39.7[a]	28.3[a]	3.7[a]	3.7[a]	1.3[a]	8.0[a]	9.7[a]	13.0[a]	293.3[a]

[*] Values in the same column with the same letter are not significantly different using SNK at $\alpha = 0.05$ level

Table 21: The effects of mulch, irrigation, and N on the mean alate aphid population in 1996 (means based on 1 pan trap per plot)

Treatment	July 3	July 10	July 17	July 24	July 31	Aug. 7	Aug. 14	Aug. 21	Aug. 28	Sept. 4	Sept. 11	Sept. 18	Season Total
Black, Drip, Weekly	2.7^{a}	4.0^{a}	13.0^{b}	8.0^{ab}	0.3^{a}	18.7^{a}	4.0^{a}	6.0^{a}	4.7^{bc}	1.7^{a}	0.0^{a}	1.0^{a}	51.7^{bc}
Silver, Drip, Weekly	1.0^{a}	0.7^{a}	2.0^{b}	5.7^{abc}	1.3^{a}	16.3^{a}	0.7^{a}	2.7^{a}	1.0^{c}	1.0^{a}	0.3^{a}	0.0^{a}	32.3^{c}
Black, Drip, SPAD	3.0^{a}	2.0^{a}	13.0^{b}	4.0^{bc}	2.0^{a}	15.7^{a}	0.3^{a}	7.3^{a}	4.3^{bc}	0.7^{a}	1.3^{a}	0.0^{a}	48.3^{bc}
Silver, Drip, SPAD	0.7^{a}	2.7^{a}	5.0^{b}	3.7^{bc}	1.0^{a}	12.7^{a}	3.3^{a}	4.0^{a}	1.3^{c}	3.3^{a}	0.3^{a}	0.3^{a}	38.3^{bc}
Black, Drip, None	2.5^{a}	2.7^{a}	6.0^{b}	7.0^{abc}	0.0^{a}	17.0^{a}	2.3^{a}	8.0^{a}	4.3^{bc}	3.7^{a}	0.0^{a}	1.7^{a}	50.3^{bc}
Silver, Drip, None	1.0^{a}	1.0^{a}	6.0^{b}	1.7^{c}	0.0^{a}	8.7^{a}	2.7^{a}	8.0^{a}	2.0^{c}	0.7^{a}	0.0^{a}	0.0^{a}	29.7^{c}
None, Drip, None	7.7^{a}	15.5^{a}		5.7^{ab}	1.7^{a}	16.0^{a}	4.0^{a}	8.7^{a}	7.0^{b}	2.3^{a}	1.7^{a}	0.3^{a}	65.3^{b}
None, None, None	5.3^{a}	13.3^{a}	32.7^{a}	22.3^{a}	0.7^{a}	19.3^{a}	3.7^{a}	12.3^{a}	11.7^{a}	3.3^{a}	2.0^{a}	1.3^{a}	128.0^{a}

* Values in the same column with the same letter are not significantly different using SNK at $\alpha = 0.05$ level.



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 4: Effect of mulch colour, irrigation type, and N fertilization level on mean alate aphid population in the 1995 season (means based on 1 pan trap per plot)

on potato. However, irrigation has a small, but not statistically significant, effect in lowering alate aphid populations. Archer et al. (1995) found significantly more aphids on non-irrigated wheat plants which were stressed.

Table 22 gives the results of planned contrasts of the alate aphid population in 1995. This table also shows that during the period of highest infestation mulch type was the significant factor influencing alate aphid populations.

In 1996 the data from the following dates were not normally distributed: July 24, August 14, and September 4. Therefore the data were log transformed to normalize the data. The values given on these dates, which are presented in Tables 21 and 22, are based on the raw data. However, the statistical differences are those of the transformed data.

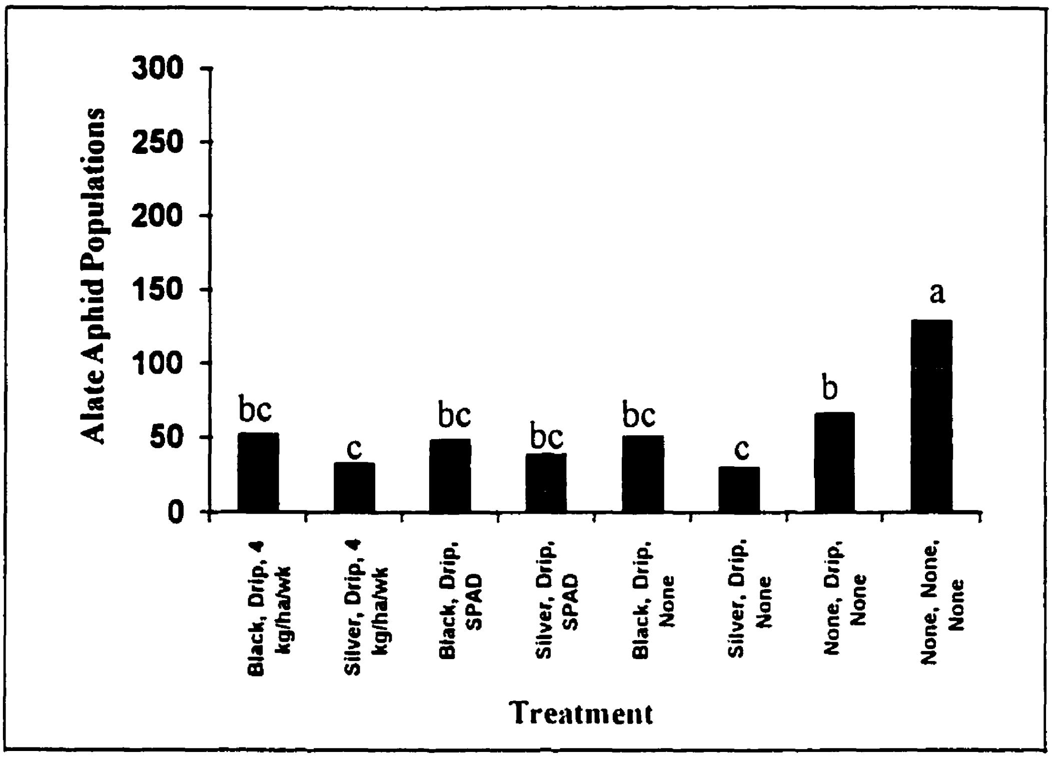
In 1996, significant differences in alate aphid populations occurred on July 17, July 24, and August 28 (Table 21). July 17 and 24 were the dates of highest alate aphid populations in the 1996 season. On all the dates with significant differences in winged aphid populations, silver mulch had low populations. On July 24 and August 28, the control treatment (NNN) had the significantly highest alate aphid population. The season total of aphid populations reflected these trends, as the non-mulched treatments had the highest alate aphid populations. The control treatment had the significantly highest population and the silver mulch treatments had the lowest populations, followed by the black mulch and then by the non-mulched treatments. Figure 5 is the graph of the mean season totals of alate aphid populations. Fertigation did not seem to have an effect, but irrigation significantly lowered aphid populations. Archer et al. (1995) reported the same findings of the effect of fertilization and irrigation on the population of aphids on wheat.

Table 22: Summary table of F values for effects of planned contrasts on alate aphid populations in 1995

Contrast[Note]	June 27	July 4	July 11	July 18	July 25	Aug. 8	Aug . 15	Aug. 29	Sept. 12	Sept. 19	Season Total
fert. vs. no fert.	2.31	0.43	0.27	0.27	0.08	1.40	0.83	1.03	0.01	0.00	0.36
weekly vs. SPAD	0.09	0.41	0.01	2.46	0.13	0.01	0.03	0.18	1.80	0.47	0.02
black vs. silver	18.03**	15.24**	4.63*	11.12**	0.13	2.46	0.86	0.00	0.54	2.93	52.38***
micro. vs. drip	0.29	0.89	0.54	0.58	0.25	0.47	1.72	1.53	0.03	0.85	2.10
irrig. vs. no irrig.	0.13	0.21	1.96	3.85	2.12	0.16	0.57	1.62	0.25	0.00	1.98

Note: -fertilization vs. no fertilization = BDW, BDS vs. BDN
-weekly vs. SPAD = BDW, SDW vs. BDS, SDS
-black vs. silver = BDW, BDS vs. SDW, SDS
-microjet vs. drip = NMN vs. NDN
-irrigation vs. no irrigation = NMN, NDN vs. NNN

* probability value < 0.05
** probability value < 0.005
*** probability value < 0.0005



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 5: Effect of mulch colour, irrigation type, and N fertilization level on mean alate aphid population in the 1996 season (means based on 1 pan trap per plot)

Table 23 shows the planned contrasts for the 1996 season. On five dates (July 3, July 10, July 17, August 28, and September 11) there was a significant effect of mulched treatments compared with non-mulched treatments which lead to a significant effect on the season total population of alate aphids. There was also a significant effect of the black mulched treatments compared with the silver mulched treatments on August 28 which caused a significant effect on the season total alate aphid population. Finally there was a significant effect of drip irrigated treatments compared with non-irrigated treatments which caused a significant effect ($p < 0.0005$) on the season total alate aphid populations.

Although 1995 and 1996 had differences in alate aphid populations, both years show that mulch type has an effect on the populations on the plants; silver mulch clearly being superior to black mulch which was better than no mulch at all. Several researchers have found plastic mulch to be beneficial in lowering aphid populations on the plants particularly silver mulch (Brown et al.,1993; Cartwright et al., 1990; Csizinszky et al., 1995; Kring, 1970; Summers et al., 1995; Toscano et al., 1979). In 1996, irrigation also had an effect on aphid populations as well.

For both the alate and apterous aphids, silver mulch significantly reduces populations in comparison with black mulch. As well, irrigation may have a significant effect on the populations, although this would be best evaluated using more non-irrigated controls. Fertigation does not have any significant effects. The main difference between alate and apterous aphid populations is that alate aphid populations are decreased on mulched treatments, whereas apterous populations are increased on mulched treatments in comparison with non-mulched treatments.

Table 23: Summary table of F values for effects of planned contrasts on alate aphid populations in 1996

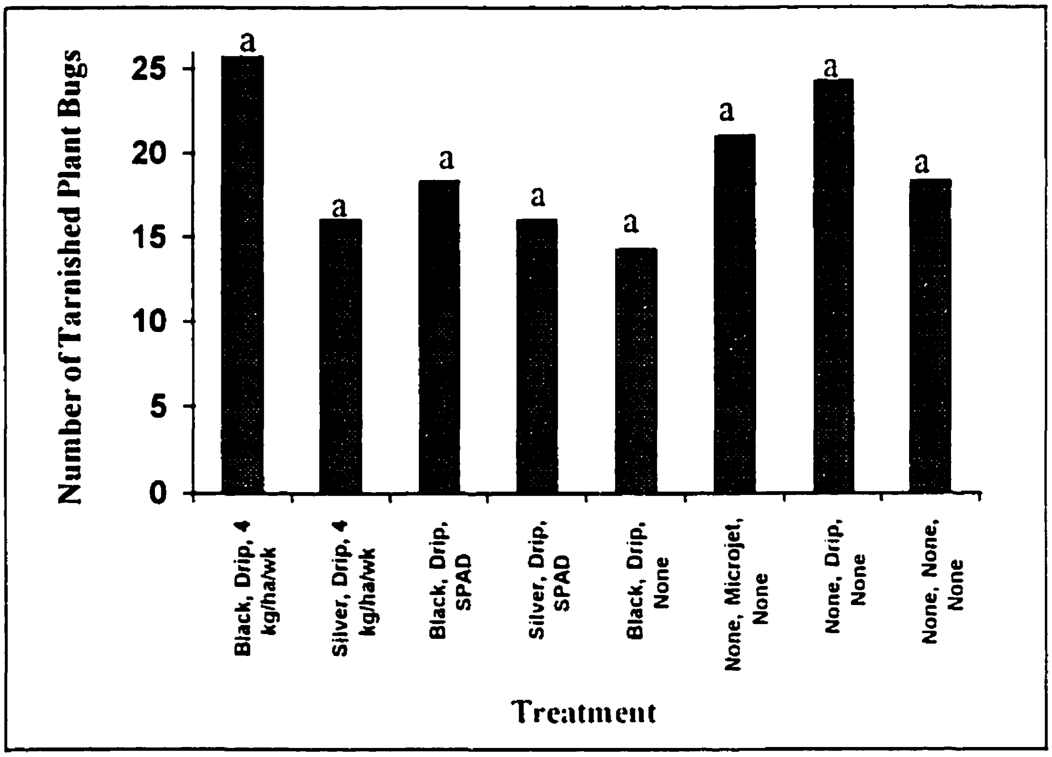
Contrast[Note]	July 3	July 10	July 17	July 24	July 31	Aug. 7	Aug. 14	Aug. 21	Aug. 28	Sept. 4	Sept. 11	Sept. 18	Season Total
fert. vs. no fert.	0.02	0.04	0.05	0.07	2.12	0.57	0.12	1.11	0.14	0.31	1.85	0.98	0.25
weekly vs. SPAD	0.00	0.27	0.36	0.40	0.52	0.52	0.13	0.17	0.00	0.42	2.46	0.33	0.05
black vs. silver	1.32	0.00	5.24	0.58	0.00	1.47	0.00	0.69	12.60**	0.16	0.41	2.66	10.79**
mulch vs. no mulch	9.22*	5.71*	35.20**	0.11	2.17	0.32	0.79	0.03	9.14*	0.02	10.26*	0.49	11.08**
drip vs. no irrig.	1.09	0.03		12.58*	0.58	0.26	0.03	0.62	10.16*	0.47	0.31	1.47	50.86***

Note: -fertilization vs. no fertilization = BDW, SDW, BDS, SDS vs. BDN, SDN
-weekly vs. SPAD = BDW, SDW vs. BDS, SDS
-black vs. silver = BDW, BDS, BDN vs. SDW, SDS, SDN
-mulch vs. no mulch = BDN, SDN vs. NDN
-drip vs. no irrigation = NDN vs. NNN

* probability value < 0.05
** probability value < 0.005
*** probability value < 0.0005

4.4 TARNISHED PLANT BUG

The tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), is attracted by the sweet smell of the nectar of many plants. It then feeds on the flowers and stems of these plants often causing the flowers to drop (Carr, 1979). They may also feed on the pepper fruit causing indentations on the fruit (Howard et al., 1994). Lindquist and Sorensen (1970) found that they were also attracted to plants infested with aphids. They attributed this to the sweet smell of the honeydew that the aphids excrete.

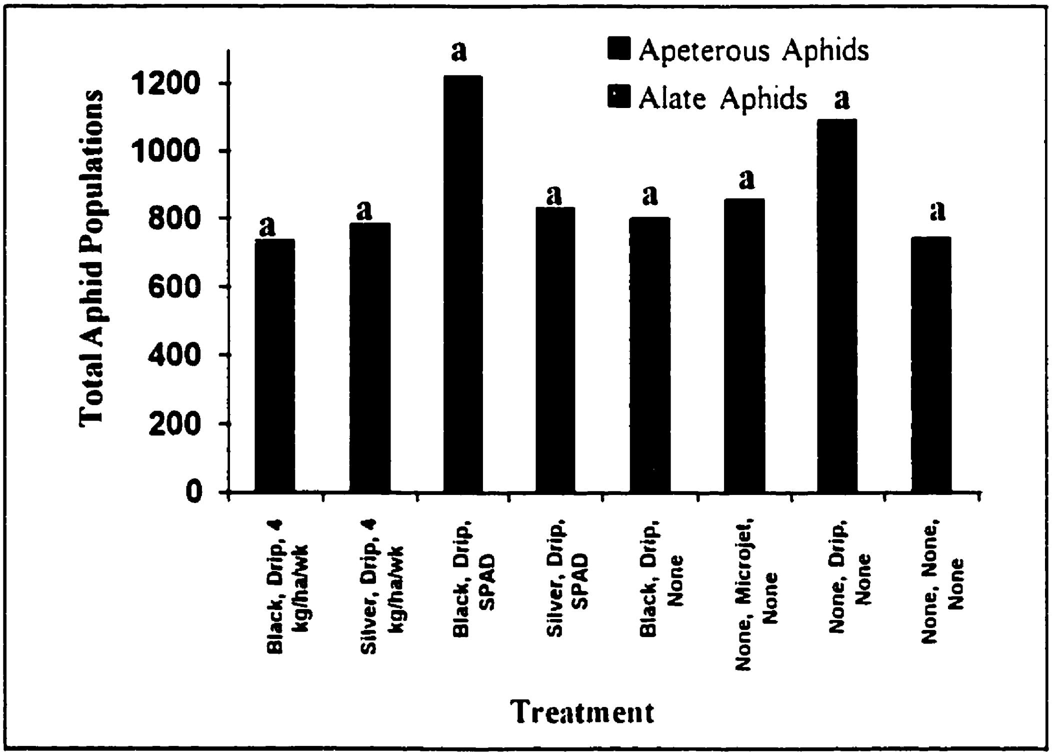


*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 6: Effect of mulch colour, irrigation type, and N fertilization level on mean number of tarnished plant bugs in the 1995 season (means based on 9 plants per plot)

The number of tarnished plant bugs was counted on nine plants per plot on a weekly basis. The counts started on June 27 and July 3 and were seen until September 19 and September 18 in 1995 and 1996, respectively.

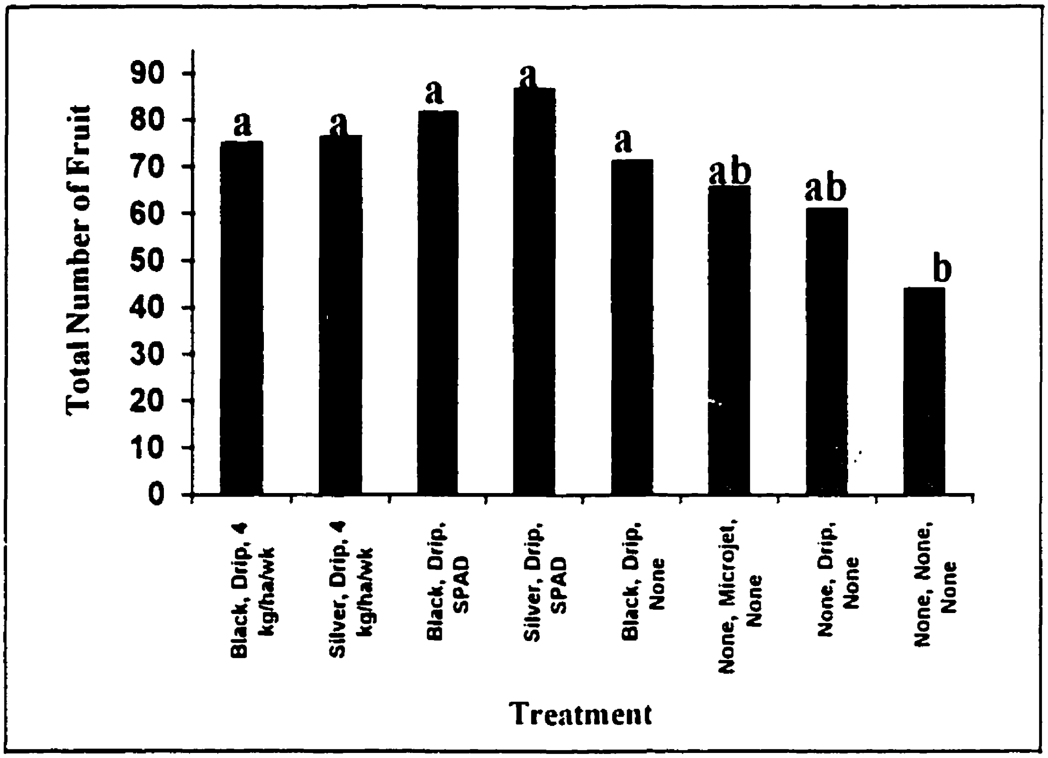
There are no significant differences in the mean number of insects among the treatments (Figure 6) or in the planned contrasts in 1995.



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 7: Effect of mulch colour, irrigation type, and N fertilization level on mean total aphid population in the 1995 season

Figure 7 shows the season total populations of alate and apterous aphids. With the exception of the BDW and BDS treatments, Figures 7 and 8 look very similar. Thus it may be that tarnished plant bug populations are dependent on aphid populations as they are attracted by the sweet scent of the aphid honeydew as shown by Lindquist and Sorensen (1970).

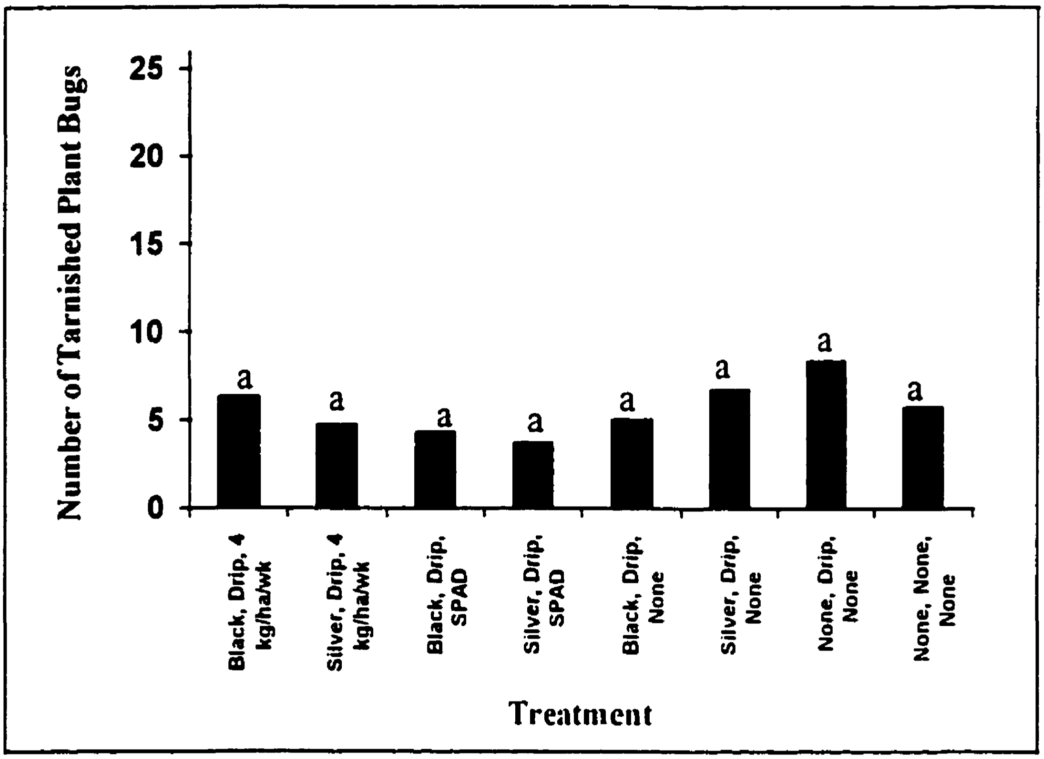


*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 8: Effect of mulch colour, irrigation type, and N fertilization level on mean total number of fruit in the 1995 season (means based on 9 plants per plot)

Figure 8 represents the mean total number of fruit in the 1995 season. With the exception of treatment BDW, comparing Figures 7 and 9 reveals that treatments which had high numbers of tarnished plant bugs had lower numbers of fruit.

In 1996 the number of tarnished plant bugs observed was extremely low and no significant differences were noted among the treatments (Figure 9).



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 9: Effect of mulch colour, irrigation type, and N fertilization level on mean number of tarnished plant bugs in the 1996 season (means based on 9 plants per plot)

4.5 EUROPEAN CORN BORER

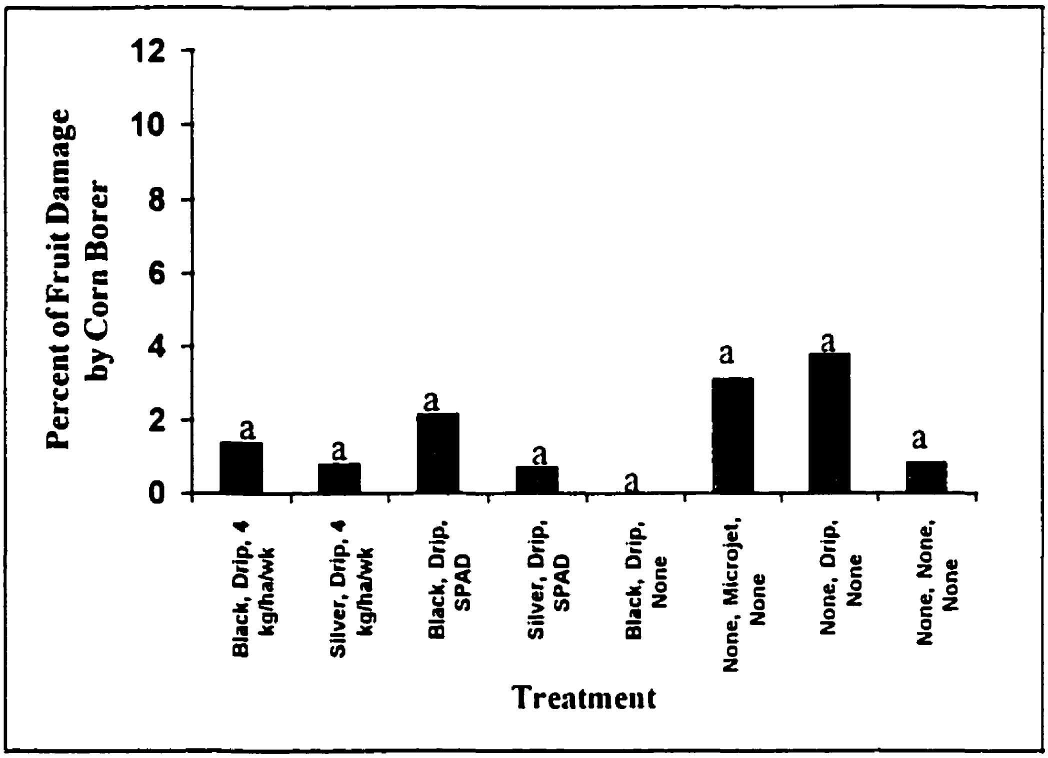
The European corn borer, *Ostrinia nubilalis* (Hubner), is a major pest of pepper. The larva typically enters the fruit through the calyx leaving saw-dust-like droppings around the hole. The European corn borer can have one to two generations per year in Canada. The damage done to the peppers starts in mid-July and continue until early August or late September (Howard et al., 1994).

Damaged fruit were harvested from August 23 and August 26 until September 20 and October 2 in 1995 and 1996, respectively. Fruit were harvested from nine plants per plot and the percent of damaged fruit was calculated. The data were transformed using an arcsine transformation and analyzed (Zar, 1974).

In 1995 there was minimal damage caused by the European corn borer (1.5%). There are no significant differences when comparing treatments (Figure 10). However, plants grown on silver mulch (SDW, SDS) have a lower percentage of damaged fruit than those grown on black mulch (BDW, BDS) regardless of the level of fertigation or irrigation.

A planned contrast which compared irrigated treatments (NMN and NDN) to a non-irrigated treatment (NNN) showed that irrigated treatments had significantly higher ($p=0.02$) percentages of fruit damaged by European corn borer (3.1% and 3.8%, respectively) than the non-irrigated treatment (0.8%). These irrigated treatments had the highest percentages of damage compared to all the other treatments (Figure 10). Royer and McNeil (1993) found that females tended to aggregate in locations of high humidity.

Apparently, there is an increased sensitivity to pheromones at high levels of humidity. Perhaps the irrigated plots had higher humidity levels than non-irrigated plots. A planned contrast which compared fertilized treatments (BDW and BDS) with a non-fertilized treatment (BDN) showed that fertigation had a significant (p=0.03) effect on the percentage of damaged fruit. Fertilized treatments had higher percentages of damaged fruit (1.4% and 2.1%, respectively) than the non-fertilized treatment (0.0%).

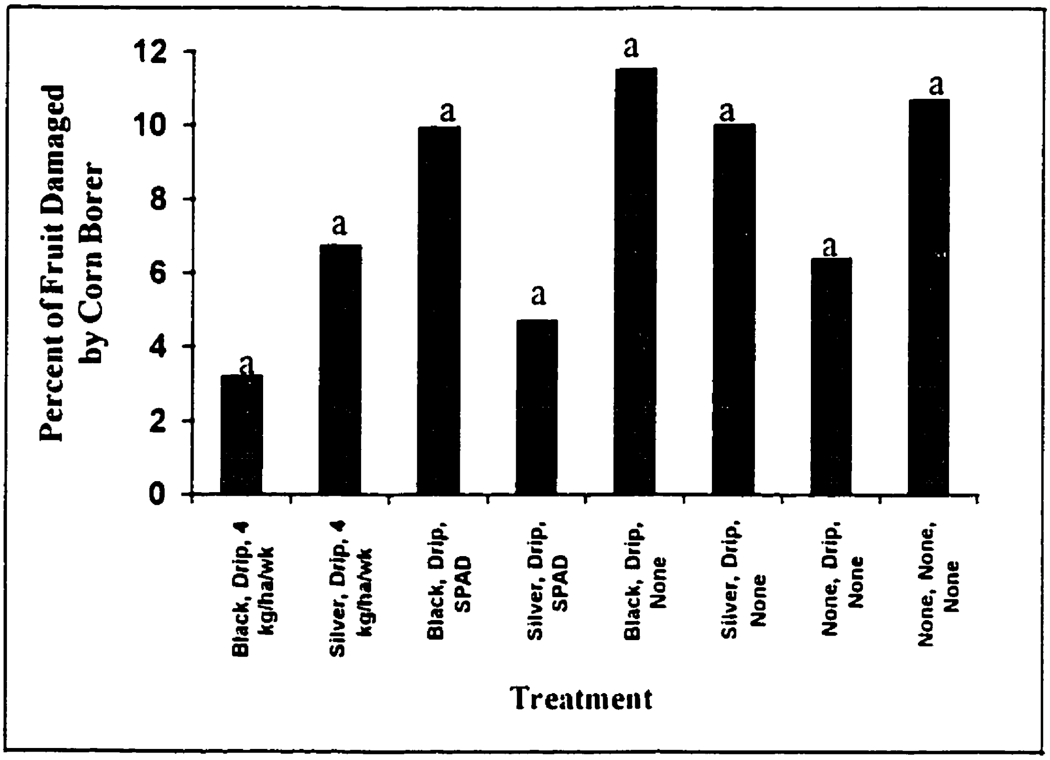


*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 10: Effect of mulch colour, irrigation type, and N fertilization level on mean percentage of fruit damaged by corn borer in the 1995 season (means based on 9 plants per plot)

In 1996 approximately 8% of all the fruit harvested showed corn borer damage although no significant differences were observed among treatments (Figure 11) or among the planned contrasts.

Splittstoesser and Brown (1991) described how plastic films create a more uniform microclimate by moderating climatic excesses of sun, rain, and wind. It is possible that treatments which were mulched, fertilized, and irrigated, in this research, provided such an environment over the growing season with higher humidity levels thereby favouring corn borer aggregation.



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 11: Effect of mulch colour, irrigation type, and N fertilization level on mean percentage of fruit damaged by corn borer in the 1996 season (means based on 9 plants per plot)

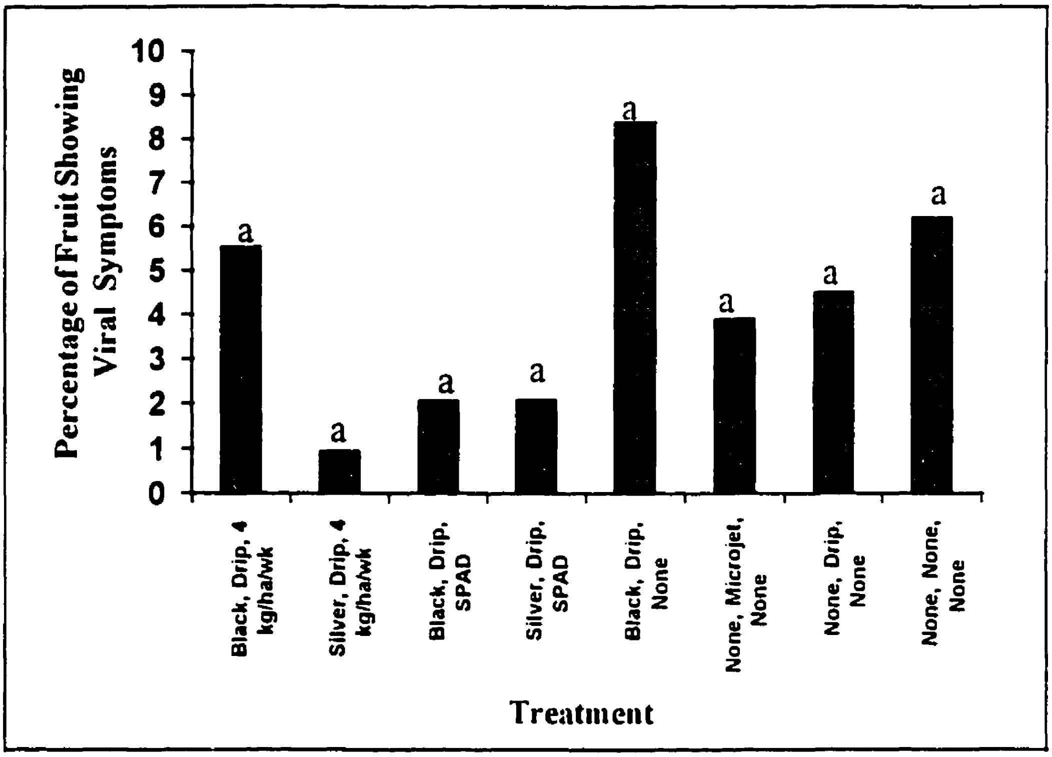
4.6 VIRUSES

In Québec, most of the viral infections are cucumber mosaic viruses or complexes with cucumber mosaic virus. Viruses are known to be most efficiently spread by aphids (Howard et al., 1994; Sherf and MacNab, 1986). Many researchers have shown a relationship between the number of aphids present and the amount of viral infection in the field (Brown et al., 1993; Lamont et al., 1990; Smith et al., 1964, Wolfenbarger and Moore, 1968). Wyman et al. (1979) showed that reflective, aluminum mulches could reduce virus incidence in summer squash by 94%.

Fruit were harvested from nine plants per plot and percent fruit showing viral damage was calculated. The percentage data were transformed using an arcsine transformation (Zar, 1974). Damaged fruit occurred throughout the harvest season in both years.

In 1995 less than 4% of the fruit harvested showed viral symptoms. There are no significant differences among the treatments (Figure 12) or in the planned contrasts. The irrigated treatments (NMN and NDN) had lower percentages of damage than the non-irrigated treatment (NNN). The silver mulch treatments (SDW, SDS) as well as the black mulch, SPAD fertilized treatment (BDS) had the lowest percentages of damaged fruit.

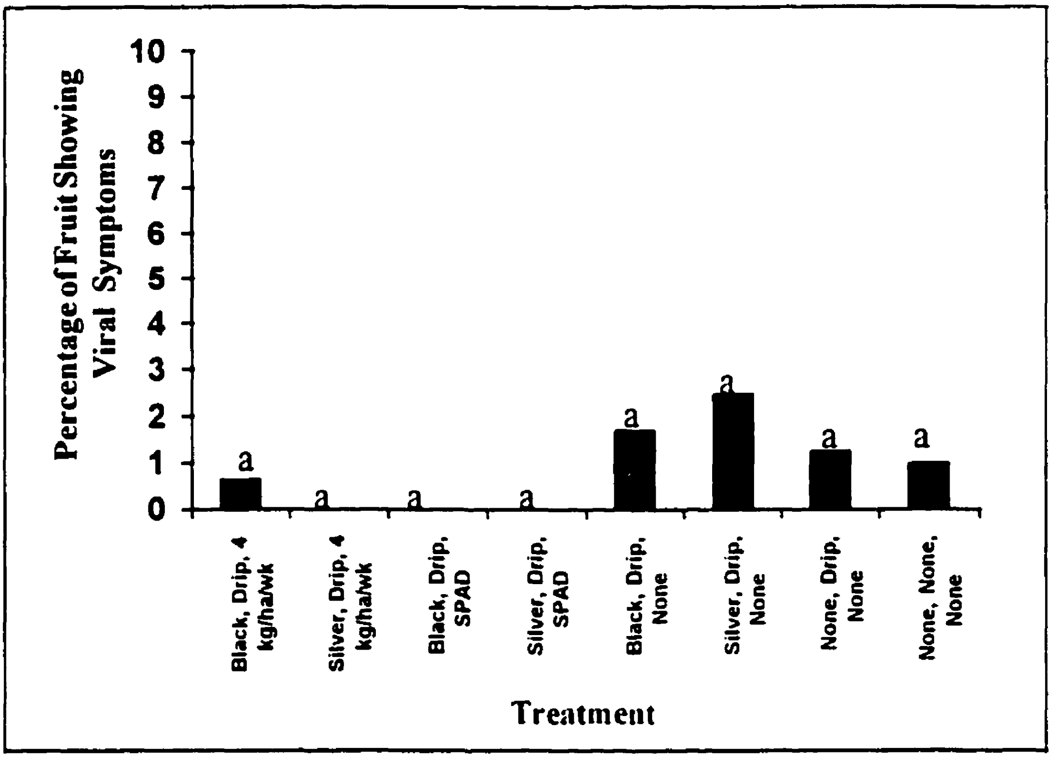
Comparing Figure 12 with Figure 4, which shows the alate aphid populations in the 1995 season, reveals that treatments which had high percentages of damaged fruit generally had greater alate aphid populations with the exception of BDW and BDN. Perhaps these percentages of damaged fruit would have been lower if they had been calculated on a fruit weight basis. The average weight of a culled fruit was lower on these treatments than on the other treatments. The silver mulch treatments (SDW and SDS) had the lowest number of alate aphids and the lowest percentages of virus damaged fruit. Brown et al. (1993) had found that silver mulch treatments had the lowest incidence of virus as well as the lowest populations of aphids. They also found that the other colours of mulch had intermediate effects to the silver mulch and bare ground treatments. Wyman et al. (1979) also found that aluminum mulch was superior to other colours of mulch in reducing viral incidence.



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 12: Effect of mulch colour, irrigation type, and N fertilization level on mean percentage of pepper fruit showing viral symptoms in the 1995 season (means based on 9 plants per plot)

The 1996 season had a lower percentage of fruit damaged by viruses (1.0%) than the 1995 season (3.9%). This might be due to the fact that 1995 had much higher alate aphid populations (Figure 4) than 1996 (Figure 5). The effect of mulch colour, irrigation type, and fertilization level on the mean percentage of fruit damaged in the 1996 season is shown in Figure 13. There are no significant differences among the treatments or in the planned contrasts.



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 13: Effect of mulch colour, irrigation type, and N fertilization level on mean percentage of pepper fruit showing viral symptoms in the 1996 season (means based on 9 plants per plot)

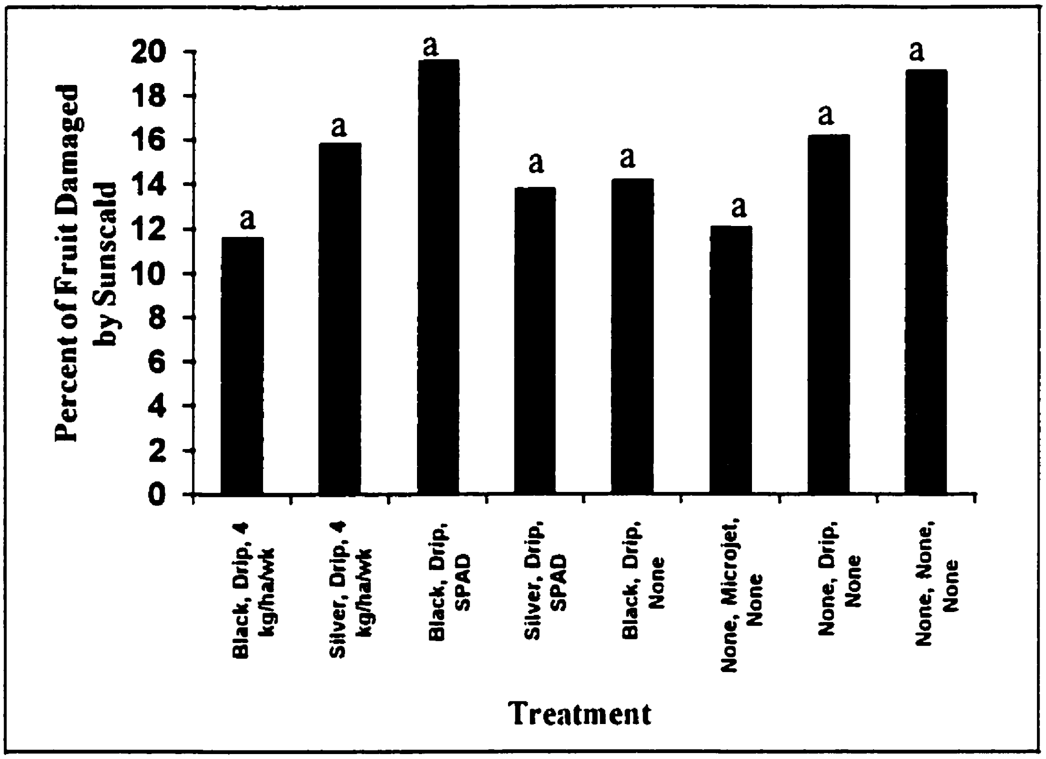
There was no clear relationship between the percentage of damaged fruit (Figure 13) and the alate aphid populations (Figure 5). Perhaps a relationship would be more obvious if it had been calculated on a fruit weight basis since the NDN and NNN treatments had the highest average cull weight.

4.7 SUNSCALD

Sunscald is a physiological condition where the tissue is "burned" when it is exposed to direct sunlight. It occurs when the older leaves do not protect the fruit or other young tissue from the light particularly when it is very hot and humid (Howard et al., 1994). VanDerwerken and Wilcox-Lee (1988) showed that with irrigation or mulch the percentage of marketable peppers increased due to a decrease in sunscald.

Fruit were harvested and counted from nine plants per plot and the percent of sunscalded fruit was calculated. The percentage data were transformed using an arcsine transformation (Zar, 1974). Sunscalded fruit occurred throughout the 1995 and 1996 harvest seasons.

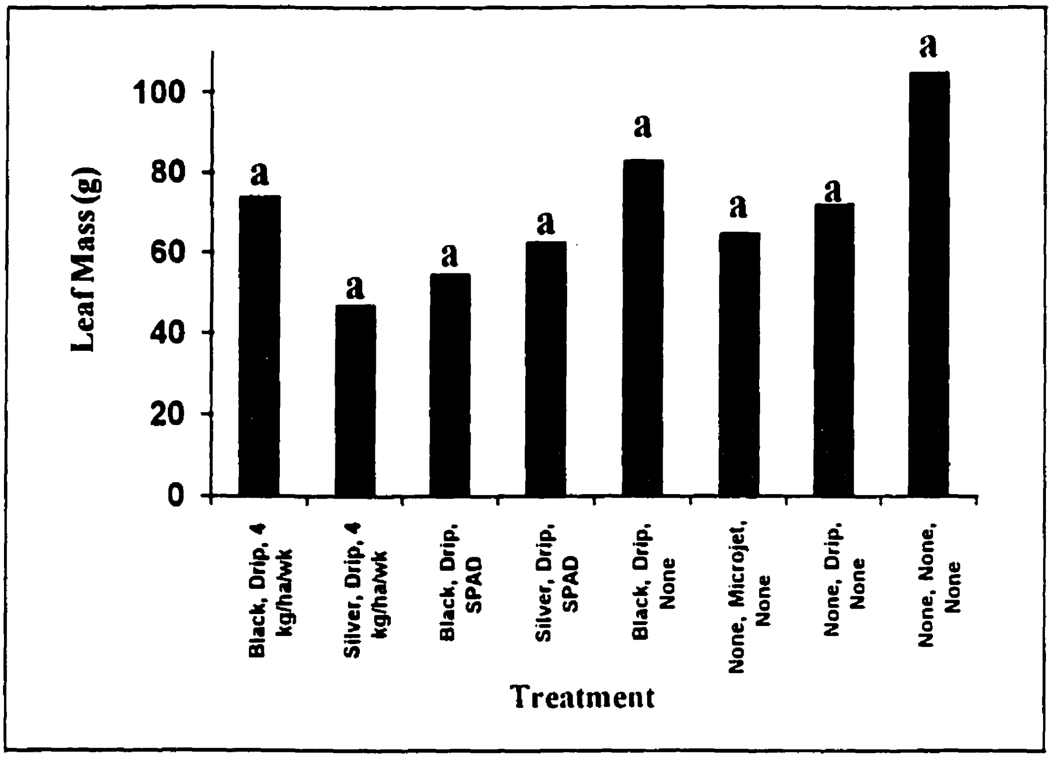
There are no significant differences among the treatments (Figure 14) or in the planned contrasts in 1995. Madramootoo and Rigby (1991) found that there was an inverse relationship between dry leaf mass and the percentage of sunscald. If Figure 14 is compared with the leaf mass (Figure 15) taken at the end of the season, then a similar



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 14: Effect of mulch colour, irrigation type, and N fertilization level on mean percentage of fruit damaged by sunscald in the 1995 season (means based on 9 plants per plot)

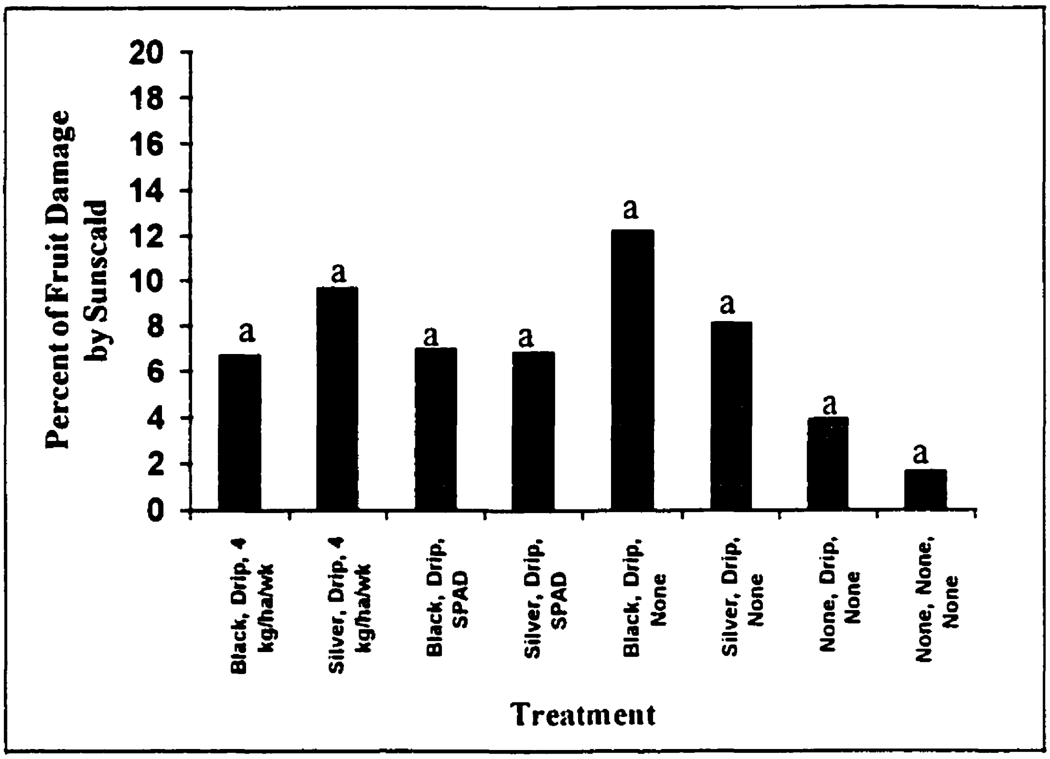
relationship is observed with the exception of treatments NNN and NMN. This may be because the NNN treatment produced the heaviest culls. Smaller fruits have a higher resistance to sunscald than larger fruits because of increased efficiency of convective cooling (Barber and Sharpe, 1971).



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 15: Effect of mulch colour, irrigation type, and N fertilization level on mean dry weight leaf mass in the 1995 season (means based on 2 plants per plot)

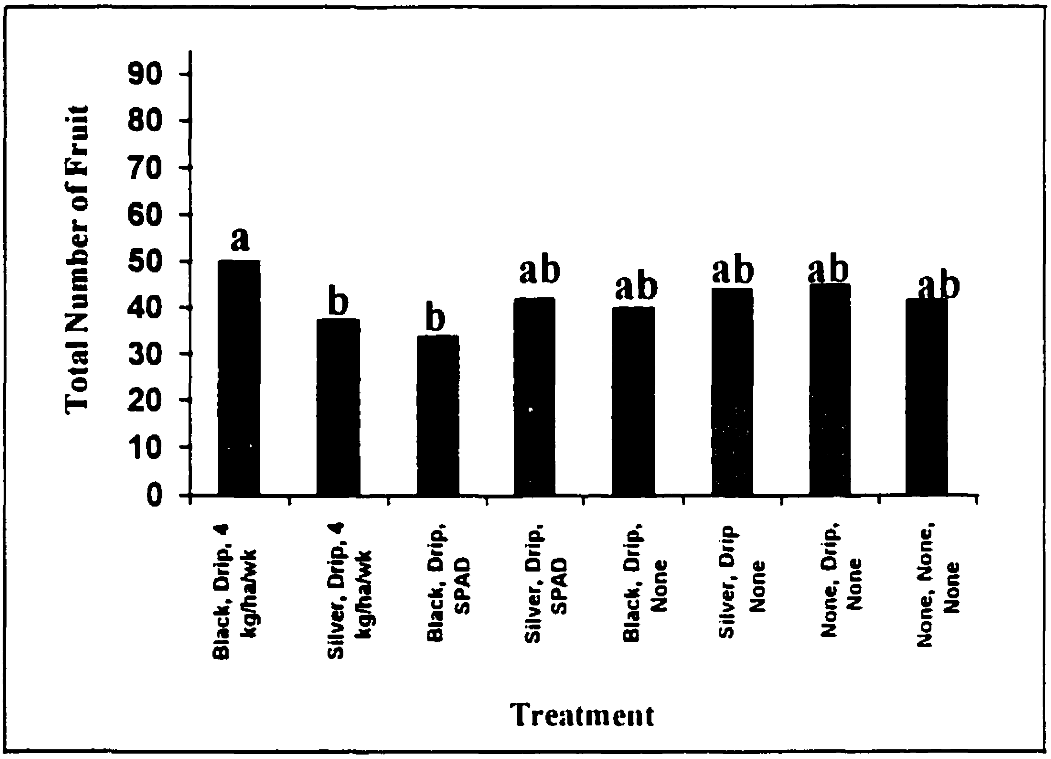
In 1996, there are no significant differences among the treatments (Figure 16) or in the planned contrasts. This season had a low percentage of sunscalded fruit which may have resulted from a combination of factors such as a low fruit number of fruit (Figure 17), cooler temperatures and less rainfall (Table 8) than in the previous year.



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

Figure 16: Effect of mulch colour, irrigation type, and N fertilization level on mean percentage of fruit damaged by sunscald in the 1996 season (means based on 9 plants per plot)

The absorption of infrared radiation by water in the plant tissue may cause overheating of the tissue and therefore sunscald (Adegoroye and Jolliffe, 1983). Perhaps the higher temperatures and amount of rainfall during the 1995 season compared with the 1996 season caused the overheating of the tissue water resulting in the greater percentage of sunscalded fruit in 1995 (15.2%) compared with 1996 (6.7%).



*All bars with the same letter are not significantly different at the alpha=0.05 level SNK.

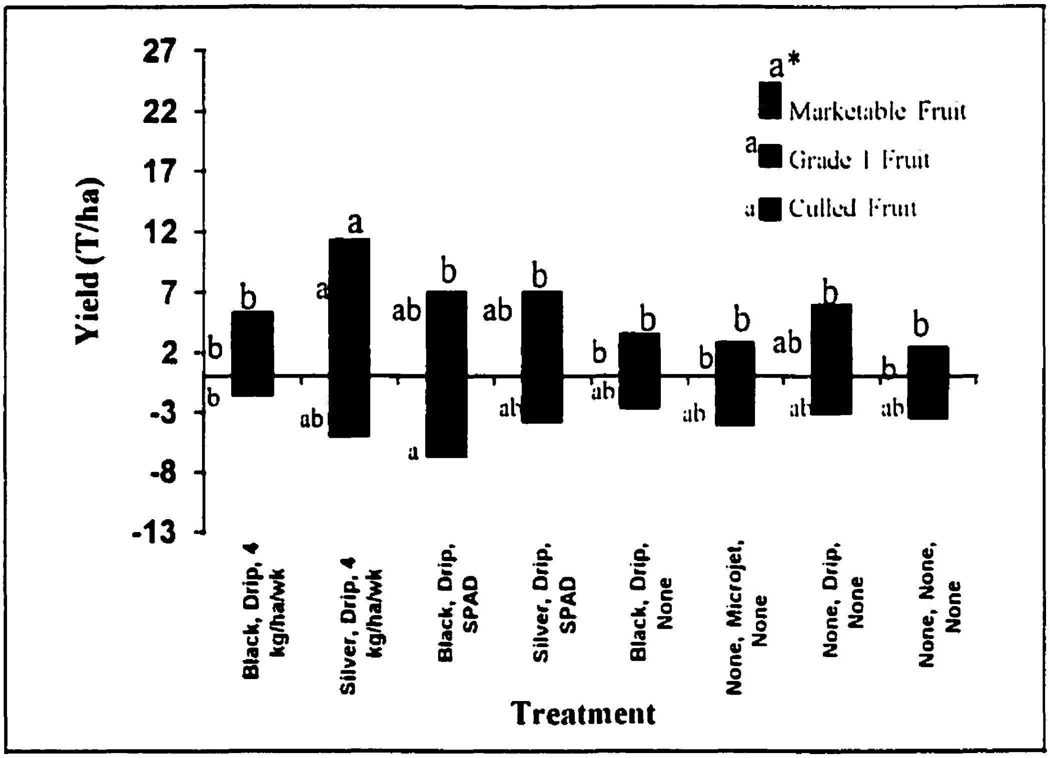
Figure 17: Effect of mulch colour, irrigation type, and N fertilization level on mean total number of fruit in the 1996 season (means based on 9 plants per plot)

4.8 YIELD

Pepper fruit were harvested red and graded into three categories: grade 1 fruit, grade 2 fruit, and culls based on a modified classification scheme of Aziz (1994), Rigby (1988), and Telios (1994). Marketable fruit consisted of grade 1 fruit and grade 2 fruit. Yields were also separated into three time classes since the price of peppers varies within the season. Early yields were collected on three dates within the August 23 to August 30 and August 26 to September 2 time period in 1995 and 1996, respectively. Midseason yields were harvested on three dates within the September 2 to September 9 and September 6 to September 16 time period in 1995 and 1996, respectively. The late yields were harvested on three dates in 1995 within the time period of September 13 to September 23 and on two dates in 1996, September 23 and September 30.

4.8.1 The 1995 Harvest

Figure 18 shows the mean early season yields (T/ha) for 1995. With the exception of BDW, all the fertilized treatments had high early marketable yields, ranging from 7.0 to 11.3 T/ha, and grade 1 fruit yields, ranging from 5.3 to 7.5 T/ha. One possible explanation for the low yields of the BDW treatment is that there was an interaction between soil temperature and nutrient availability. Most of the black mulch treatments had higher soil temperatures than the silver mulch treatments (Table 24). This was the case with the BDW treatment which had a mean maximum soil temperature of 27.2°C and 26.0°C in June and July, respectively. The SDW treatment had mean maximum temperatures of 25.6°C and 25.1°C in June and July, respectively. Higher soil temperatures have been reported to increase nutrient availability (Hankin et al., 1982). The BDW treatment was fertilized on a weekly basis. Perhaps the increased nutrient availability coupled with the weekly fertigation gave these plants too much N so that they were producing vegetatively instead of reproductively. In fact, the foliar N% values (Table 10) show that BDW was always above the minimum foliar N% values determined by Fletcher et al. (1993). The cooler temperatures under the silver mulch coupled with the weekly applications of N resulted in the significantly highest production of marketable



*All bars with the level of significance located at the same position with the same size font are significant at the alpha=0.05 level SNK.

Figure 18: Effect of mulch colour, irrigation type, and N fertilization level on mean early yields (T/ha) of grade 1, marketable, and culled fruit of pepper (cv King Arthur) in 1995 (means based on 9 plants per plot)

Table 24: Mean monthly maximum, minimum, and average soil temperatures (°C) in each mulched, irrigated, and N fertilized treatment in the 1995 Season

Treatment	June			July			August			September		
	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
Black, Drip, Weekly (BDW)	27.2	21.5	24.3	26.0	22.6	24.2	24.2	21.7	22.9	18.8	16.2	17.4
Silver, Drip, Weekly (SDW)	25.6	20.7	23.0	25.1	22.3	23.6	23.8	21.6	22.6	19.0	16.0	17.5
Black, Drip, SPAD[*] (BDS)	27.2	21.4	24.1	26.9	22.7	24.6	26.3	21.8	23.8	19.3	15.8	17.5
Silver, Drip, SPAD (SDS)	26.8	21.1	23.9	25.9	22.6	24.2	24.5	21.8	23.1	19.4	16.0	17.6
Black, Drip, None (BDN)	25.7	20.7	23.1	26.0	22.3	24.0	24.8	21.5	23.0	18.5	15.8	17.1
None, Microjet, None (NMN)	25.8	19.0	22.1	25.4	20.6	22.8	25.6	19.5	22.3	18.9	13.8	16.2
None, Drip, None (NDN)	25.3	20.4	22.7	26.1	21.7	23.6	24.5	20.4	22.3	17.4	14.5	16.0
None, None, None (NNN)	26.4	20.5	23.2	26.1	21.7	23.7	25.5	20.6	22.8	18.5	14.2	16.2
Air	30.9	13.2	23.2	30.4	16.1	23.7	28.8	14.6	22.5	21.2	7.6	16.6

[*]SPAD = Soil Plant Analysis Development Meter

yields compared with the other treatments and a significantly highest production of grade 1 yields compared with the BDW, BDN, NMN, and NNN treatments.

It was expected that the mulched plants yield more than their non-mulched counterparts as reported by (Bhella, 1988; Sweeney et al., 1987; VanDerwerken and Wilcox-Lee, 1988). However, the BDN treatment had early yields comparable to those of the non-mulched treatments (Figure 18). This may be due to the fact that this treatment had lower soil temperatures than the other black mulch treatments in the months of June and July (Table 24). In fact, this treatment had similar temperatures to that of the SDW treatment. The BDN treatment was not receiving additional fertilizer, but the SDW treatment was receiving additional fertilizer on a weekly basis. Perhaps the BDN treatment was occasionally N deficient. The foliar N% values (Table 10) show that the BDN treatment was N deficient on July 31, 1995.

The effect that the differences in soil temperature had on early yields between the black and the silver mulch can also be seen in Table 25 which shows the effects of specific planned contrasts. The early yield contrasts show that the use of black versus silver mulch has a significant effect on early marketable yields. Figure 18 shows that it was the silver mulch which had higher yields than black mulch.

Of the non-mulched, non-fertilized treatments, the NDN treatment had the highest early marketable and grade 1 yields on a weight basis (Figure 18). This may be because the water was applied via drip irrigation and therefore it was given directly in the root zone of the plant (Tindall et al., 1991). The microjet treatment sprayed water on the

Table 25: Summary table of F values for effects of planned contrasts on yields in 1995

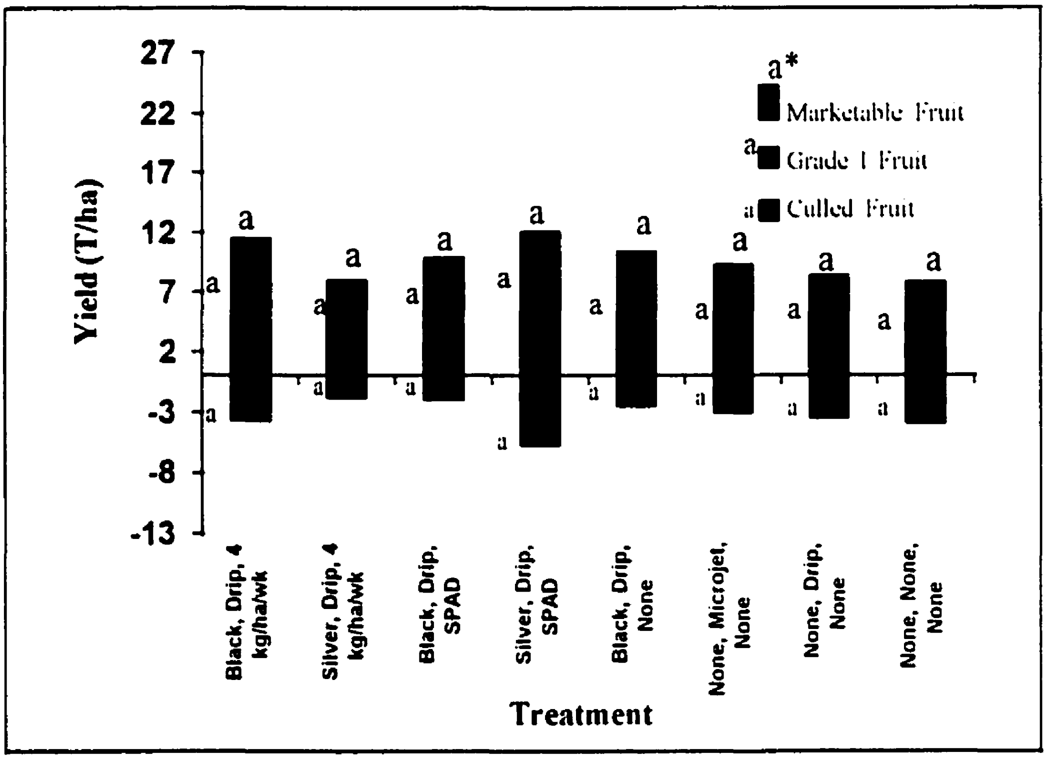
Contrast[Note]	Early			Midseason			Late			Total		
	Grade 1	Marketable[a]	Cull	Grade 1	Marketable	Cull	Grade 1	Marketable	Cull	Grade 1	Marketable	Cull
fert. vs. no fert.	2.01	4.15	1.70	0.18	0.02	0.04	1.61	3.49	0.27	0.14	0.00	1.17
weekly vs. SPAD	0.04	1.44	4.76*	0.09	0.50	0.70	0.23	0.21	2.70	0.33	0.08	6.20*
black vs. silver	4.26	8.37*	0.09	0.06	0.13	0.52	0.08	0.04	2.36	1.32	1.69	0.04
micro. vs. drip	1.83	4.56*	0.67	0.12	0.11	0.06	0.81	1.10	0.60	0.00	0.02	0.00
irrig. vs. no irrig.	1.50	2.39	0.00	0.00	0.22	0.18	4.69*	2.51	3.04	3.86	4.77*	0.10

Note: -fertilization vs. no fertilization = BDW, BDS vs. BDN
-weekly vs. SPAD = BDW, SDW vs. BDS, SDS
-black vs. silver = BDW, BDS vs. SDW, SDS
-microjet vs. drip = NMN vs. NDN
-irrigation vs. no irrigation = NMN, NDN vs. NNN

* probability value < 0.05
[a] Marketable yields includes Grades 1 and 2

leaves of the plant and it was distributed over a larger soil surface area. Consequently, there was a larger surface area for evaporation. It is possible that the plant received less water than the drip irrigated plants. The difference in marketable yield between microjet and drip irrigated plants was significant according to the planned contrasts in Table 25.

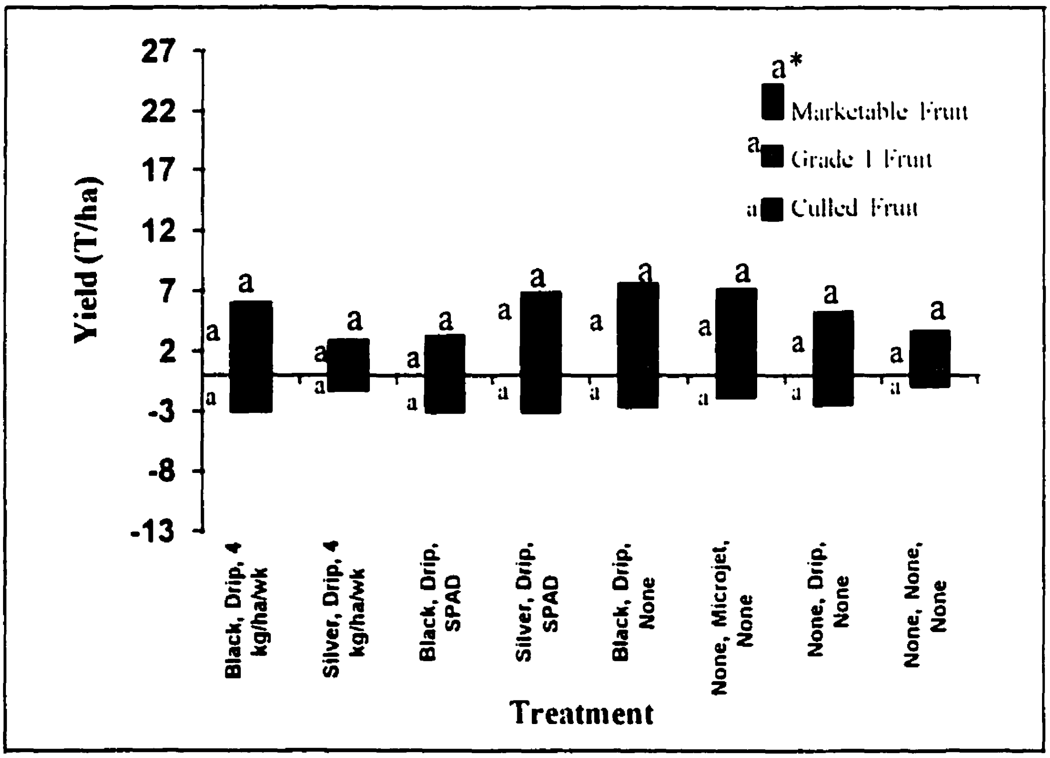
The mean midseason yields in 1995 are given in Figure 19 in T/ha. The midseason marketable and grade 1 yields as well as culled fruit are all statistically similar



*All bars with the level of significance located at the same position with the same size font are significant at the alpha=0.05 level SNK.

Figure 19: Effect of mulch colour, irrigation type, and N fertilization level on mean midseason yields (T/ha) of grade 1, marketable, and culled fruit of pepper (cv King Arthur) in 1995 (means based on 9 plants per plot)

within the given grade of fruit. The BDW treatment (which had low early yields) and the SDS treatment (which had average early yields) had the highest midseason yields. Table 24 shows that in August the mean maximum soil temperature of the BDW treatment decreased to 24.2°C from the June and July values. Perhaps at this temperature the nutrient availability and uptake was such that the plants allocated their energy to reproductive development. The SDS treatment had similar yields and also had similar August soil temperatures to the BDW treatment.



*All bars with the level of significance located at the same position with the same size font are significant at the alpha=0.05 level SNK.

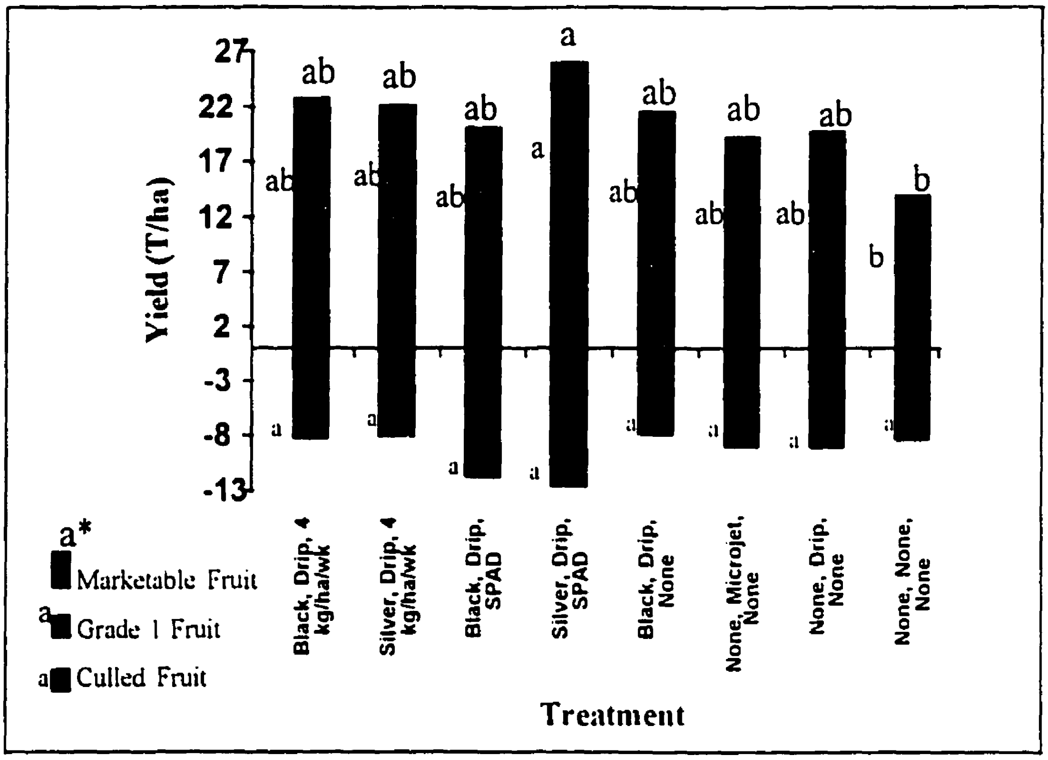
Figure 20: Effect of mulch colour, irrigation type, and N fertilization level on mean late yields (T/ha) of grade 1, marketable, and culled fruit of pepper (cv King Arthur) in 1995 (means based on 9 plants per plot)

Of the non-fertilized treatments, the mulched treatment (BDN), had the highest midseason yield (Figure 19) and both the irrigated treatments (NMN, NDN) had higher midseason yields than the non-irrigated treatment (NNN). These findings have been confirmed by other researchers who have demonstrated that mulches and irrigation (Bhella, 1988; VanDerwerken and Wilcox-Lee, 1988) both increase yield.

The mean late yields in 1995 are given in Figure 20 in T/ha. Mean late marketable and grade 1 yields as well as culled fruit are all statistically similar within the given grade of fruit. The SDW and BDW treatments had the lowest late yields of the fertilized treatments. These treatments had high and average marketable yields in the early and midseason. The BDW and SDS treatments had average late yields. These treatments had low and average yields in the early and midseason. The non-fertilized treatments had average to high yields with the exception of NNN. These treatments all had low yields early in the season. Thus, the late yields seem to be a function of the rest of the season's yield.

The planned contrasts in Table 25 show that the grade 1 yields in the late season are significantly affected by the difference between irrigated and non-irrigated treatments. Figure 20 shows that the irrigated treatments gave higher yields than the non-irrigated treatments. The effect of irrigation has been confirmed by many researchers (Bhella, 1988; Tindall et al., 1991; VanDerwerken and Wilcox-Lee, 1988).

The only treatment that had consistently high or average yields throughout the season was the SDS treatment while the NNN treatment consistently had low yields (Figures 19, 20, and 21). This is reflected in Figure 21 which gives the mean total yields



*All bars with the level of significance located at the same position with the same size font are significant at the alpha=0.05 level SNK.

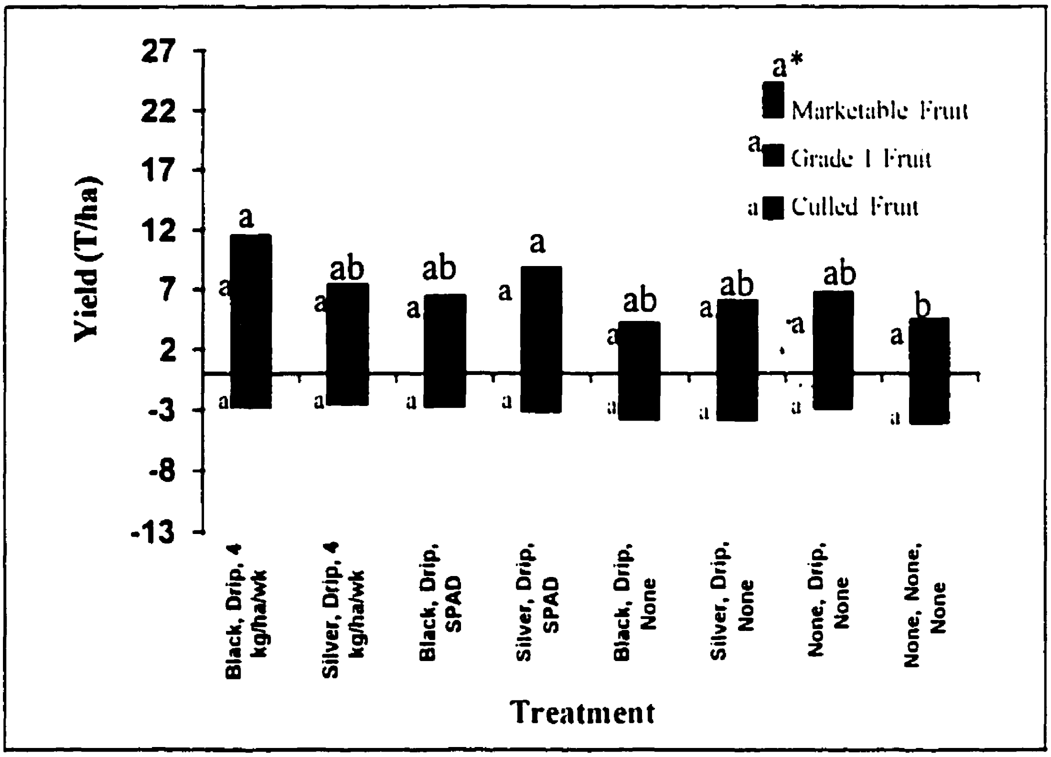
Figure 21: Effect of mulch colour, irrigation type, and N fertilization level on mean total yields (T/ha) of grade 1, marketable, and culled fruit of pepper (cv King Arthur) in 1995 (means based on 9 plants per plot)

in 1995 in T/ha. All the other treatments had total yields (both marketable and grade 1 yields) which were similar to each other. Therefore the major difference in these treatments seems to be the time of fruit production. Since higher early season yields are desirable in Québec because of the higher market value of early fruit, the preferred treatments are those that produce earlier in the season. Thus, the fertilized treatments performed better than the non-fertilized treatments in the 1995 season.

The treatments fertilized using the SPAD method had the largest number of culls (Figure 21). According to Table 25, the treatments fertilized using the SPAD method had a significantly higher numbers of culls than the weekly fertilized treatments. In the case of SDS, the high number of culls is actually a relatively low percentage of the total yields. However, the BDS treatment could have resulted in better yields if the number of culls had been similar to that of the weekly fertilized treatment. The treatments fertilized using the SPAD method may have had more culls because the greater number of fruit resulted in more fruit exposed to the sun than on other treatments.

2. The 1996 Harvest

The mean early yields in T/ha for the 1996 season are given in Figure 22. The BDW and SDS treatments had the highest early yields. These yields were significantly higher than those of the NNN treatment. At the lower levels of additional N, the silver mulch treatments (SDS and SDN) had higher early yields than the black mulch treatments (BDS and BDN). However, at the highest level of N fertilization, the black mulch treatment (BDW) had a higher yield than the silver mulch treatment (SDW). Table 26 gives the mean soil temperatures. In June, the BDW treatment had higher soil temperatures than the SDW treatment. Perhaps the increased nutrient availability by the higher temperatures as reported by (Hankin et al., 1982) caused BDW to have higher yields than SDW. The soil temperatures in June in the BDS and SDS treatments were almost identical. Since there was a decrease in stress on the silver mulch due to lower alate aphid populations (see Figures 5 and 6), it is possible the yield was higher than that of the BDS treatment. This may also be the case for the BDN and SDN treatments since the temperatures in these treatments were also similar. Another possible explanation for the higher yields on the silver mulched treatments (SDS and SDN) is that the increased reflection off the silver mulch may have increased the amount of photosynthesis (Bauerle, 1982), increased the photosynthates, and lead to an increase in production.



*All bars with the level of significance located at the same position with the same size font are significant at the alpha=0.05 level SNK.

Figure 22: Effect of mulch colour, irrigation type, and N fertilization level on mean early yields (T/ha) of grade 1, marketable, and culled fruit of pepper (cv King Arthur) in 1996 (means based on 9 plants per plot)

Table 26: Mean monthly maximum, minimum, and average soil temperatures (°c) in each mulched, irrigated, and N fertilized treatment in the 1996 season

Treatment	June			July			August			September		
	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.	Max.	Min.	Ave.
Black, Drip, Weekly (BDW)	25.0	19.3	21.7	25.1	20.5	22.6	24.5	20.7	22.6	19.1	16.6	17.8
Silver, Drip, Weekly (SDW)	24.2	19.2	21.3	24.7	20.5	22.4	24.4	20.8	22.5	19.3	16.7	17.9
Black, Drip, SPAD* (BDS)	24.4	19.2	21.4	24.8	20.4	22.4	24.7	20.6	22.6	19.3	16.6	17.8
Silver, Drip, SPAD (SDS)	24.4	19.2	21.3	24.2	20.4	22.2	23.5	20.7	22.0	18.7	16.6	17.5
Black, Drip, None (BDN)	24.4	18.7	21.1	25.2	20.2	22.5	24.6	20.5	22.5	19.2	16.3	17.6
Silver, Drip, None (SDN)	24.0	18.8	21.0	24.5	20.1	22.1	24.5	20.4	22.3	19.1	16.2	17.6
None, Drip, None (NDN)	23.7	18.2	20.5	24.1	18.9	21.3	23.7	19.0	21.3	18.0	14.8	16.3
None, None, None (NNN)	23.1	18.6	20.6	23.2	20.0	21.3	24.1	20.1	22.1	18.7	15.7	17.1
Air	24.9	13.6	18.7	27.0	15.1	20.5	28.7	14.1	20.9	21.5	11.0	15.8

*SPAD = Soil Plant Analysis Development Meter

The BDN and SDN treatments had lower early yields than the other mulched treatments, but they also have more culled fruit (Figure 22). The extra fertilizer given to the SPAD and weekly fertigated treatments may have increased the amount of vegetative growth (Minchin et al., 1981; Spiers and Braswell, 1993; Tan et al., 1996) sufficiently to protect the fruit from sunscald. This difference between fertilized and non-fertilized treatments, was found to be significant in the planned contrasts for early grade 1 and marketable fruit given in Table 27.

Among the non-mulched treatments, the drip irrigated treatment (NDN) had higher early yields than the non-irrigated treatment (NNN) (Figure 22). Irrigation has been shown to be a very important factor influencing yield (Bhella, 1988; Tindall et al., 1991; VanDerwerken and Wilcox-Lee, 1988).

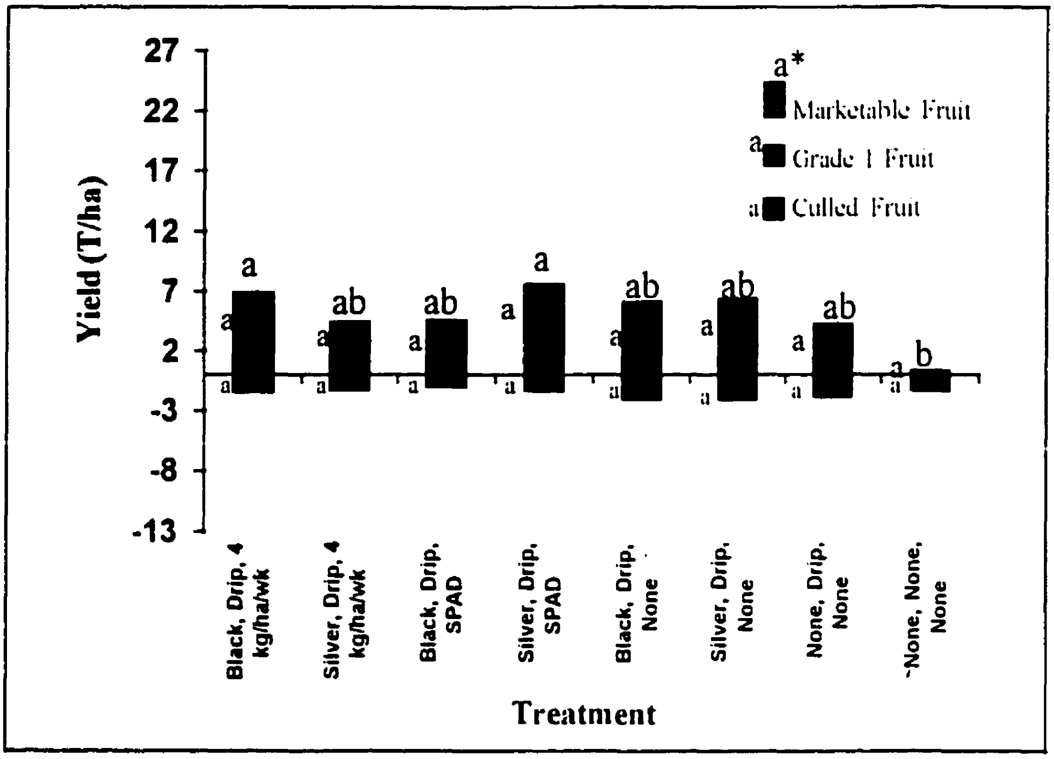
Figure 23 gives the mean midseason yields (T/ha) of grade 1, marketable, and culled fruit in 1996. The midseason yields are lower than the early yields, but the treatments are statistically different in the same manner as the early yields and follow a similar trend. The difference in the relative yields between the early and midseason is

Table 27: Summary table of F values for effects of planned contrasts on yields in 1996

Contrast[Note]	Early			Midseason			Late			Total		
	Grade 1	Marketable	Cull	Grade 1	Marketable	Cull	Grade 1	Marketable	Cull	Grade 1	Marketable	Cull
fert. vs. no fert.	6.05*	10.60*	3.52	0.03	0.10	3.66	0.01	0.20	3.07	2.61	2.08	9.37*
weekly vs. SPAD	0.62	2.35	0.21	0.08	0.08	0.15	0.74	0.19	1.00	0.27	0.64	0.26
black vs. silver	0.17	0.00	0.04	0.44	0.04	0.04	0.25	0.04	0.76	0.79	0.04	0.36
mulch vs. no mulch	0.13	1.18	1.40	0.51	1.44	0.09	1.57	1.66	0.40	0.46	0.29	1.58
drip vs. no irrig.	0.39	1.63	1.64	2.41	4.22	0.61	0.15	0.09	1.48	2.73	4.16	0.00

Note: -fertilization vs. no fertilization = BDW, SDW, BDS, SDS vs. BDN, SDN
-weekly vs. SPAD = BDW, SDW vs. BDS, SDS
-black vs. silver = BDW, BDS, BDN vs. SDW, SDS, SDN
-mulch vs. no mulch = BDN, SDN vs. NDN
-drip vs. no irrigation = NDN vs. NNN

* probability value < 0.05

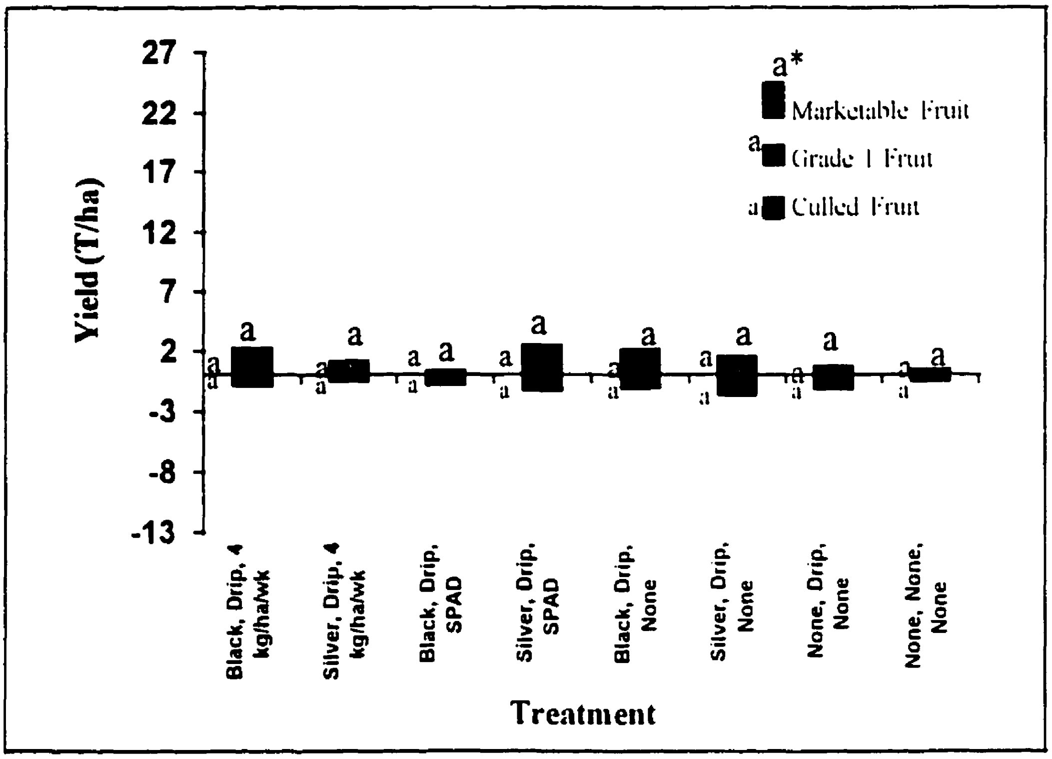


*All bars with the level of significance located at the same position with the same size font are significant at the alpha=0.05 level SNK.

Figure 23: Effect of mulch colour, irrigation type, and N fertilization level on mean midseason yields (T/ha) of grade 1, marketable, and culled fruit of pepper (cv King Arthur) in 1996 (means based on 9 plants per plot)

that the BDN treatment had a higher yield (relative to the other treatments). This may be due to the fact that the treatment had a higher soil temperature in July (Table 26). The black mulch treatments which had maximum soil temperatures above 25°C (BDW, BDN) gave similar yields.

Figure 24 shows the mean late 1996 yields (T/ha) for the various grades of fruit. Once again there is a similar shape to this bar graph as to the early and midseason bar graphs. However, the yields are lower than the early and midseason yields and there is

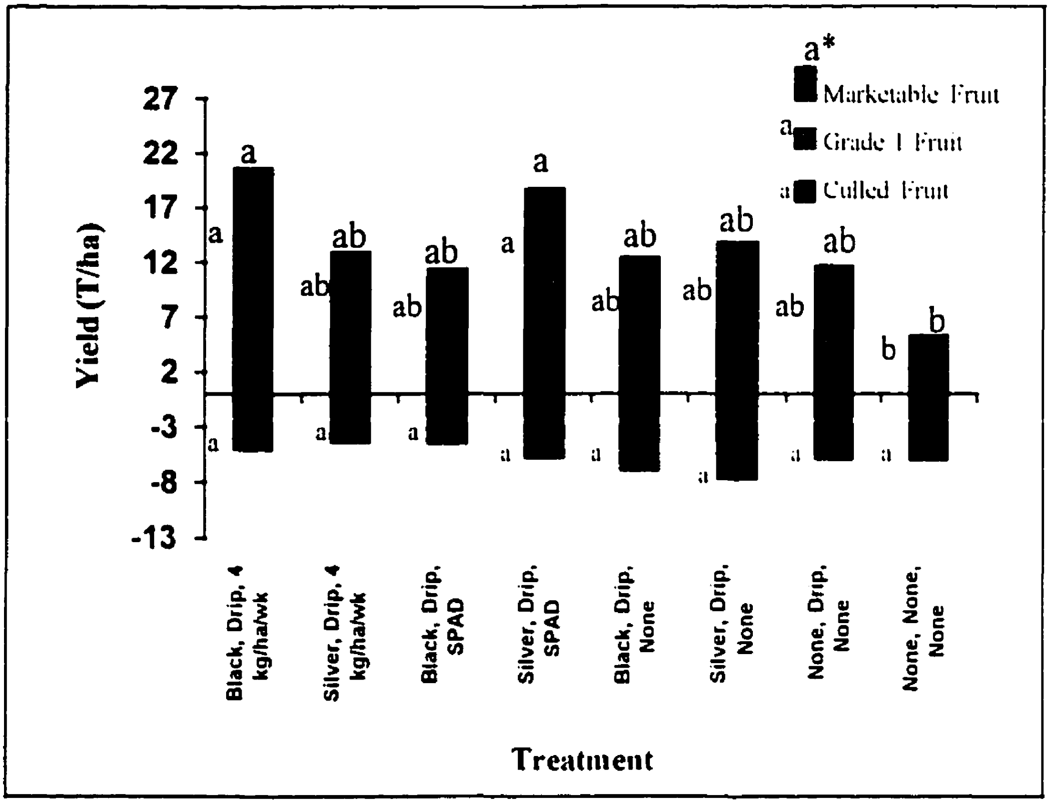


*All bars with the level of significance located at the same position with the same size font are significant at the alpha=0.05 level SNK.

Figure 24: Effect of mulch colour, irrigation type, and N fertilization level on mean late yields (T/ha) of grade 1, marketable, and culled fruit of pepper (cv King Arthur) in 1996 (means based on 9 plants per plot)

no significant difference among the treatments within a grade of fruit. The late season marketable yields are very low and range from a low of 0.4 T/ha (BDS and NNN) to a high of 2.4 T/ha (SDS).

Figure 25 gives the mean total yield of the 1996 season in T/ha for grade 1, marketable, and culled fruit. The pattern of the bar graph remains similar. An explanation for this trend throughout the season may be that there was a block effect on the yields which may be confounding the effects of the treatments.



*All bars with the level of significance located at the same position with the same size font are significant at the alpha=0.05 level SNK.

Figure 25: Effect of mulch colour, irrigation type, and N fertilization level on mean total yields (T/ha) of grade 1, marketable, and culled fruit of pepper (cv King Arthur) in 1996 (means based on 9 plants per plot)

The SDS and BDW treatments had the highest total yields (Figure 25). The lowest yields came from the NNN treatment. The SDW and BDS treatments had similar yields to the BDN, SDN, and NDN treatments. One of the benefits of mulch is that it preserves the soil moisture. In this cooler season (compared with 1995) there may have been less evaporation which would have limited the use of the mulch. Although the NNN treatment is statistically lower than that of the BDW and SDS treatments, its yield is lower than that of all the other treatments. Thus the benefit of irrigation, as has been reported by (Bhella, 1988; Madramootoo and Rigby, 1991; Tindall et al., 1991; VanDerwerken and Wilcox-Lee, 1988) has been clearly demonstrated.

Table 27 which presents the planned contrasts for the 1996 season shows that the fertigated treatments have significantly different amounts of culled fruit from non-fertigated treatments. Figure 25 shows that the non-fertigated treatments (BDN and SDN) have a higher amount of culled fruit than the fertigated treatments (BDW, SDW, BDS, and SDS). The non-fertigated treatments may have had less leaf area and therefore more sunscalded fruit than the fertigated treatments (Minchin et al., 1981; Spiers and Braswell, 1993; Tan et al., 1996).

The 1995 season was generally hotter than the 1996 season. In terms of marketable yield, 1996 had higher early yields (ranging from 4.2 to 11.5 T/ha) than 1995 (ranging from 2.4 to 11.3 T/ha). The 1995 season had much higher midseason yields (ranging from 7.8 to 12.0 T/ha) than 1996 (ranging from 0.3 to 7.6 T/ha). The 1995 season had much higher late season yields as well (ranging from 2.9 to 7.6 T/ha) compared with 1996 (ranging from 0.4 to 2.4 T/ha). This resulted in higher total yields in 1995 (ranging from 13.9 to 26.0 T/ha) compared with the 1996 season (ranging from 5.3 to 20.6 T/ha). In both years, treatments BDW and SDS preformed best.

V CONCLUSIONS

The principle objective of this research was to increase the efficiency of N application. The Minolta SPAD-502 chlorophyll meter seemed to be an effective in-field device for detecting N deficiencies and therefore in scheduling and reducing N applications, inspite of the absence of a strong correlation between foliar N and SPAD values. In both years, the SPAD fertilized plants had total yields which were similar to the weekly fertilized plants, even though the SPAD fertilized plants had 28 kg N/ha to 42 kg N/ha less than the weekly fertilized plants. The SPAD method of determining N application could be improved if further research was conducted into which leaf to use for the SPAD meter readings at the various developmental stages of the plant.

The second objective was to evaluate the silver and black plastic mulch. The silver mulch decreased the alate and apterous aphid populations compared with the black mulch. In general, however, mulching decreased the alate aphid populations, but increased the apterous aphid populations. There were no significant effects of mulching or the colour of mulch on the tarnished plant bug populations, or on the percentage of fruit damaged by European corn borer, viruses, or sunscald. However, the tarnished plant bug population appeared to be influenced by the total (alate and apterous) aphid population. This was probably due to the attraction of tarnished plant bugs to the sweet smell of the aphid honeydew (Lindquist and Sorensen, 1970). The percentage of fruit damaged by viruses also appeared to be related to the total alate aphid population. Aphids are known to vector viruses and it is likely that the alate aphids are responsible for the transmission of viruses from one plant to another (Basky, 1984). The percentage of fruit damaged by viruses may have been better correlated with alate aphid populations and/or mulch colour if the percentage of damaged fruit had been calculated on a fruit weight basis.

Although there was no relationship between percentage of fruit damaged by European corn borer and mulch, the percentage of damaged fruit did seem to be increased by the irrigated treatments. This may be the result of the corn borer aggregating in locations which are more humid (Royer and McNeil, 1993).

Mulch, N fertilization, and irrigation all improved early yields. Irrigation improved yields throughout the seasons. In both years, the BDW and SDS treatments gave the best yields.

The colour of mulch, the level of N fertilization, and the type of irrigation were evaluated for their effects on the yield and quality of peppers. This research indicates that irrigation is necessary, and that drip irrigation is convenient and efficient. Mulch, particularly silver mulch is effective in lowering deleterious insect populations and in reducing virus problems. Nitrogen fertilization improves early yields. Scheduling N applications according to the SPAD meter increases N efficiency without causing yield reductions.

Although this research addressed the initial objectives set forth, there are still unanswered questions that could form the basis for further research.

Firstly, the SPAD method of timing and scheduling N applications could be the subject of research. An experiment could be carried out to determine if a specific leaf on a pepper plant should be consistently sampled for SPAD readings or if the leaf sampled should depend on the growth stage of the plant. Is there a particular leaf of which the consistent use would result in a better correlation between the SPAD reading and foliar N, or that would cause the SPAD method to be an effective method for more or all growth stages? How many SPAD readings from that leaf are required to obtain the best correlation between the SPAD reading and the foliar N?

Secondly, the microjet irrigation method was not adequately evaluated in this study. An experiment comparing microjet to other irrigation methods, combined with the different fertilizer regimes is in order, to evaluate differences in the incidence and severity of physiological and pathological disorders on pepper. Does microjet irrigation cool the crop to prevent sunscald? Does it enhance disease spread? If low levels of disease incidence occur, an inoculated treatment could provide valuable information in answering these questions.

VI REFERENCES

Adegoroye, A.S. and P.A. Jolliffe. 1983. Initiation and control of sunscald injury of tomato fruit *Lycopersicon esculentum*, solar injury, radiation stress. *J. Am. Soc. Hortic. Sci.*, 108(1): 23-28.

Andrews, J. 1984. *Peppers: the Domesticated Capsicums*. University of Texas Press; Austin. 170 p.

Archer, T.L., E.D. Bynum Jr., A.B. Onken and C.W. Wendt. 1995. Influence of water and nitrogen fertilizer on biology of the Russian wheat aphid (Homoptera: Aphididae) on wheat. *Crop Prot.*, 14(2): 165-169.

Aziz, F. 1994. Effect of mulch on the soil microenvironment, yield of pepper (*Capsicum annuum* L.), and aphid population. Ste. Anne-de-Bellevue, Qué: McGill University; M.Sc. Thesis. 67 p.

Barber, H.N. and P.J.H. Sharpe. 1971. Genetics and physiology of sunscald of fruits. *Agr. Meteorol.*, 8: 175-191.

Basky, Z. 1984. Effect of reflective mulches on virus incidence in seed cucumbers. *Prot. Ecol.*, 6: 57-61.

Batal, K.M. and D.A. Smittle. 1981. Response of bell pepper to irrigation, nitrogen, and plant population. *J. Amer. Soc. Hort. Sci.*, 106(3): 259-262.

Bauerle, W.L. 1982. See the light. *Am. Veg. Grower Greenhouse Grower*, 30(6): 40.

Bhella, H.S. 1988. Tomato response to trickle irrigation and black polyethylene mulch. *J. Amer. Soc. Hort. Sci.*, 113(4): 543-546.

Blackmer, T.M. and J.S. Schepers. 1994. Techniques for monitoring crop nitrogen status in corn. *Comm. soil sci. plant anal.*, 25(9/10): 1791-1800.

Blackmer, T.M. and J.S. Schepers. 1995. Use of a chlorophyll meter to monitor nitrogen status and schedule fertigation for corn. *J. Prod. Agric.*, 8(1): 56-60.

Bokhari, U.G. 1976. Influence of temperatures, water stress and nitrogen treatments on chlorophyll and dry matter of western wheatgrass. *J. Range Manage.*, 29(2): 127-131.

Bostanian, N.J. 1994. The tarnished plant bug and strawberry production. *Agriculture and Agri-Food Canada Technical Bulletin.* 1994-1E. Saint-Jean-sur-Richelieu Research Station.

Bottril, D.E. and J.V. Possingham. 1969. The effect of mineral deficiency and leaf age on the nitrogen and chlorophyll content of spinach chloroplasts. *Biochem. Biophys. Acta,* 189: 80-84.

Brown, J.E., J.M. Dangler, F.M. Woods, K.M. Tilt, M.D. Henshaw, W.A. Griffey and M.S. West. 1993. Delay in mosaic virus onset and aphid vector reduction in summer squash grown on reflective mulches. *HortScience,* 28(9): 895-896.

Carr, A. 1979. *Rodale's Color Handbook of Garden Insects.* Rodale Press, Inc.; Emmaus, Pa. pp. 9-15, 59-61, 75, 91.

Cartwright, B., B.W. Roberts, T.K. Hartz and J.V. Edelson. 1990. Effects of mulches on the population increase of *Myzus persicae* (Sulzer) on bell peppers. *Southwest. Entomol.*, 15(4): 475-479.

Cochran, H.L. 1938. A morphological study of flower and seed development in pepper. *J. Agric. Res.*, 56(6): 395-419.

Conway, K.E., B.D. McCraw, J.E. Motes and J.L. Sherwood. 1989. Evaluations of mulches and row covers to delay virus diseases and their effects on yield of yellow squash. *Appl. Agric. Res.*, 4(3): 201-207.

Corsoro, S., D.L. Coffey and P. Lambdin. 1980. Suppression of the turnip aphid, *Lipaphis erysimi* (Kltb), on cabbage by reflective mulches and acephate. *Tenn. Farm Home Sci. Prog. Rep. Tenn. Agric. Exp. Stn.*, 116: 36-37.

C.P.V.Q. 1982. Légumes. Conseils des Productions Végétales du Québec. Agdex 250/20. Ministère de l'Agriculture, des Pêcheries et de l'Alimentation du Québec. 64-65.

Csizinszky, A.A., D.J. Schuster and J.B. Kring. 1995. Color mulches influence yield and insect pest populations in tomatoes. *J. Amer. Soc. Hort. Sci.*, 120(5): 778-784.

Dorland, R.E. and F.W. Went. 1947. Plant growth under controlled conditions: Growth and fruiting of the chili pepper (*Capsicum annuum*). *Am. J. Bot.*, 34(8): 393-401.

Dwyer, L.M., A.M. Anderson, B.L. Ma, D.W. Stewart, M. Tollenaar and E. Gregorich. 1994. Quantifying the nonlinearity in chlorophyll meter response to corn leaf nitrogen concentration. *Can. J. Plant Sci.*, 74: 179-182.

Environment Canada. 1995. *Monthly Meteorological Summary*, Atmospheric Environment Service: Montreal International Airport, June, July, August, and September Issues of 1995: 1-6.

Environment Canada. 1996. *Monthly Meteorological Summary*, Atmospheric Environment Service: Montreal International Airport, June, July, August, and September Issues of 1996: 1-6.

Fletcher, J., R. Hochmuth and G. Hochmuth. 1993. Calibration of N and K fresh sap quick-test procedures for polyethylene-mulched peppers. *Proc. Natl. Agric. Plastics Congr.*, 24: 147-152.

Grunwald, C., L.P. Bush and C.J. Keller. 1971. Variation in sterols, alkaloids, and polyphenols of two Nicotiana varieties under different nitrogen fertilization and drying processes. *J. Agr. Food Chem.*, 19(2): 216-221.

Handley, D.T. and J.E. Pollard. 1993. Microscopic examination of tarnished plant bug (Heteroptera: Miridae) feeding damage to strawberry. *J. Econ. Entomol.*, 86(2): 505-510.

Hankin, L., D.E. Hill and G.R. Stephens. 1982. Effect of mulch on bacterial populations and enzyme activity in soil and vegetable yields. *Plant and Soil.*, 64: 193-201.

Hartman, P.L., H.A. Mills and J.B. Jones. 1986. The Influence of nitrate:ammonium ratios on growth, fruit development, and element concentration in 'Floradel' tomato plants. *J. Amer. Soc. Hort. Sci.*, 111(4): 487-490.

Hartz, T.K., M. LeStrange and D.M. May. 1993. Nitrogen requirements for drip irrigated peppers. *HortScience*, 28(11): 1097-1099.

Heacox, L. 1995. The colors of designer fields. *Am. Veg. Grow.*, 43: 12-56.

Hochmuth, G.J. 1994. Efficiency ranges for nitrate-nitrogen and potassium for vegetable petiole sap quick tests. *HortTechnology*, 4(3): 218-222.

Howard, R.J., J.A. Garland and W.L. Seaman. 1994. *Diseases and Pests of Vegetable Crops in Canada*. M.O.M. Printing Ltd.; Ottawa. pp. 269-289.

Jansson, R.K. and Z. Smilowitz. 1986. Influence of nitrogen on population parameters of potato insects: abundance, population growth, and within-plant distribution of the green peach aphid, *Myzus persicae* (Homoptera: Aphididae). *Environ. Entomol.*, 15(1): 49-55.

Jemison, J.M. and D.E. Lytle. 1996. Field evaluation of two nitrogen testing methods in Maine. *J. Prod. Agric.*, 9(1): 108-113.

Johnketty, I. and S.P. Palaniappan. 1996. Use of chlorophyll meter for nitrogen management in lowland rice. *Fert. Res.*, 45: 21-24.

Jones, R.A.C. 1991. Reflective mulch decreases the spread of two non-persistently aphid transmitted viruses to narrow-leafed lupin (*Lupinus angustifolius*). *Ann. appl. Biol.*, 118: 79-85.

Kantety, R.V., E. van Santen, F.M. Woods and C.W. Wood. 1996. Chlorophyll meter predicts nitrogen status of tall fescue. *J. Plant Nutr.*, 19(6): 881-899.

Khattat, A.R. and R.K. Stewart. 1975. Damage by tarnished plant bug to flowers and setting pods of green beans. *J. Econ. Entomol.*, 68(5): 633-636.

Kring, J.B. 1970. Determining the number of aphids over reflective surfaces. *J. Econ. Entomol.*, 63(4): 1350-1353.

Kring, J.B. and D.J. Schuster. 1992. Management of insects on pepper and tomato with UV-reflective mulches. *Fla. Entomol.*, 75(1): 119-129.

Lamont, W.J., K.A. Sorensen and C.W. Averre. 1990. Painting aluminum strips on black plastic mulch reduces mosaic symptoms on summer squash. *HortScience*, 25: 1305.

Ledeboer, F.B., C.R. Skogley, and C.G. McKiel. 1971. Soil heating studies with cool season turfgrasses. II. Effects of N fertilization and protective covers on performance and chlorophyll content. *Agron. J.*, 63: 680-685.

Lindquist, R.K. and E.L. Sorensen. 1970. Interrelationships among aphids, tarnished plant bugs, and alfalfas. *J. Econ. Entomol.*, 63(1): 192-195.

Locascio, S.J. and J.G.A. Fiskell. 1977. Pepper production as influenced by mulch, fertilizer placement, and nitrogen rate. *Proc. Soil Crop Sci. Soc. Fl.*, 36: 113-117.

Locascio, S.J., J.G.A. Fiskell, D.A. Graetz and R.D. Hauck. 1985. Nitrogen accumulation by pepper as influenced by mulch and time of fertilizer application. *J. Amer. Soc. Hort. Sci.*, 110(3): 325-328.

Locascio, S.J., J.G.A. Fiskell and F.G. Martin. 1981. Responses of bell pepper to nitrogen sources. *J. Amer. Soc. Hort. Sci.*, 106(5): 628-632.

Locascio, S.J., S.M. Olson and F.M. Rhoads. 1989. Water quantity and time of N and K application for trickle-irrigated tomatoes. *J. Am. Soc. Hortic. Sci.*, 114(2): 265-268.

Madramootoo, C.A. and M. Rigby. 1991. Effects of trickle irrigation on the growth and sunscald of bell peppers (*Capsicum annuum* L.) in southern Québec. *Agric. Water Manage.*, 19: 181-189.

Madramootoo, C.A., M. Rigby, A.F. MacKenzie and K.A. Stewart. 1993. Yield response of bell peppers to four irrigation levels and three nitrogen fertilizer rates in a humid climate. *ICID Bull.*, 42(1): 63-72.

Mailloux, G., R.O. Paradis and J.G. Pilon. 1979. Developpement saisonnier de la punaise terne, *Lygus lineolaris* (P. de B.) (Hemipteres: Miridae), sur fraisiers, framboisiers et pommiers dans le Sud-Ouest du Québec. *Ann. Soc. Entomol. Qué.*, 24 (1): 48-64.

Marti, H.R. and H.A. Mills. 1991. Calcium uptake and concentration in bell pepper plants as influenced by nitrogen form and stages of development. *J. Plant Nutr.*, 14(11): 1177-1185.

Miller, C.H., R.E. McCollum and S. Claimon. 1979. Relationships between growth of bell peppers (*Capsicum annuum* L.) and nutrient accumulation during ontogeny in field environments. *J. Amer. Soc. Hort. Sci.*, 104(6): 852-857.

Minchin, F.R., R.J. Summerfield and M.C.P. Neves. 1981. Nitrogen nutrition of cowpeas (*Vigna unguiculata*): effects of timing of inorganic nitrogen applications on nodulation, plant growth and seed yield. *Trop. Agric.*, 58(1): 1-12.

Minks, A.K. and P. Harrewijn. 1987. *Organization (structure) of populations and species, and speciation*. Elsevier, Amsterdam. pp. 415-430.

Minotti, P. 1995. Wise ways to apply nitrogen. *Am. Veg. Grow.*, 43: 18-21.

Monteiro, A.A. and C.M. Portas. 1986. Mild winter concept and cropping systems in solanaceae protected cultivation. *Acta Hortic.*, 191: 21-34.

O'Sullivan, J. 1979. Response of peppers to irrigation and nitrogen. *Can. J. Plant Sci.*, 59: 1085-1091.

Paterson, T.A., T.M. Blackmer, D.D. Francis and J.S. Schepers. 1993. Using a chlorophyll meter to improve N management. *NebGuide*. Cooperative Extension, Institute of Agriculture and Natural Resources, University of Nebraska. G93-1171-A: D-13-D15.

Payero, J.O., M.S. Bhangoo and J.J. Steiner. 1990. Nitrogen fertilizer management practices to enhance seed production by 'Anaheim Chili' peppers. *J. Amer. Soc. Hort. Sci.*, 115(2): 245-251.

Retig, N., N. Aharoni and N. Kedar. 1974. Acquired tolerance of tomato fruits to sunscald. *Sci. Hortic.*, 2(1): 29-33.

Rigby, M. 1988. Trickle fertigation of bell peppers in Southern Québec. Ste-Anne-de-Bellevue, Qué: McGill University; M.Sc. Thesis. 106 p.

Rigby, M., C.A. Madramootoo, J.F. Argall, and K.A. Stewart. 1988. Trickle irrigation of peppers in Eastern Canada. *Proceedings on Planning Now for Irrigation and Drainage IR Div/ASCE*, 303-311.

Riggs, D. 1994. Drip irrigation yields impressive results. *Grower*. Cooperative Extension Service, U.S. Department of Agriculture, College of Agriculture and Natural Resources, University of Connecticut. July 1994. 94(7): 6-7.

Roberts, B.W. and J.A. Anderson. 1994. Canopy shade and soil mulch affect yield and solar injury of bell pepper. *HortScience*, 29(4): 258-260.

Royer, L. and J.N. McNeil. 1993. Effect of relative humidity conditions on responsiveness of european corn borer (*Ostrinia nubilalis*) males to female sex pheromone in a wind tunnel. *J. of Chem. Ecol.*, 19(1): 61-68.

Rylski, I. and A.H. Halevy. 1972. Factors controlling the readiness to flower of buds along the main axis of pepper (*Capsicum annuum* L.). *J. Amer. Soc. Hort. Sci.*, 97(3): 309-312.

Saulnier, T.P. and E.G. Reekie. 1995. Effect of reproduction on nitrogen allocation and carbon gain in *Oenothera biennis*. *J. Ecol.*, 83: 23-29.

Schalk, J.M., C.S. Creighton, R.L. Fery, W.R. Sitterly, B.W. Davis, T.L. McFadden and A. Day. 1979. Reflective film mulches influences insect control and yield in vegetables. *J. Amer. Soc. Hort. Sci.*, 104(6): 759-762.

Schalk, J.M. and M.L. Robbins. 1987. Reflective mulches influence plant survival, production, and insect control in fall tomatoes. *HortScience*, 22(1): 30-32.

Schepers, J.S., D.D. Francis, M. Vigil and F.E. Below. 1992. Comparison of corn leaf nitrogen concentration and chlorophyll meter readings. *Commun. Soil Sci. Plant Anal.*, 23: 2173-2187.

Scott, S.J., P.J. McLeod, F.W. Montgomery and C.A. Hander. 1989. Influence of reflective mulch on incidence of thrips (Thysanoptera: Thripidae: Phlaeothripidae) in staked tomatoes. *J. Entomol. Sci.*, 24(4): 422-427.

Shelby, R.A., W.H. Greenleaf and C.M. Peterson. 1978. Comparative floral fertility in heat tolerant and heat sensitive tomatoes. *J. Amer. Soc. Hort. Sci.*, 103: 778-780.

Sherf, A.F. and A.A. MacNab. 1986. *Vegetable Diseases and Their Control*. 2nd ed. John Wiley and Sons, Inc. Toronto. pp. 502-543.

Smith, F.F., G.V. Johnson, R.P. Kahn and A. Bing. 1964. Repellency of reflective aluminum to transient aphid virus-vectors. *Phytopathology*, 54: 748.

Somos, A. 1984. *The Paprika*. Akademiai Kiado, Budapest. 302 p.

Spiers, J.M. and J.H. Braswell. 1993. Nitrogen rate and source affects leaf elemental concentration and plant growth in muscadine grapes. *J. Plant Nutr.*, 16(8): 1547-1554.

Splittstoesser, W.E. and J.E. Brown. 1991. Current changes in plasticulture for crop production. *Proc. Natl. Agric. Plastics Congr.*, 23: 241-253.

Statistics Canada. 1995. *Fruit and Vegetable Production, September 1995*. Cat. No. 22-003. Ottawa, Canada, Canadian Government Publishing Centre. 64(2): 22-23.

Stewart, R.K. and A.R. Khattat. 1980. Pest status and economic thresholds of the tarnished plant bug, *Lygus lineolaris* (Hemiptera (Heteroptera): Miridae), on green beans in Québec. *Can. Entomol.*, 112: 301-305.

Storlie, C.A. 1992. Irrigation scheduling with tensiometers. *Rutgers Cooperative Extension Fact Sheet*. Cooperative Extension, Rutgers University, New Brunswick, NJ. FS 657.

Stroehlein, J.L. and N.F. Oebker. 1979. Effects of nitrogen and phosphorus on yields and tissue analyses of chili peppers. *Commun. Soil Sci. Plant Anal.*, 10: 551-563.

Summers, C.G., J.J. Stapleton, A.S. Newton, R.A. Duncan and D. Hart. 1995. Comparison of sprayable and film mulches in delaying the onset of aphid-transmitted virus diseases in zucchini squash. *Plant Dis.*, 79: 1126-1131.

Sweeney, D.W., D.A. Graetz, A.B. Bottcher, S.J. Locascio and K.L. Campbell. 1987. Tomato yield and nitrogen recovery as influenced by irrigation method, nitrogen source, and mulch. *HortScience*, 22(1): 27-29.

Tachibana, Y. 1981. Control of aphid-borne viruses in faba bean by mulching with silver polyethylene film in Japan. *F-A-B-I-S Newl. Faba Bean Inf. Serv.*, 3: 56.

Tan, C.S. 1995. Effect of drip and sprinkle irrigation on yield and quality of five tomato cultivars in southwestern Ontario. *Can. J. Plant Sci.*, 75: 225-230.

Tan, C.S., C.F. Drury, J.D. Gaynor, I. van Wesenbeeck and M. Soultani. 1996. Effect of water-table management and nitrogen supply on yield, plant growth and water use of corn in undisturbed soil columns. *Can. J. Plant Sci.*, 76: 229-235.

Teolis, I. 1994. An evaluation of pepper/bean intercropping using different plant populations and bean cultivars. Ste. Anne-de-Bellevue, Qué: McGill University; M.Sc. Thesis. 93 p.

Thomas, L.P. and M.A. Watson. 1988. Leaf removal and the apparent effects of architectural constraints on development in *Capsicum annuum*. *Amer. J. Bot.*, 75(6): 840-843.

Thornbury, D.W., C.A. Paterson, J.T. Dessens and T.P. Pirone. 1990. Comparative sequence of the helper component (HC) region of potato virus Y and the HC-defective strain, potato virus C. *Virology*, 178: 573-578.

Tindall, J.A., R.B. Beverly and D.E. Radcliffe. 1991. Mulch effect on soil properties and tomato growth using micro-irrigation. *Agron. J.*, 83: 1028-1034.

Toscano, N.C., J. Wyman, K. Kido, H. Johnson and K. Mayberry. 1979. Reflective mulches foil insects. *Calif. Agric.*, 33: 17-19.

Turner, F.T. and M.F. Jund. 1991. Chlorophyll meter to predict nitrogen topdress requirement for semidwarf rice. *Agron. J.*, 83: 926-928.

VanDerwerken, J.E. and D. Wilcox-Lee. 1988. Influence of plastic mulch type and frequency of irrigation on growth and yield of bell pepper. *HortScience*, 23(6): 985-988.

Wells, P.W., G.P. Dively and J.M. Schalk. 1984. Resistance and reflective foil mulch as control measures for the potato leaf hoppper (Homoptera: Cicadellidae) on *Phaseolus* species [*Empoasca fabae*, common dry bean]. *J. Econ. Entomol.*, 77(4): 1046-1051.

Wolfenbarger, D.O. and W.D. Moore. 1968. Insect abundance on tomatoes and squash mulched with aluminum and plastic sheeting. *J. Econ. Entomol.*, 61: 34-36.

Wood, C.W., D.W. Reeves, R.R. Duffield and K.L. Edmisten. 1992. Field chlorophyll measurements for evaluation of corn nitrogen status. *J. Plant Nutr.*, 15(4): 487-500.

Wyman, J.A., N.C. Toscano, K. Kido, H. Johnson and K.S. Mayberry. 1979. Effects of mulching on the spread of aphid-transmitted watermelon mosaic virus to summer squash. *J. Econ. Entomol.*, 72(1): 139-143.

Zalom, F.G. 1981a. Effects of aluminum mulch on fecundity of apterous *Myzus persicae* on head lettuce in a field planting. *Ent. exp. & appl.*, 30: 227-230.

Zalom, F.G. 1981b. The influence of reflective mulches and lettuce types on the incidence of aster yellows and abundance of its vector, *Macrosteles fascifrons* (Homoptera: Cicadellidae), in Minnesota. *Gt. Lakes Entomol.*, 14(3): 145-150.

Zar, J.H. 1974. *Biostatistical Analysis*. Prentice-Hall, Inc.; Englewood Cliffs, N.J. pp. 185-186.

Zhou, X. and N. Carter. 1991. The effects of nitrogen and fungicides on cereal aphid population development and the consequences for the aphid-yield relationship in winter wheat. *Ann. Appl. Biol.*, 199(3): 433-441.

Zornnoza, P., J. Caselles and O. Carpena. 1989. Effect of NO_3:NH_4 ratio and light intensity on nitrogen partitioning in pepper plants. *J. Plant Nutr.*, 12(3): 307-316.