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Goulart, Barbara Louise

THE INFLUENCE OF TRICKLE IRRIGATION, NITROGEN, BEDTYPE AND SPACING ON THE GROWTH AND YIELD OF STRAWBERRY (FRAGARIA X ANANASSA, DUCH.)

The Ohio State University

PH.D. 1984

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THE INFLUENCE OF TRICKLE IRRIGATION, NITROGEN, 
BEDTYPE AND SPACING ON THE GROWTH AND YIELD OF STRAWBERRY

(Fragaria X ananassa, Duch.)

DISSEhATION

Presented in Partial Fulfillment of the Requirements for
the Degree Doctor of Philosophy in the Graduate
School of The Ohio State University

By

Barbara L. Goulart, B.S., M.S.

* * * * *

The Ohio State University
1984

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THE INFLUENCE OF TRICKLE IRRIGATION, NITROGEN, RAISED BEDS AND SPACING ON THE GROWTH AND YIELD OF STRAWBERRY

(Fragaria X ananassa, Duch.)

By

Barbara Louise Goulart

The Ohio State University, 1984

Two experiments were conducted from 1980-1983 at two different sites. Experiment I tested the influence of trickle irrigation with varying nitrogen injection rates (0-76 kg/ha/yr), raised beds and mother plant spacing (13 and 50 cm) on 'Scott' and 'Redchief' strawberry. 'Scott' root and total dry weight was higher, and yields/unit area lower on raised as compared to flat beds. 'Redchief' yield/unit area was unaffected by bedtype but higher at closer spacings. In 1982 'Redchief' on raised beds had higher early yield from plants at closer spacings.

Experiment II was designed to test the influence of raised beds, spacing (13 cm, 50 cm and 50 cm with runners set at 13 cm) and bedtype/spacing interactions on 'Redchief' vegetative and reproductive responses. The raised bed had higher soil matric potentials and more variable soil temperatures than the flat bed. Plants on raised beds had a deeper more uniform root distribution,
poorer runner establishment and earlier yield than those on flat beds. Earliness of yield was enhanced by the closer spacing on raised beds, and plants at 13 cm had more crowns/unit area than those at the other two spacings on raised beds. Total yield/unit area was not influenced by any treatment.
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Finally, special thanks to Mr. John Gardner, whose computer expertise and babysitting services allowed the timely completion of this dissertation.
DEDICATION

To my parents,
John and Ester Bowling

and my daughter
Beth

whose love and belief in me provided
the foundation for this dissertation.
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Chapter I
INTRODUCTION

Raised bed culture of strawberries has been a common practice in the irrigated agriculture of California and Florida, but only in recent years has it been considered as a viable system for production in the East and Midwest. Due to the cultivar, soil and climatic differences between the Midwest and, for example, California, the strawberry plant's physiological responses (vegetative and reproductive) to the alteration of the soil environment are of interest, particularly in light of our inability to precisely control the excess soil moisture brought about by unpredictable rains, and magnified by high soil water holding capacity and compaction. It is known that waterlogging often reduced strawberry plant yield and vigor. If raised beds have potential for increasing productivity, irrigation regimes, plant spacing and fertilization practices may also need to be re-evaluated.

The biological response to these cultural manipulations is complex and unclear. If, for example, raised beds indeed elicit higher strawberry yields, it is not known whether light distribution, internal soil water/air pore space alterations, or a balance of these and/or other factors is responsible for the difference. An alteration in light distribution would suggest a possibility for increased photosynthetic production, while the alteration of the root environment would suggest a root-synthesized growth substance, water, or nutrient absorption/transport
phenomenon to be the fundamental cause of a change in physiological response. An understanding of the strawberry plant's response to alterations in spacing, bed system and water/nutrient relations will enhance existing knowledge of plant/environment interactions.

The specific objectives of this project were:

1. To evaluate the effects of daily applications of trickle irrigation with nitrogen injection on strawberry growth and yield,
2. To investigate the effects of raised bed culture on the growth and yield responses of strawberry, and
3. To determine the influence of mother plant spacing on growth and yield in raised beds.

For Experiment I (1980-1982) the plot was designed to test all factors (trickle irrigation/nitrogen rate, bedtype, and spacing) simultaneously on two cultivars, 'Scott' and 'Redchief'. 'Scott' was a relatively new cultivar which was reputed to be a vigorous mid-season early bearer. 'Redchief' was also a mid-season cultivar, and had been a reliable bearer in Ohio for many years.

Experiment II (1982-1983) was initiated to further delineate the complex interactions recorded in Experiment I. It was limited to one cultivar, 'Redchief', and tested the effects of raised beds, mother plant spacings, and their interactions (objectives 2-3).
Chapter II
LITERATURE REVIEW

2.1 THE STRAWBERRY PLANT

The strawberry plant is a highly adaptable herbaceous perennial which is composed of leaves, a crown, which is perennial in nature, and a fibrous root system composed of transient and "permanent" roots (Darrow, 1966; Boyce and Matlock, 1966). Leaves arise at successively higher points on the crown in a 2/5 spiral arrangement, while new adventitious (main) roots arise from meristems within the vascular core at the nodes at the base of each leaf (Mann, 1930). As a result of this growth habit, strawberry plants have increasingly poor root-soil contact (Darrow, 1966; Dana, 19—). The root system is shallow, with 80 to 90% of the roots in the top 6 inches of a clay or loam soil (Shrader, 1941; Mann and Ball, 1927). In sandy soils, roots may extend much deeper (Bauckmann, 1975; Boyce and Matlock, 1966; Dana, 19—; Darrow, 1966; Nelson and Wilhelm, 1957; Rom and Dana, 1959). The large, or main roots of the mature strawberry plant are characterized by a polyderm (a peripheral covering of alternating bands of suberized and unsuberized cells), and secondary tissues. These main roots are adventitious and perennial. Main roots grow in length, and produce lateral and sub-lateral branches which actively absorb nutrients and water (Nelson and Wilhelm, 1957). Transient in nature, the lateral roots are essentially "feeder" roots,
developing no secondary tissue, and dying at the end of each growing season (Darrow, 1966; Nelson and Wilhelm, 1957). The strawberry root system is highly susceptible to damage from water-logging. Transient roots are killed by wet conditions and new adventitious roots fail to develop properly (Shoemaker, 1978). Wet conditions also increase leaf, fruit and root disease incidence.

Following is a seasonal outline of the established strawberry plant's growth cycle:

2.1.1 Spring

The plant begins growth, drawing heavily on nitrogen and carbohydrate reserves in the crown and roots. By the time the plant has fruited, both reserves are diminished to one half or less (Boyce and Matlock, 1966; Long and Murneek, 1937). Starch and hemicelluloses are hydrolyzed and moved to actively growing regions in the plant (Long, 1935). April is the low point for root starch and hemicellulose content. Young leaves are high in nitrogen and sugars (Boyce and Matlock, 1966; Long, 1935).

Root systems of newly set plants develop slowly, having no "primary" roots until late June. Up until mid-June, the dry weight of the roots decreases, while that of the crowns increases¹ (Boyce and Matlock, 1966).

¹ At all times of the year, there exists a reciprocal relationship between starch and sugar, and hemicelluloses and sugar in the plant (Long, 1935; Long and Murneek, 1937).
2.1.2 **Summer**

The second critical demand peak for stored food occurs with runner formation. At the end of runner production, carbohydrate reserves are reduced from 50-75% (in winter) to 4-5%. Runner plants produced at the end of the summer yield less than those produced earlier in the season (Boyce and Matlock, 1966).

2.1.3 **Autumn**

Maximum leaf area is accompanied by intensive photosynthetic activity in the fall (Darrow, 1966). The leaf area at this time determines the extent of fruit bud production. Fruitfulness is associated with a balance between nitrogenous and carbohydrate materials (Long and Murneek, 1937). At this time, 50-70% of the total sugars are in the leaves, and the plant is 3% sugar, 7% starch, 15% hemicellulose, 28% total carbohydrates, and 1% nitrogen (Long and Murneek, 1937). Leaf nitrogen increases until November, when 80% of the nitrogen is in the leaves. As autumn yellowing occurs, leaf nitrogen decreases from 2.5% to less than 1% (Long, 1935). Maximum root growth and development, flower bud initiation, and branch crown formation occur in late summer to autumn (Boyce and Matlock, 1966; Dana, 19—; Darrow, 1966; Long and Murneek, 1937; Mann and Ball, 1927; Nelson and Wilhelm, 1957; Rom and Dana, 1959). As the season advances, there is a pronounced accumulation of polysaccharides. There is a rapid flow of soluble carbohydrates\(^2\) to the roots and crown (Long and Murneek, 1937). Starch and hemicellulose content

\(^2\) Carbohydrate levels vary from 2.3-12.4%, similar to levels found in apple trees (Long and Murneek, 1937).
increases in roots and crowns (Long, 1935; Long and Murneek, 1937).

2.1.4 Winter

Total sugars continue to increase in the roots, from 40% in December to 70% in February (Long and Murneek, 1937). Nitrogen is stored in the roots and crown (Long, 1935). Root growth occurs until soil is frozen. In Missouri, leaf area is lowest in February (Long and Murneek, 1937). As winter progresses, starch and hemicellulose is hydrolized to sugars, probably for plant respiration (Long, 1935, Long and Murneek, 1937). Crown tissue injury occurs during winter dormancy if the crown reaches temperatures of 20-25 F (Buckley and Moore, 1982).

2.2 CULTURAL MANAGEMENT OF STRAWBERRIES

2.2.1 Soil moisture

Optimal soil moisture management is critical for the strawberry plant, because this shallow-rooted plant is readily stressed by excessive or deficient soil water. Secondary branching of laterals are inhibited by soil moisture levels above 50% or below wilting percentage (Boyce and Matlock, 1966; Collins and Smith, 1970; Mann and Ball, 1927; Rom and Dana, 1959). Mann and Ball (1927) concluded that strawberry "little leaf", a condition in which leaves are stunted, was often a result of waterlogged soil. Collins and Smith (1970) cited a soil moisture tension of 2.03 bars as being conducive to good development of feeder roots. Dry conditions also inhibit nutrient uptake, and result in a rapid reduction in the plant's photosynthetic rate (Boyce and Matlock, 1966; Kinnanen and
Sako, 1979). Thorsrud (1955) obtained 39.2 percent higher yield, and 26.5 percent greater size using irrigation. Kinnanen and Sako (1979) indicate that, using overhead irrigation on clay soils, the percentage of rotted fruit increased (also found by Cannell, et al., 1961), and harvest was delayed in both the current and following season when 30 mm of water was applied. Heavy irrigation prior to flower bud initiation reduced the number of flowers for the following year. The highest number of flowers per plant occurred on plants which were exposed to a dry period in August, and watered in September.

In 1961, Cannell, et al. induced earlier yields using plastic mulch. He also found that decreased moisture in unmulched beds decreased Fe and Mg uptake, however N uptake increased with decreasing soil water.

2.2.2 Nitrogen nutrition

If moisture is not limiting, the number of flower clusters and their size is dependent on soil nutrients (Boyce and Matlock, 1966). Strawberries are among the most sensitive fruit plants to nitrogen fertilization (Waltman, 1951). There is conflict in the literature as to nitrogen fertilization of the strawberry. Long and Murneek (1937) reported that increased nitrogen levels increase leaf area which induced more flowers and fruit. Rom and Dana (1962) found that applications of N-P-K at the time of flower bud initiation increased leaf area and leaf number, but had no significant effect on flower number. Dana (19--) cites poor correlations between plant nutrient content and plant production.
Gardner (1923) and Loree (1925) independently recommended a very early spring application of immediately available nitrogen, however both cautioned that if applied too close to harvest, nitrogen would cause soft berries, poor color, and excessive runner production. Waltman (1951) reported reduced yields from spring nitrogen application. Nitrogen application in late summer and fall is critical (Gardner, 1923; Loree, 1925; Long and Murneek, 1937). More recent recommendations exclude spring applications of nitrogen (Funt, 1976; Shoemaker, 1978).

Breen and Martin (1981) established cultivar differences in the capacity to take up nitrogen. 'Olympus', a poor runnering cultivar accumulated less nitrogen in pot culture than either 'Hood' or 'Benton'. The study also established that these three cultivars had a broad optimal range of nitrogen, and asserted that after a certain level (in this case, 3.6 g/liter) additional nitrogen was either detrimental or uneffective in eliciting vegetative or reproductive responses.

2.2.3 Raised beds

In their discussion of strawberry "small leaf", Mann and Ball (1937) proposed either "mounding up" of the plants, or "taking furrows between the rows" to divert excess moisture from the roots. Shoemaker (1978) refers to "hill culture", which is effective on some cultivars. In 1955, Tompkins increased yield by using a hill system, but conceded that runner removal was both laborious and difficult to maintain.

There has been renewed interest in raised bed culture for strawberry production in the past 10-15 years. With
the development of mechanized runner removal, and the possibility of breeding strawberries less prone to runnering, the practical problems of a high density raised bed system of culture may be feasible in the East and Midwest. In California, Voth, et al. (1967) found that plants on 10 cm beds yielded higher than those on 20 cm beds, as did those plants mulched with clear polyethylene. High yields on low beds were attributed to lower salt build up and lower temperatures in the low beds. Using 3 bed heights, Albregts and Howard (1979) found no differences in yield due to bed height in Florida.

Review of the literature pertaining to eastern/midwestern climates also reveals conflicting data. Buckley and Moore (1982) testing 'Cardinal', and Swartz et al. (1982) testing 'Earliglow', 'Guardian' and 'Redchief' found no differences in yield due to bed height. Boyce and Reed (1983) tested the effect of mulch and raised beds on strawberry plant yield, and found that yield decreased if the raised beds were not mulched. In addition, both unmulched and raised beds were consistently colder than mulched and/or flat beds.

Hancock and Roueche (1983) had higher yields on flat beds as compared to raised on plantings of 'Midway' and 'Guardian'. Craig and Aalders (1966) found no significant differences in yield between matted rows, spaced matted rows and the hill system on 'Sparkle', 'Redcoat' and 'Surecrop' in Nova Scotia.
2.2.4 Spacing

The literature on optimal plant spacing reveals conflicting conclusions. Christopher and Shutak (1937) and Christopher (1941) maintained that 5 to 7 inches between runner plants was optimal for 'Howard 17' and 'Dorsett' strawberry plants. Bell and Downes (1961) recommended a 12 inch spacing for 'Robinson', due to high branch crown formation at this spacing. Tompkins (1958) recommended a 6 inch spacing for highest yields. Rom and Dana (1962) noted that leaves from the denser matted row had less N, P, and K than those from a spaced row on 'Robinson' strawberries.

Cooper and Vaile (1945) state that as plants per square foot increased, individual berry weight decreased.

Hancock, et al. (1982) cited a high level of interaction among 12 cultivars when yield and spacing were correlated. 'Redchief' yielded highest in matted rows with mother plants established at 18 inch spacings (as compared to 24 and 30 inch spacings). The highest yield per plant consistently occurred when runners were removed, but generally, a higher number of plants per acre resulted in a higher yield.

'Naratoga' and 'Torrey' cultivars at 6 by 6 inch spacings yielded more marketable fruit, but also had a higher percentage of cull fruit when compared to 12 by 12 inch spacings on double rows (Freeman, 1981).

'Bounty' had the highest yield in an uncontrolled matted row, or at a close spacing of 2 plants per .093 meters (3.6 inches) (Craig, 1975).

In plantings of 'Earliglo', 'Guardian' and 'Redchief', Swartz et al. (1982) found that as plant or crown density increased, individual plant productivity decreased due to a
decreased number of trusses per plant of crown. Fruit set was also reduced at increased densities. It is apparent that there is much controversy concerning optimal strawberry spacing. It can be expected, since optimal plant spacing is so highly dependent on specific climatic and soil conditions, as well as on the cultivar selection.

2.2.5 **Trickle irrigation**

Trickle irrigation on strawberries appears to have many advantages over furrow or overhead irrigation systems (Locascio and Myers, 1979). Its advantages include:

1. 50% reduction in water (Locascio and Myers, 1979)
2. 50% reduction in actual nitrogen needed3 (Miller, et al., 1976; Locascio et al., 1977; Smith et al., 1979).
3. Smaller pumps and lower initial costs than overhead irrigation (Locascio and Myers, 1979).
4. Potential for precise control of plant nutrients, pesticides (Locascio and Myers, 1979; Rolston et al., 1979)
5. Increased yields (Locascio and Myers, 1979)
6. Dry crop middles, resulting in less weed activity.

Because weeds may be less troublesome, and pesticides and plant nutrients may be applied through trickle systems, growers may also avoid compaction of soil in areas where it may be a concern. Disadvantages of trickle include emitter

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3 Albregts and Howard (1979) suggest that nitrogen may be more available for efficient plant use because the prevention of excessive soil moisture reduces fertilizer leaching. Raised beds in combination with trickle would, therefore, minimize leaching.
clogging, limited soil water distribution, and it can not be used for frost control (Locascio and Myers, 1979). Economic data to evaluate the benefit of having two systems (overhead for frost control and trickle for other purposes) is not available.

In Florida, Locascio (1975) reported that strawberry yields would be increased with trickle, due to the removal of soluble salts from the root area. Soluble salts move with the trickle wetting front, whereas with overhead irrigation, they migrate toward the soil surface.

In another study, Locascio et al. (1977) increased strawberry yields 37% using trickle, compared to a non-irrigated control. When 50% N-P-K or the granular rate was injected with trickle, yields were 20% higher than non-trickled plants. Higher yields were obtained with 135-78-149 kg/ha (N-P-K) than with 94-55-104. Early yields were higher using trickle, than with overhead or no irrigation. Total weight and size was also highest on trickle-treated plants. Myers and Locascio (1972) found no significant yield differences between trickle, overhead, or furrow irrigation.
Chapter III
MATERIALS AND METHODS

3.1 EXPERIMENT I

Experiment I was conducted in cooperation with the growers at the McConnell Berry Farm near Mt. Vernon, Ohio. It was designed to test the effects of trickle irrigation, nitrogen rate, bedtype and spacing on the growth and yield of 'Scott' and 'Redchief' strawberries.

3.1.1 Site

The Chili silt loam present at this site is characterized as a deep, well-drained soil (0.6-2.0 inches/hour permeability) which is formed in stratified outwash deposits. The parent material is largely sandstone and shale with a large amount of quartz pebbles stratified beneath the upper horizons. The soil is slightly to strongly acid, with 1-3% organic matter, an available water capacity* of 0.10-0.14 inch water per inch soil, and a moist bulk density of 1.30-1.55 (National cooperative soil survey, 1979). In spite of the characteristically good internal drainage of this soil type, the field used for Experiment I was only well drained in some areas, with water remaining in certain areas for several days after and inch or more of rain or irrigation. Soil chemical tests were conducted by the Research-Extension Analytical Lab.

* Available water capacity is defined as the difference in water content of the soil at field capacity and that at the wilting point.
(REAL) of the Ohio Agricultural Research and Development Center in Wooster, Ohio. They indicated adequate nutrient reserves, and a pH of 5.8, for which 36.3 kg of agricultural limestone was added per 93 square meters. The soil, having previously been planted in strawberries was fumigated with 303 kg/ha of methyl bromide/chloropicrin (98%/2%) on May 5, 1980. Plastic was removed on May 10. The moisture release curve of the soil was determined using a tension table for pressures to -0.6 atmospheres, and porous ceramic plate extractors for -1, -6, and -15 atmospheres.

The water on the site was tested and contained the following: 94.3 ppm Ca, 29.8 ppm Mg, 2.9% K, 4.6% Na, 0.5 ppm Fe, 540 TDS (salt concentration), pH, 7.9. Interpretation of this data by Professor Melville Palmer (1980) indicated no serious particle content of potentially clogging the irrigation system.

3.1.2 Treatments

On May 23 and 24, 1980, 'Scott' and 'Redchief' strawberry plants (source: Bountiful Ridge Nursery, Princess Anne, Md., and Allen's Nursery, Salisbury, Md.) were planted. The two cultivars were grown on 2 bedtypes (flat and 25 cm raised) with two spacings (13 and 50 cm) with 6 fertilizer/trickle irrigation treatments in a factorial experiment (Figure 1).

All rows were ran north/south, with row centers 96.5 cm apart. Treatments were arranged in a split/split plot design (main plots, bedtype; subplots, fertilizer/trickle irrigation treatments; sub-sub plots, cultivars) in 3 randomized complete blocks. Fertilizer/trickle irrigation treatments were:
*** treatments: 1 = No trickle, Full rate N$^z$
2 = No trickle, $\frac{1}{2}$ rate N
3 = Trickle only
4 = Trickle, $\frac{1}{4}$ rate N
5 = Trickle, $\frac{1}{2}$ rate N
6 = Trickle, Full rate N

$^z$Full rate N = 71.7 kg actual N/ha.

Figure 1. Flow chart of treatments for Experiment I.
1. Granular N, full rate, banded over plants
2. Granular N, 1/2 rate, banded over plants
3. No N, trickle irrigation only
4. 1/4 rate injected N, trickle irrigation
5. 1/2 rate injected N, trickle irrigation
6. Full rate injected K, trickle irrigation

The full rate of nitrogen was the current extension recommendation from The Ohio State University, 72 kg actual N/hectare per season. For granular treatments, half (36 kg) was applied in June, 1980 and the remaining half in August. During the bearing years of the planting, half of the N was applied at renovation and half in August. Trickle irrigation was delivered via polyethylene bi-wall irrigation tube with inner wall orifices at 152.4 cm and outer- at 30.5 cm. Under 1057 g/square cm pressure (maintained by an in-line pressure regulator) the bi-wall delivered 2.8 liters/ minute/30.5 meters of tube. The actual nitrogen concentration in the root zone was calculated to be 46.7 ppm. Nitrogen was injected on treatments 3 through 6 using an Electro Feeder chemical metering pump (Model E-170, distributed by Water Quality Control, Oak Lawn, Illinois) from mid-June through October 1. The trickle system was operated by first clearing the lines with well-water for 7 minutes, injecting a 7850 ppm ammonium nitrate solution into the trickle system for 28, 14, 7 or 0 minutes (for treatments 6, 5, 4 and 3, respectively) and following nitrogen injection with clear

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5 Nitrogen source was ammonium nitrate, 34-0-0 manufactured by C.P. Industries, Inc., Long Grove, Illinois.
water until total trickle irrigation time was 49 minutes daily. Trickle irrigation was discontinued in mid-October.

3.1.3 Environmental monitoring

Soil moisture was monitored from mid-May through mid-October using tensiometers at 15, 30 and 45 cm depths in 1980 and 1981, and from mid-May to July 1 (through harvest) of 1982. Each tensiometer depth was replicated 3 times. Tensiometers were also originally placed at a 7.5 cm depth but could not be maintained at the low matric potential of this shallow depth. A hygrothermograph and evaporation pan with a micrometer hook gauge was on site, and measured temperature, relative humidity and pan evaporation, respectively. Minimum/maximum temperatures were recorded daily. Rainfall was measured using an on site recording rain gauge.

Photosynthetically active radiation (PAR) was measured once in October, 1981 (when leaf area is highly correlated with the following year's yield,) and once during harvest of 1982. At both sampling dates, a chip (190S8 quantum) sensor with a Licor (LI-185B) quantum radiometer photometer measured PAR, with 6 replications of each bedtype and spacing treatment (2 readings/plot).

3.1.4 Maintenance

Overhead irrigation was applied as needed for frost control in both bearing years. In 1980, blossoms were removed on June 24 and again on July 1. The pesticide applications are documented in Appendix 1. The herbicide schedule was supplemented with hand weeding as necessary. Plants were renovated on July 1, 1981 by mowing tops, and
narrowing rows to 16 inches with a roto-vator. Runners were not controlled. Mulch was not put down in 1980-81, but was applied in December of 1981 at a rate of 6720 kg per hectare.

3.1.5 Data collection

Plant growth and nutritional status was evaluated using leaf nutrient analysis and plant samples. For nutrient analysis, fully expanded leaf blades were taken in August of 1980 and 1981. Three plant samples/treatments were taken in March of 1981 and 1982. Crowns were separated from roots, and fresh weights recorded. Plant tissue was then freeze dried using a sublimation process, and dry weights recorded.

Leaf area was measured in October 1981 and 1982, by removing all leaf blades in a 15 x 45 cm area in the canopy and measuring area with a Licor area meter (Model LI-3000).

 Marketable yield, cull weight and berry size (gm/ton) were recorded from the center 3 meters of each 5.5 meter plot from June 8 through June 17 in 1981, and from June 6 through June 27 in 1982, resulting in about a two-thirds reduction in fruit yield. Fruit yield reduction was largely a result of a heavy leather rot (Phytophthora cactorum) infection.

October has been established as the time of year when leaf area is most highly correlated with yield the following year.
3.1.6 Statistical Analysis

For leaf area data, 1981 plant data, and yield data, means were analyzed with an analysis of variance (modified for a split-split plot). Cultivars were analyzed separately. In cases where interactions between trickle/nitrogen, bedtype and/or spacing occurred, the means were further analyzed by separating bedtypes and spacings. To further test the influence of the trickle/nitrogen treatments, each data set (cultivar, bedtype, spacing) was independently analyzed with a regression analysis, using data from the non-trickle treatments (1 and 2) for the "granular" regression, and data from the trickle treatments (3-6) for the "injected" regression. Results of regression analysis are reported in the text only if the alpha value was greater than or equal to .05. Other regression results, (r-squared and p(F)) are documented in Appendix A.

The PAH and leaf area data were analyzed for bedtype and spacing effects only using an analysis of variance. All means were separated by Tukey's New Studentized Range Test.

3.2 EXPERIMENT II

3.2.1 Site

The experimental plot was located at the Horticultural Research Farm of The Ohio State University at Columbus, Ohio.

The soil was a Miamian silt loam, a well-drained medium textured soil. The Miamian silt loam lacks the stratification of the Chili silt loam. This soil, specified by the USDA soil survey as MiC2 is eroded, and has a moderately low permeability of 0.2-0.6 inches/hour.
The pH ranges from 5.6-7.3 and the soil has an available water capacity of .14-.19 inches water/inch soil. The soil on the site was, as characterized, well-drained, but slowly permeable (USDA, 1980). This type of soil, having moderate to high water-holding capacity and moderate to poor internal drainage is typical of many Ohio soils where strawberries may be planted. Soil analysis was conducted by the REAL of the Ohio Agricultural Research and Development Center in Wooster, Ohio. Analysis indicated adequate nutrient reserves (Matlock, 1954) and a pH of 6.8. The soil moisture release curve was determined by the same method employed in Experiment I. Soil was fumigated with methyl bromide/chloropicrin (67%/33%) in October of 1981 under favorable conditions. Beds were shaped with a Marvin land plane on April 16, 1982.

3.2.2 Treatments

On May 23, 1982, 'Redchief' strawberry plants (source: Allen's Nursery, Salisbury, Md.) were planted on two bedtypes (flat and 30.5 cm raised) at 3 spacings (13 cm, 50 cm, and 50 cm with runner plants placed at 13 cm) in a factorial experiment. Runners for the placed runner treatment were placed and set with wire hairpins on July 6-7, 1982. All other runners were removed and counted as they elongated. Treatments were arranged in a split plot design in 8 randomized complete blocks. An additional 8 plots were planted per treatment to be used solely for plant sample collection. Split plots were bordered by guard rows to minimize edge effects.
3.2.3 **Environmental monitoring**  

Soil moisture was monitored daily at 15, 30, and 45 cm as in Experiment I. In addition, monthly 20 cm gravimetric core samples were taken throughout the growing season of 1982, divided into three equal sections, and analyzed for moisture content. Soil temperature was monitored daily using soil thermometers at 10 and 15 cm. Ambient temperature and rainfall data were obtained from an adjacent weather station (The Ohio State Agronomic Research Farm, Columbus, Ohio). Raised bed shape and dimension was monitored throughout the growing season of 1982 by monthly measurements of top, base and height of beds.  

PAR was measured at 1/2 canopy height twice (pre- and post-harvest; 5/12/82 and 7/1/82) using a line quantum sensor (Li-191SB with a Licor LI-185B quantum radiometer photometer) and once, replicated over time (pre-harvest: 5/29/83-6/8/83) using PAE sensitive chips which integrated light diurnally (Licor 510 light integrators).

3.2.4 **Maintenance**  

Fertilizer was uniformly applied according to The Ohio State University Extension Service recommendations: 36 kgs actual N per hectare after planting, with the application repeated in August. Blossoms were removed as needed from planting through June 6. The pesticide applications are documented in Appendix 2. The herbicide schedule was supplemented with manual removal of weeds.  

The plot was mulched with wheat straw in late December at a rate of 4480 kg/ha. Straw was removed on April 19, 1983. Plants were protected from frost with overhead irrigation as needed in spring of 1983. Full bloom occurred on May 15.
3.2.5 **Data Collection**

Plant growth and nutritional status was evaluated by analyzing leaves taken in August of 1982. Plant root distribution was determined by excavating plants in mid- to late October, 1982 in three 7.5 cm layers. Plants for excavation were isolated using an air-driven tree digger which delineated a uniform core of 35 by 35 by 25.4 cm. for each plot. Roots from each layer were excavated, cleaned in tap water, airdried, weighted and frozen at 0 degrees C. Crowns were also treated in this manner, and the number of branch crowns for each plant was recorded. Plants were sampled again in April (pre-bloom) and early June (pre-harvest). All plant samples were freeze dried using a sublimation process, dried weights recorded, and analyzed for soluble and insoluble carbohydrates using a colorimetric carbohydrate analysis procedure developed at OARDC (Ferree, 1983; unpublished).7

Leaf area was determined by removing all leaves from a 15 X 45 cm area in the row, and measuring the area with a Licor area meter (Model LI-3000). Marketable yield, cull weight and berry size (grams per berry) were recorded for each 3 meter plot from June 10 through June 25.

3.2.6 **Statistical Analysis**

All data was analyzed with an analysis of variance for split plots. Where interactions occurred, bedtypes were further analyzed separately to delineate spacing differences. Means were separated by Tukey's New Studentized Range Test.

7 Developed from methods by Hoffman, 1937 and Smith, 1969.
Chapter IV
RESULTS

4.1 EXPERIMENT I

This experiment was designed to test the influence of trickle irrigation, nitrogen injection, raised beds, spacing, and the interactions of these factors on the growth and yield of 'Scott' and 'Redchief' strawberries.

4.1.1 Environmental monitoring

4.1.1.1 Soil type

The moisture release curve was determined experimentally (Figure 2). Between pressures of 20 and 800 kPa, soil moisture retention dropped dramatically indicating water is fairly easily removed from this soil between those pressures, but was much less available at matric potentials below 800 kPa.

4.1.1.2 Bed definition

The raised bed height and width was measured on July 17, 1981, and found to be 23 cm high with a top width of 25 cm. There were no outstanding differences in soil matric potential between raised and flat beds (Figure 3). In August at the 15 cm depth, the soil in the flat beds was recorded as having slightly higher matric potentials. In the lower two depths, differences did occur, though they were slight, and exhibited no particular trend.

- 23 -
Figure 2. Experimentally determined moisture release curve for a Chili silt loam: 0-15 cm depth.
Figure 3. Soil matric potential of a strawberry planting in a Chili silt loam at 15, 30 and 45 cm depths: Planting year, 1980.
Soil temperature at the 10 cm depth appeared to be slightly higher after mid-June in the raised bed compared to the flat (Figure 4). In early June, however, the flat beds were slightly warmer than the raised at this depth. At 15 cm, there were virtually no differences between raised and flat bed temperatures.

Photosynthetically active radiation (PAR) interception (October, 1981) differed little between bedtypes or spacings on 'Scott' or 'Redchief' strawberries (Table 1). On 'Redchief' at the center ground level (location 2), the canopy of plants at 50 cm was less dense (allowed more PAR to penetrate) than the canopy of plants at 13 cm.

During harvest of 1982, there was little difference in PAR values between bedtype or spacing were detected (Table 2). On 'Redchief', more PAR penetrated the raised bed at 1/2 canopy level (location 2) than the flat bed. It should be noted, however, that the difference of 5% full sun was repeatedly not statistically different, indicating a high level of variability.
Figure 4. Ambient and soil temperatures (10 and 15 cm depths) of a strawberry planting in a Chili silt loam: Planting year, 1980.
Table 1. The influence of bedtype and spacing on photosynthetically active radiation at 5 locations in the canopy of 'Scott' and 'Redchief' strawberry: October, 1981.

<table>
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<th>% full sun</th>
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<td>1</td>
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<td>4</td>
<td>5</td>
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<tr>
<td>'SCOTT'</td>
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<tr>
<td>raised</td>
<td>55.0</td>
<td>20.0</td>
<td>35.1</td>
<td>39.4</td>
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<td>29.0</td>
<td>15.9</td>
<td>38.0</td>
<td>35.7</td>
<td>63.3</td>
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<tr>
<td>spacing</td>
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<tr>
<td>50 cm</td>
<td>31.2</td>
<td>19.1</td>
<td>37.1</td>
<td>43.1</td>
<td>64.6</td>
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<tr>
<td>13 cm</td>
<td>52.7</td>
<td>16.8</td>
<td>35.9</td>
<td>32.1</td>
<td>41.4</td>
</tr>
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| 'REDCHIEF'       |            |      |      |      |      |
|                  |            |      |      |      |      |
| raised           | 49.9       | 28.5 | 50.8 | 45.1 | 52.8  |
| flat             | 45.6       | 27.0 | 39.6 | 32.0 | 38.7  |
| spacing          |            |      |      |      |      |
| 50 cm            | 51.0       | 32.0 | 48.3 | 38.5 | 39.2  |
| 13 cm            | 44.5       | 23.5 | 42.1 | 38.6 | 52.3  |

Means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

Y numbers 1-5 indicate the location within the strawberry canopy:
1 = eastern edge, ground level
2 = center, ground level
3 = western edge, ground level
4 = east of center, ½ canopy height
5 = west of center, ½ canopy height
Table 2. The influence of bedtype and spacing on photosynthetically active radiation at 5 locations in the canopy of 'Scott' and 'Redchief' strawberry: Harvest, 1982.

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<td>raised</td>
<td>38.0</td>
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<td>57.9</td>
<td>47.6</td>
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<td>50 cm</td>
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<td>14.1</td>
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<tr>
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<td>53.1</td>
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<td>9.8</td>
<td>9.7 b</td>
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</tbody>
</table>

*numbers 1-4 indicate the location within the strawberry canopy:
1=center, 1/2 canopy height
2=western edge, 1/2 canopy height
3=eastern edge, 1/2 canopy height
4=center, ground level

\textsuperscript{2}means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).
4.1.2 **Plant growth responses**

4.1.2.1 **Leaf analysis**

1980, 'Scott'. On 'Scott', there were no differences between the trickle/nitrogen treatments for any element (Table 3). There were 3 interactions between the trickle/nitrogen treatments and bedtype.

The mean nitrogen concentration interaction between the trickle/nitrogen treatments and bedtype indicated no difference between raised and flat beds for any trickle/nitrogen treatment (Figure 5). There were also no differences among trickle/nitrogen treatments on the flat beds. However, on raised beds, leaf nitrogen concentration in treatments 2 and 4 was greater than that from treatment 6.

There were no differences in leaf Mg concentration between raised and flat beds within any of the trickle/nitrogen treatments, and no differences among trickle/nitrogen treatments on the flat beds, the trickle/nitrogen treatments differed on the raised beds, with plants from treatment 1 having a higher Mg concentration than those from treatment 3 (Figure 6).

The interaction of the trickle/nitrogen treatments and bedtype on leaf boron concentration is depicted in figure 7. For treatment 3, leaf boron was higher in leaves from plants grown on flat beds as compared to raised. No other treatments had differences between raised and flat beds. There were no differences among trickle/nitrogen treatments on raised beds. On flat beds, leaf boron content was higher in leaves from treatment 3 and 6 than from leaves in treatment 1.
Table 3. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on leaf nutrient concentration of 'Scott' and 'Redchief' strawberry: Planting year, 1980.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>B</th>
<th>Cu</th>
<th>Zn</th>
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</tr>
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<td>133</td>
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<td>103</td>
<td>394</td>
<td>31</td>
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<td>16</td>
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<td>4. Tr./1 N</td>
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<td>.24</td>
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<td>88</td>
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<td>17</td>
</tr>
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<td>111</td>
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<td>.86</td>
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<td>98</td>
<td>333</td>
<td>***</td>
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</tr>
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<td>109 C</td>
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<td>18 BC</td>
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<td>99 C</td>
<td>368</td>
<td>34</td>
<td>4</td>
<td>19 BC</td>
</tr>
<tr>
<td>6. Tr./3 N</td>
<td>2.23</td>
<td>.26</td>
<td>1.47</td>
<td>.88</td>
<td>.28</td>
<td>125 BC</td>
<td>362</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>1. no/1 N</td>
<td>2.40</td>
<td>.26</td>
<td>1.47</td>
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<td>.28</td>
<td>134</td>
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<td>1.49</td>
<td>.86</td>
<td>.26</td>
<td>128</td>
<td>386 B</td>
<td>33</td>
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<td>19</td>
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</tbody>
</table>

* means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F) = .01, lower case p(F) = .05).

Y for trickle/nitrogen treatments, "no" = no trickle, "Tr." = trickle, "1 N" = full rate nitrogen, or 71.7 kg actual N/ha.

*** indicates a statistical interaction. Data is presented in subsequent table or figure.
Figure 5. The influence of trickle irrigation, nitrogen rate and bedtype on 'Scott' leaf N.
Figure 6. The influence of trickle irrigation, nitrogen rate and bedtype on 'Scott' leaf Mg concentration.
Figure 7. The influence of trickle irrigation, nitrogen rate and bedtype on 'Scott leaf B concentration.
1980, 'Redchief'. There were differences among trickle/nitrogen treatments for leaf Mn and Zn content (Table 3). Leaves from plants under treatments 3, 4 and 5 had a lower Mn concentration than those from treatments 1 and 2. Zn concentration was highest on leaves under treatments 1 and 2, however only leaves under treatment 2 were statistically different from treatments 3, 4, 5 and 6. Plants from treatment 3 had the lowest leaf Zn concentration.

When comparing bedtypes, leaves from plants on raised beds had a higher P concentration and a lower Ca concentration.

When comparing spacings, plants grown at 50 cm spacings had a higher leaf Fe concentration.

There was a trickle/nitrogen treatment and bedtype interaction (Figure 8). Only plants from treatment 1 had a difference in leaf Mn concentration when comparing bedtypes, with those on raised beds having a higher concentration than those on flat beds. When comparing treatments within each bedtype, on raised beds, leaves from treatments 1 and 2 had a higher leaf Mn concentration than those in treatments 4 and 5. On flat beds this was also the case, however treatment means did not span as great a concentration range.

1981, 'Scott'. Mn and Fe leaf concentrations differed among the trickle/nitrogen treatments (Table 4). Leaf Mn was higher on plants under treatment 1 than those under treatments 3, 4 or 5, with leaves from treatments 2 and 6 having intermediate Mn concentrations. Leaf Fe response was similar, though significant to the .05 level only. Leaf Fe concentrations were higher in leaves from treatment
Figure 8. The influence of trickle irrigation, nitrogen rate and bedtype on 'Redchief' leaf Mn concentration.
1 as compared to treatments 3 and 4, with leaves from treatments 2, 5 and 6 having intermediate concentrations.

Plants grown on raised beds had lower leaf N than those on flat beds, but the other nutrients tested for were not affected by bedtype (Table 4). Leaf K was influenced by spacing in that plants at 50 cm had higher leaf K than those at 13 cm (Table 4).

Redchief' Leaf P and Mn was influenced by the trickle/nitrogen treatments (Table 4). Leaf P was higher in plants from treatments 5 and 6 than those from treatment 1. Leaf Mn was higher in plants from treatment 1 than those from treatments 3, 4 or 5.

Bedtype influenced 'Redchief' leaf N and Ca. Both elements were higher in plants from the flat beds as compared to those from raised beds (Table 4).

Analysis of the leaf Cu concentrations revealed an interaction between the trickle/nitrogen treatment and bedtype (Figure 9). There were no differences between raised and flat beds within each trickle/nitrogen treatments. When comparing the trickle/nitrogen treatments on the raised bed, plants from treatments 5 and 6 had a higher leaf Cu concentration than those from treatment 3. On flat beds, plants from treatment 6 had a higher leaf Cu concentration than those from treatments 3 or 4 (Figure 9).

A 3-way interaction between trickle/nitrogen treatment, bedtype and spacing occurred when leaf Zn concentration was analyzed (Table 5). Plants on raised beds at 13 cm had higher leaf Zn concentrations under trickle/nitrogen treatments 4, 5 and 6 than under treatments 1, 2 and 3. On the flat bed at the 13 cm spacing, the alpha value was .08, indicating a difference in means at a less stringent level.
Table 4. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on leaf nutrient concentration of 'Redchief' and 'Scott' strawberries: 2nd growing (fruited) season, 1981.

<table>
<thead>
<tr>
<th>Treatment x</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
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<td>139a</td>
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<td>6</td>
</tr>
<tr>
<td>2. No/3 N</td>
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<td>.92</td>
<td>.34</td>
<td>112AB</td>
<td>117ab</td>
<td>32</td>
<td>6</td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>2.80</td>
<td>.28</td>
<td>1.87</td>
<td>.88</td>
<td>.33</td>
<td>82 B</td>
<td>94 b</td>
<td>31</td>
<td>6</td>
</tr>
<tr>
<td>4. Tr./1/2 N</td>
<td>2.82</td>
<td>.29</td>
<td>1.88</td>
<td>.91</td>
<td>.35</td>
<td>76  B</td>
<td>97 b</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td>5. Tr./1/3 N</td>
<td>2.86</td>
<td>.30</td>
<td>1.91</td>
<td>.92</td>
<td>.36</td>
<td>73  a</td>
<td>106ab</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
<td>6. Tr./1/4 N</td>
<td>2.84</td>
<td>.29</td>
<td>1.95</td>
<td>.90</td>
<td>.33</td>
<td>87AB</td>
<td>101ab</td>
<td>33</td>
<td>6</td>
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<th>Treatment</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
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<td>1.84</td>
<td>.91</td>
<td>.34</td>
<td>94</td>
<td>107</td>
<td>33</td>
<td>6</td>
</tr>
<tr>
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<td>1.89</td>
<td>.92</td>
<td>.35</td>
<td>97</td>
<td>110</td>
<td>32</td>
<td>6</td>
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<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
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<td>1.92a</td>
<td>.93</td>
<td>.34</td>
<td>105</td>
<td>109</td>
<td>32</td>
<td>6</td>
</tr>
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<td>.35</td>
<td>85</td>
<td>109</td>
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<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
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<td>.94</td>
<td>.30</td>
<td>94</td>
<td>125</td>
<td>34</td>
<td>***x</td>
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<th>Treatment</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>Cu</th>
<th>Zn</th>
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<tbody>
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<td>***</td>
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<td>1.86</td>
<td>.92</td>
<td>.30</td>
<td>129</td>
<td>98</td>
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<td>.90</td>
<td>.30</td>
<td>107</td>
<td>109</td>
<td>33</td>
<td>6</td>
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</table>

<sup>a</sup>means in undivided columns separated by Tukey's New Studentized Range Test (uppercase p(F) = .01, lower case p(F) = .05).

<sup>b</sup>For trickle/nitrogen treatments, "no" = no trickle, "Tr." = trickle, "1 N" = full rate nitrogen, or 71.7 kg actual N/ha.

<sup>c</sup>*** indicates a statistical interaction. Data is presented on figure.
Figure 9. The influence of trickle irrigation, nitrogen rate and bedtype on leaf copper concentration of 'Redchief' strawberry.
However, the trickle/nitrogen treatment 2 elicited the higher leaf Zn concentrations, along with treatments 4, 5 and 6 (Table 5).

Plant spacing alone did not influence any nutrient levels (Table 4). However, there was a bedtype-spacing interaction for the leaf nitrogen concentration (Figure 10). Plants at 13 cm spacings had similar leaf nitrogen concentrations, while those at 50 cm had lower leaf N on raised bed as compared to flat.

4.1.2.2 Leaf area

The only leaf area difference among treatments occurred on 'Redchief' on raised beds (Table 6). The leaf area of plants at 13 cm was greater than that of plants at 50 cm.

4.1.2.3 Boot and crown weights

Spring, 1981 'Scott'.

Plant root and crown mass were unaffected by the trickle/nitrogen treatments (Table 7). Boot dry weight was higher on plants grown on raised beds as compared to those on flat. Total dry weight was also higher for plants on the raised beds.

There was an interaction between the trickle/nitrogen treatments on the fresh root:crown ratio (Figure 11). On trickle/nitrogen treatment 6, the plants on raised beds had a much higher root:crown ratio. There was no difference between bedtypes in any of the other trickle/nitrogen treatments. On the raised bed, there was no difference between the dry root:crown ratio among trickle/nitrogen treatments. On the flat bed, plants from treatment 1 had a higher dry root:crown ratio than those from treatment 6 (Figure 11).
Table 5. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on leaf Zn concentration of 'Redchief' strawberries (3-way interaction): 2nd growing season (1981).

<table>
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<th>zn concentration (ppm)</th>
<th>raised bed</th>
<th>flat bed</th>
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<td></td>
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<td>50 cm</td>
<td>13 cm</td>
</tr>
<tr>
<td>1. no/1 N</td>
<td>21 20 B 20</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>2. no/½ N</td>
<td>22 20 B 21</td>
<td>22</td>
<td>20</td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>20 20 B 22</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>4. Tr./½ N</td>
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<td>5. Tr./½ N</td>
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</tr>
<tr>
<td>6. Tr./1 N</td>
<td>22 23A 23</td>
<td>22</td>
<td>23</td>
</tr>
</tbody>
</table>

*bedtypes and spacings within bedtypes analyzed separately.

Yfor trickle/nitrogen treatments, "no"=no trickle, "Tr."=trickle, "1 N"=full ratenitrogen, or 71.7 kg actual N/ha.

*Xmeans in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).
Figure 10. The influence of spacing and bedtype on leaf nitrogen concentration of 'Redchief' strawberry.
Table 6. The influence of bedtype and spacing on leaf area of 'Redchief' and 'Scott' strawberry: October, 1981.

<table>
<thead>
<tr>
<th>spacing</th>
<th>leaf area (cm²/m²)</th>
<th>'Scott'</th>
<th>'Redchief'</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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<td>flat</td>
<td>raised</td>
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<td>50 cm</td>
<td>2186.1</td>
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<td>2274.1</td>
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<td>2534.2a</td>
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*2 means in columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05.*
Table 7. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on plant weight of 'Scott' and 'Redchief' strawberry plants: Spring, (pre-harvest), 1981.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Fresh weight (g)</th>
<th>Dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>root</td>
<td>crown</td>
</tr>
<tr>
<td>1. no/1 N</td>
<td>50.7</td>
<td>29.3</td>
</tr>
<tr>
<td>2. no/½ N</td>
<td>28.0</td>
<td>26.0</td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>38.0</td>
<td>30.0</td>
</tr>
<tr>
<td>4. Tr./½ N</td>
<td>39.9</td>
<td>27.6</td>
</tr>
<tr>
<td>5. Tr./½ N</td>
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<td>30.1</td>
</tr>
<tr>
<td>6. Tr./l N</td>
<td>34.8</td>
<td>24.8</td>
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**raised**

<table>
<thead>
<tr>
<th>Fresh weight (g)</th>
<th>Dry weight (g)</th>
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</thead>
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<td>root</td>
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</tr>
<tr>
<td>46.1</td>
<td>29.8</td>
</tr>
<tr>
<td>flat</td>
<td>32.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fresh weight (g)</th>
<th>Dry weight (g)</th>
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</thead>
<tbody>
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<td>root</td>
<td>crown</td>
</tr>
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<td>46.5</td>
<td>42.4</td>
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<tr>
<td>47.0</td>
<td>25.0</td>
</tr>
<tr>
<td>50.7</td>
<td>24.7</td>
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<tr>
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<td>48.9</td>
<td>19.9</td>
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<tr>
<td>44.3</td>
<td>21.4</td>
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**raised**

<table>
<thead>
<tr>
<th>Fresh weight (g)</th>
<th>Dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>root</td>
<td>crown</td>
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<td>56.0a</td>
<td>31.0</td>
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<tr>
<td>flat</td>
<td>43.7 b</td>
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</tbody>
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<table>
<thead>
<tr>
<th>Fresh weight (g)</th>
<th>Dry weight (g)</th>
</tr>
</thead>
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<tr>
<td>root</td>
<td>crown</td>
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<tr>
<td>50 cm</td>
<td>30.5</td>
</tr>
<tr>
<td>13 cm</td>
<td>21.7</td>
</tr>
</tbody>
</table>

For trickle/nitrogen treatments, "no"=no trickle, "Tr."=trickle, "1 N"=full rate nitrogen, or 71.7 kg actual N/ha.

Y means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

r:c refers to the ratio of root to crown mass.

*** indicates a statistical interaction. Data is presented in subsequent table or figure.
Figure 11. The influence of trickle irrigation, nitrogen rate and bedtype on the root:crown dry weight ratio of first season 'Scott' strawberry plants.
Plants at 50 cm had higher fresh crown, fresh total, dry root, dry crown and dry total weights (Table 7).

Spring, 1981 'Redchief'

Fresh and dry weights were unaffected by the trickle/fertilizer treatments (Table 7). Plants grown on raised beds had higher fresh root, fresh total and dry total weights than those grown on flat beds (Table 7).

Spacing alone did not affect the plant weights, however, the fresh and dry root weights were interactively affected by 2 and 3 way interactions, respectively.

Root fresh weight was influenced interactively by trickle/nitrogen treatments and spacing (Figure 12). Plants from treatment 2 had higher fresh root weights at the 50 cm spacing than at the 13 cm spacing. At 50 cm, there were no differences among the trickle/nitrogen treatments. On flat beds, plants from treatment 1 had a higher fresh root weight than those from treatments 2 and 6.

Root dry weight displayed a 3 way interaction between trickle/nitrogen treatment, bedtype and spacing (Table 8). On raised beds, root dry weight differed for the trickle/nitrogen treatments for plants at 50 cm spacings. Specifically, within the raised bed and the 50 cm spacing, plants under treatments 2 and 6 had higher dry root weights than those under treatment 5, with those under treatments 1, 3 and 4 intermediate. This difference was not seen on the flat beds, or on the raised beds under the 13 cm spacing regime.
Figure 12. The influence of trickle irrigation, nitrogen rate and spacing on 'Redchief' root fresh weight.
Table 8. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on root dry weight of 'Redchief' strawberries (3-way interaction): 2nd growing season (1981).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>50 cm</th>
<th>13 cm</th>
<th>50 cm</th>
<th>13 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. no/1 N</td>
<td>5397.8ab</td>
<td>9298.8</td>
<td>5549.0</td>
<td>6602.6</td>
</tr>
<tr>
<td>2. no/1/2 N</td>
<td>7348.3a</td>
<td>3946.3</td>
<td>5443.2</td>
<td>3840.5</td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>6032.9ab</td>
<td>6426.0</td>
<td>4596.5</td>
<td>3931.2</td>
</tr>
<tr>
<td>4. Tr./3/4 N</td>
<td>5307.1ab</td>
<td>8920.8</td>
<td>5866.6</td>
<td>4505.8</td>
</tr>
<tr>
<td>5. Tr./1/2 N</td>
<td>3583.4 b</td>
<td>6456.2</td>
<td>6259.7</td>
<td>3432.2</td>
</tr>
<tr>
<td>6. Tr./1 N</td>
<td>7408.8a</td>
<td>4430.2</td>
<td>3901.0</td>
<td>3175.2</td>
</tr>
</tbody>
</table>

* for trickle/nitrogen treatments, "no"=no trickle, "Tr."=trickle, "1 N"=full rate nitrogen, or 71.7 kg actual N/ha.

Y means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05.)
4.1.3 Yield responses

4.1.3.1 Scott, 1981

There were no differences due to trickle/nitrogen treatments, and no interactions between the trickle/nitrogen treatments and bedtype or spacing (Table 9). Plants yielded higher on flat beds on all three dates, however berry size was larger on raised beds. On 6/15, and for the total marketable yield, there was a bedtype/spacing interaction (Figures 13 and 14). In both cases, plants at 13 cm yielded much higher on flat beds than on raised.

4.1.3.2 Redchief, 1981

There were no differences due to trickle/nitrogen treatments, and overall, no interactions between treatment types (Table 9). Early yield (1st harvest) as well as total yield and cull weight was was higher from plots spaced at 13 cm than those at 50 cm.

4.1.3.3 Scott, 1982

The 1982 yield data was difficult to interpret due to the complex interactions which occurred between the various types of treatments (Table 10). The data indicated 3 three-way interactions for the marketable weight: the 6/11, 6/14, and 6/21 data.

On 6/11, the trickle/fertilizer treatments had no effect on yield with the exception of that from those plants on flat beds at 13 cm (Table 11). For this set of circumstances, plants from treatments 1 had a lower yield than those from treatment 2, with all other yields intermediate to those.
Table 9. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on the marketable yield (kg/ha) and berry size of 'Scott' and 'Redchief' strawberries: 1st harvest, 1981.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>6/8</th>
<th>6/11</th>
<th>6/15</th>
<th>Total</th>
<th>Cull</th>
<th>size (g/berry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. no/1 N</td>
<td>2212.8</td>
<td>3295.2</td>
<td>3319.9</td>
<td>9171.7</td>
<td>4780.9</td>
<td>17.1</td>
</tr>
<tr>
<td>2. no/1 N</td>
<td>2345.4</td>
<td>2658.3</td>
<td>2467.9</td>
<td>7641.8</td>
<td>5268.4</td>
<td>16.9</td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>1907.5</td>
<td>2824.6</td>
<td>3514.6</td>
<td>8246.4</td>
<td>6101.9</td>
<td>16.9</td>
</tr>
<tr>
<td>4. Tr./1 N</td>
<td>2418.7</td>
<td>3043.7</td>
<td>3449.6</td>
<td>7191.3</td>
<td>5575.9</td>
<td>17.2</td>
</tr>
<tr>
<td>5. Tr./1 N</td>
<td>2183.7</td>
<td>2532.9</td>
<td>3385.0</td>
<td>8110.2</td>
<td>5941.6</td>
<td>16.7</td>
</tr>
<tr>
<td>6. Tr./1 N</td>
<td>1640.2</td>
<td>2791.9</td>
<td>3036.1</td>
<td>7685.0</td>
<td>4529.1</td>
<td>17.6</td>
</tr>
</tbody>
</table>

<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td>bed</td>
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</tr>
<tr>
<td>raised</td>
<td>1902.0</td>
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<td>3352.3a</td>
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<td>5714.2</td>
<td>16.1 B</td>
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</tr>
<tr>
<td>50 cm</td>
<td>1964.6</td>
<td>2770.6 ***X</td>
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<td>5197.2</td>
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<tr>
<td>13 cm</td>
<td>2386.3</td>
<td>2945.0</td>
<td></td>
<td>5868.6</td>
<td>16.9</td>
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</table>

<table>
<thead>
<tr>
<th>Treatment</th>
<th>6/8</th>
<th>6/11</th>
<th>6/15</th>
<th>Total</th>
<th>Cull</th>
<th>size (g/berry)</th>
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<tbody>
<tr>
<td>1. no/1 N</td>
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<td>1688.7</td>
<td>1282.4</td>
<td>5677.7</td>
<td>4042.0</td>
<td>10.7</td>
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<tr>
<td>2. no/1 N</td>
<td>2232.2</td>
<td>1526.3</td>
<td>966.0</td>
<td>4724.2</td>
<td>4543.2</td>
<td>10.6</td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>2576.2</td>
<td>2175.1</td>
<td>1647.4</td>
<td>6395.3</td>
<td>4172.0</td>
<td>10.3</td>
</tr>
<tr>
<td>4. Tr./1 N</td>
<td>2506.7</td>
<td>1697.0</td>
<td>1076.4</td>
<td>5278.7</td>
<td>5413.9</td>
<td>10.6</td>
</tr>
<tr>
<td>5. Tr./1 N</td>
<td>2386.7</td>
<td>1931.6</td>
<td>1550.8</td>
<td>5868.6</td>
<td>4853.8</td>
<td>10.8</td>
</tr>
<tr>
<td>6. Tr./1 N</td>
<td>2243.9</td>
<td>1948.1</td>
<td>2069.8</td>
<td>6197.8</td>
<td>4057.1</td>
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<td>bed</td>
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<tr>
<td>raised</td>
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</table>

*means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

YFor trickle/nitrogen treatments, "no"=no trickle, "Tr."=trickle, "1 N"=full rate nitrogen, or 71.7 kg actual N/ha.

** indicates a statistical interaction. Data is presented in subsequent figure.
Figure 13. Influence of bedtype and spacing on marketable yield, 6/15 of 'Scott' strawberry: 1981, 1st harvest.
Figure 14. The influence of bedtype and spacing on total yield of 'Scott' strawberry: 1981, 1st harvest.
Table 10. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on the marketable yield (kg/ha) and berry size of 'Scott' and 'Redchief' strawberries: 2nd harvest, 1982.

<table>
<thead>
<tr>
<th>Treatment*</th>
<th>6/9</th>
<th>6/11</th>
<th>6/14</th>
<th>6/17</th>
<th>6/21</th>
<th>Total</th>
<th>Cull</th>
<th>Size (g/berry)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.no/1 N*</td>
<td>1999.9</td>
<td>1974.2</td>
<td>2854.9</td>
<td>3564.5</td>
<td>2547.3</td>
<td>10642.7</td>
<td>1194.5</td>
<td>10.6</td>
</tr>
<tr>
<td>2.no/1 N</td>
<td>1603.4</td>
<td>1373.3</td>
<td>3985.2</td>
<td>3146.2</td>
<td>3134.2</td>
<td>14659.8</td>
<td>1533.9</td>
<td>10.0</td>
</tr>
<tr>
<td>3.Tr. only</td>
<td>2271.4</td>
<td>2305.5</td>
<td>3287.6</td>
<td>2816.7</td>
<td>2253.9</td>
<td>13109.0</td>
<td>1728.9</td>
<td>12.4</td>
</tr>
<tr>
<td>4.Tr./l N</td>
<td>1224.3</td>
<td>2577.9</td>
<td>4478.9</td>
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<td>2879.6</td>
<td>12395.0</td>
<td>892.7</td>
<td>11.1</td>
</tr>
<tr>
<td>5.Tr./l N</td>
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<td>2003.5</td>
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<td>2676.4</td>
<td>12751.4</td>
<td>1300.0</td>
<td>10.6</td>
</tr>
<tr>
<td>6.Tr./l N</td>
<td>2362.2</td>
<td>2432.8</td>
<td>3693.2</td>
<td>3042.7</td>
<td>2368.4</td>
<td>13109.0</td>
<td>1510.0</td>
<td>11.3</td>
</tr>
<tr>
<td>bed</td>
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</tr>
<tr>
<td>raised</td>
<td>2042.3</td>
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<td>3850.7</td>
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<tr>
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<td>13006.3</td>
<td>1526.3</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>50 cm</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>1488.1</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>13 cm</td>
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<td></td>
<td>1231.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>*means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F) = .01, lower case p(F) = .05).</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>**For trickle/nitrogen treatments, &quot;no&quot; = no trickle, &quot;Tr.&quot; = trickle, &quot;1 N&quot; = full rate nitrogen, or 71.7 kg actual N/ha.</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*** indicates a statistical interaction. Data is presented in subsequent table or figure.</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 11. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on marketable yield (kg/ha) of 'Scott' strawberries: 6/11/82.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>RAISED</th>
<th></th>
<th>FLAT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50 cm</td>
<td>13 cm</td>
<td>50 cm</td>
<td>13 cm</td>
</tr>
<tr>
<td>1. no/1 N</td>
<td>2532.9</td>
<td>1412.8</td>
<td>1984.5</td>
<td>1786.4 b</td>
</tr>
<tr>
<td>2. no/1/2 N</td>
<td>3864.2</td>
<td>3008.3</td>
<td>2727.9</td>
<td>4252.9a</td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>2531.8</td>
<td>1786.4</td>
<td>2143.1</td>
<td>2760.0ab</td>
</tr>
<tr>
<td>4. Tr./1/4 N</td>
<td>2532.9</td>
<td>2873.1</td>
<td>2109.8</td>
<td>2597.2ab</td>
</tr>
<tr>
<td>5. Tr./1/2 N</td>
<td>2109.8</td>
<td>2013.4</td>
<td>1494.3</td>
<td>2304.8ab</td>
</tr>
<tr>
<td>6. Tr./1 N</td>
<td>2423.5</td>
<td>1655.7</td>
<td>2857.6</td>
<td>2955.0ab</td>
</tr>
</tbody>
</table>

Z means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

Y for trickle/nitrogen treatments, "no"=no trickle, "Tr.”=trickle, "1 N"= full rate nitrogen, or 71.7 kg actual N/ha.
For 6/14 yield, the trickle/nitrogen treatments affected yield only on plants on raised beds at 50 cm (Table 12). For these treatments, yield on treatment 4 was higher than that on treatments 2, 3 and 6, with yield from treatments 1 and 5 intermediate.

On 6/21, yield was affected by the trickle/nitrogen treatments only on those plants on raised beds at 50 cm (Table 13). For those data, yield was higher on treatment 4 than 5 and 6, with treatments 1, 2, and 3 intermediate.

Because of the large number of bedtype/spacing interactions, they have been presented in total in an independent table (Table 14). 'Scott' yields on raised beds were higher on plants at 50 cm on the earliest harvest and lower on those plants on the last harvest, indicating an earlier yield on plants at 50 cm on raised beds than those at 13 cm. On flat beds, the second harvest had higher yields from plants at 13 cm than those at 50 cm. On 6/17, the higher yield was on plants at 50 cm, indicating the opposite trend as was seen on raised beds. Specifically, plants at 13 cm yielded earlier than those at 50 cm on flat beds. The total yield, however, was unaffected.

4.1.3.4 Bedchief, 1982

The initial analysis of variance revealed no differences between the trickle/nitrogen treatments on any of the yield responses (Table 10).

For cull weight, a three-way interaction between trickle/nitrogen bedtype and spacing treatments is represented in Table 15. The only statistical difference between trickle/nitrogen treatments was for those plants on
Table 12. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on the marketable yield (kg/ha) of 'Scott' strawberries: 6/14/82.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>RAISED</th>
<th></th>
<th>FLAT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1. no/1 N</td>
<td>2988.3</td>
<td>3190.9ab</td>
<td>2819.1</td>
<td>2454.1</td>
</tr>
<tr>
<td>2. no/½ N</td>
<td>3482.9</td>
<td>2499.8 b</td>
<td>3895.1</td>
<td>5293.1</td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>3602.7</td>
<td>2338.2 b</td>
<td>3117.7</td>
<td>4091.2</td>
</tr>
<tr>
<td>4. Tr./½ N</td>
<td>3214.0</td>
<td>5096.7a</td>
<td>4708.3</td>
<td>4353.0</td>
</tr>
<tr>
<td>5. Tr./½ N</td>
<td>3082.2</td>
<td>3636.1ab</td>
<td>4804.6</td>
<td>2662.6</td>
</tr>
<tr>
<td>6. Tr./1 N</td>
<td>2955.0</td>
<td>2239.4 b</td>
<td>4870.0</td>
<td>5634.0</td>
</tr>
</tbody>
</table>

*Z* means in undivided columns separated by Tukey's New Studentized Range Test (upper case *p*(F)=.01, lower case *p*(F)=.05).

*Y* for trickle/nitrogen treatments, "no"=no trickle, "Tr."= trickle, "1 N"= full rate nitrogen, or 71.7 kg actual N/ha.
Table 13. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on the marketable yield (kg/ha) of 'Scott' strawberries: 6/21/82.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>RAISED</th>
<th></th>
<th></th>
<th>FIAT</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50 cm</td>
<td>13 cm</td>
<td>50 cm</td>
<td>13 cm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1. no/1 N</td>
<td>2422.1ab</td>
<td>2921.6</td>
<td>3323.4</td>
<td>1882.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. no/½ N</td>
<td>2240.5ab</td>
<td>2435.5</td>
<td>4091.2</td>
<td>3216.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>2195.1ab</td>
<td>2955.0</td>
<td>2499.8</td>
<td>1478.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Tr./¼ N</td>
<td>3084.6a</td>
<td>2921.6</td>
<td>2398.0</td>
<td>1806.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Tr./½ N</td>
<td>1568.0 b</td>
<td>2824.2</td>
<td>3214.0</td>
<td>2857.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. Tr./1 N</td>
<td>1558.3 b</td>
<td>1720.0</td>
<td>4028.6</td>
<td>1561.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Z means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

Y for trickle/nitrogen treatments, "no" = notrickle, "Tr." = trickle, "1 N" = full rate nitrogen, or 71.7 kg actual N/ha.
Table 14. Bedtype/spacing interactions on marketable yield of 'Scott' and 'Redchief' strawberries: 2nd harvest, 1982.

<table>
<thead>
<tr>
<th>Date</th>
<th>spacing</th>
<th>'SCOTT'</th>
<th></th>
<th>'REDCHIEF'</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>raised</td>
<td>flat</td>
<td>raised</td>
<td>flat</td>
</tr>
<tr>
<td>6/9</td>
<td>50 cm</td>
<td>2348.5a</td>
<td>1279.7</td>
<td>2336.1</td>
<td>1726.5b</td>
</tr>
<tr>
<td></td>
<td>13 cm</td>
<td>1743.4b</td>
<td>2298.6</td>
<td>2938.1</td>
<td>2808.4a</td>
</tr>
<tr>
<td>6/11</td>
<td>50 cm</td>
<td>2637.4Y</td>
<td>2232.2Yb</td>
<td>1991.8B</td>
<td>2985.6</td>
</tr>
<tr>
<td></td>
<td>13 cm</td>
<td>2195.8</td>
<td>2776.1a</td>
<td>3977.3A</td>
<td>3073.3</td>
</tr>
<tr>
<td>6/14</td>
<td>50 cm</td>
<td>3077.8Y</td>
<td>3970.0Y</td>
<td>2239.1B</td>
<td>3506.7</td>
</tr>
<tr>
<td></td>
<td>13 cm</td>
<td>3350.0</td>
<td>4035.8</td>
<td>5120.4A</td>
<td>3637.5</td>
</tr>
<tr>
<td>6/17</td>
<td>50 cm</td>
<td>3282.8</td>
<td>3960.8A</td>
<td>2794.0</td>
<td>3766.5A</td>
</tr>
<tr>
<td></td>
<td>13 cm</td>
<td>3409.4</td>
<td>2894.7B</td>
<td>3370.9</td>
<td>2762.0B</td>
</tr>
<tr>
<td>6/21</td>
<td>50 cm</td>
<td>2110.4Yb</td>
<td>2909.9Y</td>
<td>1805.7B</td>
<td>2754.4A</td>
</tr>
<tr>
<td></td>
<td>13 cm</td>
<td>2629.5a</td>
<td>2698.0</td>
<td>3024.8A</td>
<td>2009.3B</td>
</tr>
<tr>
<td>TOTAL</td>
<td>50 cm</td>
<td>12316.6</td>
<td>12846.3</td>
<td>9745.5b</td>
<td>14248.1</td>
</tr>
<tr>
<td></td>
<td>13 cm</td>
<td>12922.4</td>
<td>13165.9</td>
<td>16423.6a</td>
<td>13393.0</td>
</tr>
</tbody>
</table>

\(z\) means in undivided columns separated by Tukey's New Studentized Range Test (upper case \(p(F)=.01\), lower case \(p(F)=.05\)).

\(^y\) means subject to a three-way statistical interaction. Data is presented in subsequent table or figure.
flat beds at 50 cm. On those plants, cull weight was higher on treatment 3 than treatment 4, with all other treatments intermediate.

The bedtype/spacing interactions are detailed in Table 14. On raised beds, the plants at 50 cm yielded more than those at 13 cm on 6/11, 6/14, 6/21 and the total. On flat beds, only the first harvest date (6/9) had higher yield on the plants at 50 cm. Conversely, on 6/17 and 6/21, the highest yield was from plants at 50 cm.

There was an interaction between bedtype and spacing for berry size (Table 10, Figure 15). At 50 cm, berries were larger on flat beds than on raised. There was no difference in berry size on plants at 13 cm, though the mean was larger on plants on raised beds.
Table 15. The influence of trickle irrigation, nitrogen rate, bedtype and spacing on total cull weight (kg/ha) of 'Redchief' strawberries: 1982.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>RAISED</th>
<th></th>
<th>FLAT</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>50 cm</td>
<td>13 cm</td>
<td>50 cm</td>
<td>13 cm</td>
</tr>
<tr>
<td>1. no/1 N</td>
<td>945.6</td>
<td>2857.6</td>
<td>1755.4ab</td>
<td>1461.0</td>
</tr>
<tr>
<td>2. no/½ N</td>
<td>1462.0</td>
<td>2143.1</td>
<td>1624.7ab</td>
<td>1886.2</td>
</tr>
<tr>
<td>3. Tr. only</td>
<td>1784.3</td>
<td>2143.1</td>
<td>2176.5a</td>
<td>1916.1</td>
</tr>
<tr>
<td>4. Tr./½ N</td>
<td>1397.7</td>
<td>1688.0</td>
<td>972.5 b</td>
<td>1300.3</td>
</tr>
<tr>
<td>5. Tr./½ N</td>
<td>1494.0</td>
<td>1982.5</td>
<td>1104.2ab</td>
<td>1461.0</td>
</tr>
<tr>
<td>6. Tr./1 N</td>
<td>651.2</td>
<td>1818.7</td>
<td>1948.1ab</td>
<td>1301.4</td>
</tr>
</tbody>
</table>

* Zmeans in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

* Yfor trickle/nitrogen treatments, "no"=no trickle, "Tr."=trickle, "1 N"=full rate nitrogen, or 71.7 kg actual N/ha.
Figure 15. The influence of bedtype and spacing on average berry size (g/berry) of 'Scott' strawberries.
4.2 EXPERIMENT II

This experiment was designed specifically to characterize and further define the effects and interaction of bedtype and spacing on 'Redchief' strawberries.

4.2.1 Monitoring the Environment

4.2.1.1 Soil type

The moisture release curve was determined experimentally (Figure 16). The water retention of the Miamian silt loam did not have the rapid drop in moisture as pressure increased that the Chili silt loam of Experiment I exhibited. A higher percentage of water was held to the soil colloids at pressures above 20 kPa, indicating less water availability to the plants at for the same percentage of soil water.

4.2.1.2 Bed Definition

Rapid settling and erosion occurred early in the season, however, the rate of erosion decreased later in the season, so that the September bed height was 143 mm, and total top and base width were 100 and 235 mm, respectively (Figure 17).

Soil moisture at 15, 30 and 45 cm depths was monitored throughout the growing season of the planting year and the harvest season. Overhead irrigation was applied frequently as needed to the entire field. In 1982, tensiometers at all three depths in the raised beds registered higher matric potentials than those on flat beds (Figure 18).  

---

8 Gaps in solid line representing raised bed response in Figures 14 and 15 indicate instances when matric potential of soil was too negative (dry) for tensiometer to measure.
Figure 16. Experimentally determined moisture release curve for a Miamian silt loam: 0-15 cm depth.
Figure 17. Raised bed deterioration of a Miamian silt loam planted in strawberries during the planting season (1982).
This was also the case for the data from May and June of 1983 (Figure 19). In both years, and at all depths, the instances where the matric potentials were the same or very close between raised and flat beds was when the soil approached saturation (0 centibars). As the matric potential of the soil increased (soil became drier) the raised bed had much higher matric potentials than than the flat bed. It appears, therefore, that the raised bed was consistently slightly drier than the flat bed over the entire course of the experiment -- even at the 30 and 45 cm depths where few, if any roots exist.

Moisture in the topmost 20 cm of the soil was determined by gravimetric sampling throughout the growing season of the planting year. Results indicate a lower percent moisture in the raised bed in level A in May, level E in June, and levels E and C in July as compared to the flat bed (Table 16). The moisture level was most notably lower in July when the total moisture in the 20 cm core was statistically lower on the raised bed as compared to the flat.

In 1982, soil temperature at the 10 cm depth was very slightly warmer on the flat as compared to the raised bed (Figure 20). At 15 cm, this trend was not apparent. The raised bed temperature at 15 cm was more erratic, with higher highs and lower lows, though not notably colder or warmer than the flat bed.

In the spring of 1983, the 10 cm temperatures were very nearly identical, however at 15 cm, the flat bed temperature was slightly, though again, not notably higher than that of the raised bed (Figure 21).
Figure 18. Soil matric potential of a strawberry planting in a Miamian silt loam at 15, 30 and 45 cm depths: planting year, 1982.
Figure 19. Soil matric potential of a strawberry planting in a Miamian silt loam at 15, 30 and 45 cm depths: Spring, 1983.
Table 16. The influence of bedtype on the percent moisture in the top 20 cm of soil as determined by gravimetric sampling.

<table>
<thead>
<tr>
<th>Levels</th>
<th>% moisture</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>A (raised)</td>
<td>17.8 b</td>
<td>19.0</td>
<td>15.3</td>
<td>18.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(flat)</td>
<td>19.4a</td>
<td>20.0</td>
<td>16.2</td>
<td>17.6</td>
</tr>
<tr>
<td>B (raised)</td>
<td>21.9</td>
<td>20.5 b</td>
<td>16.4 b</td>
<td>18.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(flat)</td>
<td>22.5</td>
<td>23.2a</td>
<td>18.6a</td>
<td>19.8</td>
</tr>
<tr>
<td>C (raised)</td>
<td>22.1</td>
<td>22.0</td>
<td>17.4 B</td>
<td>19.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(flat)</td>
<td>23.0</td>
<td>22.9</td>
<td>19.3A</td>
<td>20.3</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>20.5</td>
<td>20.6</td>
<td>16.4 B</td>
<td>18.7</td>
</tr>
<tr>
<td></td>
<td>(raised)</td>
<td>21.6</td>
<td>22.0</td>
<td>17.9A</td>
<td>19.7</td>
</tr>
</tbody>
</table>

* Determined on a dry weight basis

<table>
<thead>
<tr>
<th>Levels</th>
<th>% moisture</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>August</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>17.8 b</td>
<td>19.0</td>
<td>15.3</td>
<td>18.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(flat)</td>
<td>19.4a</td>
<td>20.0</td>
<td>16.2</td>
<td>17.6</td>
</tr>
<tr>
<td>B</td>
<td>21.9</td>
<td>20.5 b</td>
<td>16.4 b</td>
<td>18.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(flat)</td>
<td>22.5</td>
<td>23.2a</td>
<td>18.6a</td>
<td>19.8</td>
</tr>
<tr>
<td>C</td>
<td>22.1</td>
<td>22.0</td>
<td>17.4 B</td>
<td>19.4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(flat)</td>
<td>23.0</td>
<td>22.9</td>
<td>19.3A</td>
<td>20.3</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>20.5</td>
<td>20.6</td>
<td>16.4 B</td>
<td>18.7</td>
</tr>
<tr>
<td></td>
<td>(raised)</td>
<td>21.6</td>
<td>22.0</td>
<td>17.9A</td>
<td>19.7</td>
</tr>
</tbody>
</table>

* Levels A, B, and C denote the shallowest, intermediate, and deepest third, respectively, of a 20 cm soil core.

* Means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).
Figure 20. Ambient and soil temperatures of a strawberry planting in a Miamian silt loam at 10 and 15 cm depths: Planting year, 1982.
Figure 21. Ambient and soil temperatures of a strawberry planting in a Miamian silt loam at 10 and 15 cm depths: Spring, 1983.
On 5/12, the meter sensor data indicated more sunlight penetration (% full sun) in the raised bed as compared to the flat (Table 17). By July, however, there was no detectable difference in sunlight penetration between raised and flat beds. When spacings were compared, however, differences were found on both dates, with the 50 cm mother plants having the greatest percent full sun penetration, followed by the runnered treatment, and the 13 cm spaced mother plants.

Data from the integrators indicated an interaction between bedtype and spacing (Figure 22). Plants at 50 cm allowed more PAR penetration on raised beds than plants at the same spacing on flat beds, indicating less interception of PAR at 1/2 canopy height by the plants on raised beds, or a more open canopy at this spacing. Differences in PAR penetration were not detected on the other two spacings when comparing bedtypes.
Table 17. The influence of bedtype and spacing on 'Redchief' strawberry photosynthetically active radiation interception at ½ canopy height.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>% full sun 5/12</th>
<th>% full sun 7/1</th>
</tr>
</thead>
<tbody>
<tr>
<td>raised</td>
<td>48.8A</td>
<td>23.9</td>
</tr>
<tr>
<td>flat</td>
<td>41.6 B</td>
<td>24.3</td>
</tr>
<tr>
<td>13 cm</td>
<td>38.9 C</td>
<td>17.8 C</td>
</tr>
<tr>
<td>50+&lt;sup&gt;r&lt;/sup&gt;</td>
<td>43.8 B</td>
<td>26.0 B</td>
</tr>
<tr>
<td>50 cm</td>
<td>52.9A</td>
<td>28.6A</td>
</tr>
</tbody>
</table>

<sup>Z</sup>means in undivided columns separated with Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

<sup>Y</sup>cm spacings indicate distance in row between original plants. "50+<sup>r</sup>" indicates original plants planted at 50 cm with daughter plants placed at 13 cm.
Figure 22. The influence of bedtype and spacing on photosynthetically active radiation interception of 'Redchief' strawberry plants at $\frac{1}{2}$ canopy height.
4.2.2 Plant growth responses

4.2.2.1 Leaf analysis

Leaf analysis indicated no deficiency of any element on any treatment (Table 18).

Leaf nitrogen content was unaffected by bedtype or spacing.

Leaf analysis of phosphorus (P) indicated that there was an interaction between bedtype and spacing (Figure 23). Plants at 13 cm and at 50 cm with runners had similar P content regardless of bedtype. Plants at 50 cm had more P on raised than on flat beds. In addition, those plants had a higher P content than either of the other spacings on raised or flat beds.

Potassium (K) was higher in plants on raised beds as compared to those on flat (Table 18). In examining the interaction, it becomes apparent that the plants on flat beds spaced at 50 cm are much lower in K than all other treatments (Figure 24).

Calcium (Ca) content was higher on plants grown on flat beds as compared to raised (Table 18). Plants at 13 cm had a higher Ca leaf concentration than those at 50 cm, with the runnered treatment intermediate to them.

An interaction between bedtype and spacing also occurred for leaf manganese (Mn) concentration (Figure 25). Plants spaced at 50 cm with runners had equivalent levels of leaf Mn, while those at 13 and 50 cm had more leaf Mn when grown on raised beds.

Plants at 50 cm had higher leaf copper than those in the other two treatments, and leaf zinc was highest in plants grown on raised beds.

Leaf magnesium, iron and boron were unaffected by bedtype and spacing.
Table 18. The influence of bedtype and spacing on leaf nutrient concentration of 'Redchief' strawberry: planting year, 1982.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>B</th>
<th>Cu</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td>raised</td>
<td>2.28</td>
<td>.36</td>
<td>1.55A</td>
<td>.13 B</td>
<td>.35</td>
<td>52</td>
<td>412</td>
<td>53</td>
<td>6</td>
<td>49</td>
</tr>
<tr>
<td>flat</td>
<td>2.30</td>
<td>.35</td>
<td>1.49 B</td>
<td>.14A</td>
<td>.35</td>
<td>49</td>
<td>392</td>
<td>54</td>
<td>6</td>
<td>43</td>
</tr>
<tr>
<td>13 cm</td>
<td>2.28</td>
<td>***</td>
<td>***</td>
<td>.14A</td>
<td>.36</td>
<td>***</td>
<td>420</td>
<td>53</td>
<td>5</td>
<td>46</td>
</tr>
<tr>
<td>50+r</td>
<td>2.27</td>
<td>.13 B</td>
<td>.35</td>
<td></td>
<td></td>
<td>388</td>
<td>53</td>
<td>5</td>
<td>46</td>
<td></td>
</tr>
<tr>
<td>50 cm</td>
<td>2.31</td>
<td>.14AB</td>
<td>.35</td>
<td></td>
<td></td>
<td>398</td>
<td>54</td>
<td>6</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

*Z* means in undivided columns separated by Tukey's New Studentized Range Test (upper case *p*(F)=.01, lower case *p*(F)=.05.

Y cm spacings indicate distance in row between original plants. "50+r" indicates original plants planted at 50 cm with daughter plants placed at 13 cm.

X*** indicates a statistical interaction. Data is presented in subsequent table or figure.
Figure 23. The influence of bedtype and spacing on leaf
P concentration of 'Redchief' strawberry plants.
Figure 24. The influence of bedtype and spacing on leaf K concentration of 'Redchief' strawberry.
Figure 25. The influence of bedtype and spacing on leaf Mn concentration of 'Redchief' strawberry plants.
4.2.2.2 Leaf area, crown number, runner number

October leaf area per unit area was unaffected by bedtype but was higher on both 13 cm spaced plants and runnered plants as compared to plants at 50 cm spacings (Table 19).

Branch crown number was characterized by an interaction between bedtype and spacing (Figure 26). On raised beds, the runnered treatment had the lowest number of branch crowns, while on flat beds the widest spacing had the lowest number of branch crowns.

The number of runners per unit area was highest on plants spaced at 13 cm (Table 19). Runners per plant, however, were influenced by bedtype and spacing, interactively (Figure 27). Plants at 50 cm had more runners on raised beds as compared to flat, while the other two spacings had equivalent numbers or runners on raised or flat beds.

4.2.2.3 Root and crown mass

Root and crown mass were evaluated at 3 separate sampling dates: October (pre-winter), April (pre-bloom) and June (pre-harvest). The October sampling was an excavation, removing roots in 3 layers (0-7.5, 7.5-15.0 and 15.0-22.5 cm depths). For the April and June sampling, only total root and crown mass were recorded.

October root mass in the 0-7.5 and 7.5-15.0 cm levels were not influenced by bedtype alone (Table 20). However, when bedtypes were analyzed separately, plants on raised beds spaced at 13 cm had a higher mass of roots in the 15.0-22.5 as compared to the other two spacings.
Table 19. The influence of bedtype and spacing on 'Redchief' strawberry leaf area, crown number and runner number in October.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>cm$^2$/m$^2$</th>
<th>crown #</th>
<th>crown /3 m.</th>
<th>Runner # /plant</th>
</tr>
</thead>
<tbody>
<tr>
<td>raised</td>
<td>40786.7</td>
<td>7.7</td>
<td>293.7</td>
<td>22.4</td>
</tr>
<tr>
<td>flat</td>
<td>37506.3</td>
<td>7.5</td>
<td>282.6</td>
<td>20.9</td>
</tr>
<tr>
<td>13 cm$^x$</td>
<td>46575.2A ***</td>
<td>406.1A</td>
<td>243.2 B</td>
<td></td>
</tr>
<tr>
<td>50+r</td>
<td>41154.9A</td>
<td>29708.6 B</td>
<td>215.2 B</td>
<td></td>
</tr>
</tbody>
</table>

Zleaf area

Ymeans in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05.

Xcm spacings indicate distance in row between original plants. "50+r" indicates original plants planted at 50 cm with daughter plants placed at 13 cm.
Figure 26. The influence of bedtype and spacing on branch crown number of 'Redchief' strawberry.
Figure 27. The influence of bedtype and spacing on runner number per plant of 'Redchief' strawberry plants.
Table 20. The influence of bedtype and spacing on 'Redchief' strawberry root and crown dry weights at 3 sampling dates.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>OCTOBER</th>
<th>APRIL</th>
<th>JUNE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>root mass</td>
<td>mass</td>
<td>R:C</td>
</tr>
<tr>
<td>bedtype</td>
<td>0-7.5X</td>
<td>7.5-15</td>
<td>15-22.5</td>
</tr>
<tr>
<td>raised</td>
<td>8.7</td>
<td>4.2</td>
<td>1.5a</td>
</tr>
<tr>
<td>flat</td>
<td>10.6</td>
<td>2.9</td>
<td>0.4b</td>
</tr>
<tr>
<td><strong>BEDTYPES SEPARATED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>RAISED</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 cm</td>
<td>12.4a</td>
<td>6.0</td>
<td>1.6</td>
</tr>
<tr>
<td>50+r</td>
<td>6.4b</td>
<td>2.3</td>
<td>1.1</td>
</tr>
<tr>
<td>50 cm</td>
<td>7.4b</td>
<td>4.3</td>
<td>1.7</td>
</tr>
<tr>
<td><strong>FLAT</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 cm</td>
<td>15.0A</td>
<td>2.9</td>
<td>0.4</td>
</tr>
<tr>
<td>50+r</td>
<td>11.4A</td>
<td>3.7</td>
<td>0.4</td>
</tr>
<tr>
<td>50 cm</td>
<td>5.3B</td>
<td>2.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

z Due to the nature of the excavation, weights are reported on a per unit basis.
y Per plant basis.
x Numbers indicate cm depths of soil.
w Ratio of roots to crown mass.
vy p(F) = .07.
u Means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F) = .01, lower case p(F) = .05).
t cm spacings indicate distance in row between original plants. "50+r" indicates original plants planted at 50 cm with daughter plants placed at 13 cm.
On the flat bed, plants at 13 cm and the runnered treatment both had larger root mass in the 0-7.5 level than did plants at 50 cm. On raised beds, the runnered treatment plant's root mass was equivalent to that of the 50 cm spaced plant, while on flat beds, runnered plants had a root mass equivalent to that of the 13 cm spaced plants. This difference was large enough to be reflected in the total root dry weight. Root mass from the 15-22.5 cm depth was higher on plants in raised beds compared to those in flat beds.

There was an interaction between bedtype and spacing regarding crown mass (Figure 28). Crown mass per unit area was lowest on the runnered treatment on the raised beds. On the flat bed, the lowest crown mass was for plants grown at 50 cm, with the runnered plants' crown mass intermediate to those at 50 and 13 cm.

The root:mass ratio was somewhat higher \((p(F)=.07)\) for plants grown on raised beds as compared to those on flat (Table 20).

Root mass samples from the April sampling (on a per plant basis) were unaffected by spacing on the raised bed. On the flat bed, root mass was highest on plants at 50 cm. Crown mass at this time was unaffected by bedtype or spacing.

There were no differences in root or crown mass in June between bedtypes or among spacings (Table 20).

Soluble and insoluble carbohydrate data for roots and crowns in October indicated no differences in soluble carbohydrates for crowns (Table 21). Insoluble carbohydrates were higher in plant roots on flat beds as compared to raised.
Figure 28. The influence of bedtype and spacing on crown dry weight of 'Redchief' strawberry plants.
Table 21. The influence of bedtype and spacing on soluble and insoluble carbohydrate concentration of 'Redchief' strawberry roots and crowns.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>crowns</th>
<th>roots</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$S^2$</td>
<td>IN</td>
</tr>
<tr>
<td>OCTOBER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>raised</td>
<td>4.9</td>
<td>9.9</td>
</tr>
<tr>
<td>flat</td>
<td>4.9</td>
<td>8.3</td>
</tr>
<tr>
<td>APRIL</td>
<td></td>
<td></td>
</tr>
<tr>
<td>raised</td>
<td>6.3A</td>
<td>5.0 b</td>
</tr>
<tr>
<td>flat</td>
<td>5.6 B</td>
<td>5.8a</td>
</tr>
<tr>
<td>JUNE</td>
<td></td>
<td></td>
</tr>
<tr>
<td>raised</td>
<td>5.4</td>
<td>5.1</td>
</tr>
<tr>
<td>flat</td>
<td>5.4</td>
<td>5.1</td>
</tr>
</tbody>
</table>

(spacing, cm)

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>OCTOBER</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>5.0</td>
<td>10.1</td>
<td>6.1</td>
<td>9.0</td>
</tr>
<tr>
<td>50+r</td>
<td>4.8</td>
<td>8.9</td>
<td>6.1</td>
<td>7.8</td>
</tr>
<tr>
<td>50</td>
<td>4.9</td>
<td>8.4</td>
<td>6.1</td>
<td>8.7</td>
</tr>
<tr>
<td>APRIL</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>5.5</td>
<td>5.6a</td>
<td>7.2</td>
<td>4.2</td>
</tr>
<tr>
<td>50+r</td>
<td>6.1</td>
<td>5.4 b</td>
<td>6.9</td>
<td>3.9</td>
</tr>
<tr>
<td>50</td>
<td>6.2</td>
<td>5.1 b</td>
<td>6.3</td>
<td>4.4</td>
</tr>
<tr>
<td>JUNE</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>5.2</td>
<td>5.4</td>
<td>5.7</td>
<td>5.3</td>
</tr>
<tr>
<td>50+r</td>
<td>5.5</td>
<td>5.0</td>
<td>5.8</td>
<td>5.3</td>
</tr>
<tr>
<td>50</td>
<td>5.4</td>
<td>4.9</td>
<td>5.6</td>
<td>5.3</td>
</tr>
</tbody>
</table>

$^{Z}$"S"=soluble, "IN"=insoluble.

$^Y$Means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

$^{X}$For trickle/nitrogen treatments, "no"=no trickle, "Tr."=trickle, "1 N"=Full rate nitrogen, or 71.7 kg actual N/ha.
In April, the crowns had a higher level of soluble carbohydrates, and a lower level of insoluble carbohydrates on raised beds as compared to flat. The only difference among spacings occurred in the June crown sample, where the plants at 13 cm had a higher level of carbohydrate than either of the other spacings.

4.2.3 Yield responses

4.2.3.1 Per unit area

Marketable yield (kg/ha) was higher on raised beds than flat for the first harvest (Table 22). Subsequently, there was no difference in marketable yield when comparing raised and flat beds, with overall yields being equivalent. There was an interaction between bedtype and spacing for the first four of the five harvest dates. While spacing did not effect marketable yield on plants grown on the flat bed, the plants spaced at 13 cm outyielded the other two treatments in the first four harvests.

Overall yield, again, was not affected by spacing, though certainly there was a trend toward higher yields on the closest raised bed spacing for the total yield (Table 22).

For cull weight, the plants on flat beds were unaffected by spacing, while those on raised beds yielded highest on plants at the closest spacing (Table 23).

4.2.3.2 Per plant

Plants on raised beds and flat beds yielded equivalent amounts on a per plant basis (Table 24). Plants at the non-runnered 50 cm spacing yielded three times or more fruit per plant than plants at the other two spacings.
Table 22. The influence of bedtype and spacing on 'Redchief' strawberry marketable weight: Harvest, 1983.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>raised</td>
<td>488.2a</td>
<td>1365.5</td>
<td>2076.9</td>
<td>2126.5</td>
<td>10807.0</td>
<td>16864.3</td>
</tr>
<tr>
<td>flat</td>
<td>231.2 b</td>
<td>1169.0</td>
<td>1816.7</td>
<td>2105.5</td>
<td>13470.9</td>
<td>18793.6</td>
</tr>
</tbody>
</table>

**RAISED**

<table>
<thead>
<tr>
<th>cm spacing</th>
<th>6/10</th>
<th>6/14</th>
<th>6/17</th>
<th>6/21</th>
<th>6/25</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 cm</td>
<td>726.5A</td>
<td>1897.2A</td>
<td>3025.8A</td>
<td>2775.7A</td>
<td>11413.9</td>
<td>19735.0</td>
</tr>
<tr>
<td>50+r</td>
<td>420.7 B</td>
<td>1108.0 B</td>
<td>1748.9 B</td>
<td>1839.0 B</td>
<td>11528.8</td>
<td>16645.5</td>
</tr>
<tr>
<td>50 cm</td>
<td>317.2 B</td>
<td>1091.5 B</td>
<td>1559.3 B</td>
<td>1765.1 B</td>
<td>9478.6</td>
<td>14211.7</td>
</tr>
</tbody>
</table>

**FLAT**

<table>
<thead>
<tr>
<th>cm spacing</th>
<th>6/10</th>
<th>6/14</th>
<th>6/17</th>
<th>6/21</th>
<th>6/25</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 cm</td>
<td>239.8</td>
<td>1184.4</td>
<td>2123.5</td>
<td>2050.0</td>
<td>14492.0</td>
<td>20099.9</td>
</tr>
<tr>
<td>50+r</td>
<td>235.3</td>
<td>1229.1</td>
<td>1748.9</td>
<td>1929.8</td>
<td>12759.3</td>
<td>17902.4</td>
</tr>
<tr>
<td>50 cm</td>
<td>218.4</td>
<td>1093.2</td>
<td>1578.3</td>
<td>2326.8</td>
<td>13161.4</td>
<td>18378.2</td>
</tr>
</tbody>
</table>

[^2]: means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

[^1]: cm spacings indicate distance in row between original plants. "50+r" indicates original plants planted at 50 cm with daughter plants placed at 13 cm.
Table 23. The influence of bedtype and spacing on 'Redchief' strawberry cull weight.

<table>
<thead>
<tr>
<th>bedtype</th>
<th>6/14</th>
<th>6/17</th>
<th>6/21</th>
<th>total</th>
</tr>
</thead>
<tbody>
<tr>
<td>raised</td>
<td>648.9</td>
<td>632.1</td>
<td>1020.1</td>
<td>2311.1</td>
</tr>
<tr>
<td>flat</td>
<td>561.4</td>
<td>822.2</td>
<td>1193.0</td>
<td>2576.6</td>
</tr>
</tbody>
</table>

**RAISED**

<table>
<thead>
<tr>
<th>cm</th>
<th>981.1A</th>
<th>847.3A</th>
<th>1333.3a</th>
<th>3161.7A</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50+r</td>
<td>477.5 B</td>
<td>643.6AB</td>
<td>774.3 b</td>
<td>1895.4 B</td>
</tr>
<tr>
<td>50 cm</td>
<td>518.1 B</td>
<td>446.9 B</td>
<td>952.9ab</td>
<td>1917.8 B</td>
</tr>
</tbody>
</table>

**FLAT**

<table>
<thead>
<tr>
<th>cm</th>
<th>516.7</th>
<th>844.2</th>
<th>1350.5</th>
<th>2711.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>13 cm</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50+r</td>
<td>559.3</td>
<td>829.7</td>
<td>1192.0</td>
<td>2595.1</td>
</tr>
<tr>
<td>50 cm</td>
<td>608.2</td>
<td>792.9</td>
<td>1022.7</td>
<td>2423.8</td>
</tr>
</tbody>
</table>

^z means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05).

^

cm spacings indicate distance in row between original plants. "50+r" indicates original plants planted at 50 cm with daughter plants placed at 13 cm.
Table 24. The influence of bedtype and spacing on 'Redchief' strawberry berry size and yield per plant (g).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>size (g/berry)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>6/10</td>
<td>6/14</td>
<td>6/17</td>
<td>average</td>
<td>g/plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>raised</td>
<td>7.51 B</td>
<td>5.75 B</td>
<td>6.59</td>
<td>6.61 B</td>
<td>386.6Z</td>
<td></td>
<td></td>
</tr>
<tr>
<td>flat</td>
<td>8.33A</td>
<td>6.63A</td>
<td>6.84</td>
<td>7.27A</td>
<td>460.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 cm</td>
<td>7.56</td>
<td>6.23</td>
<td>6.42 B</td>
<td>6.74</td>
<td>263.2 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50+r</td>
<td>8.18</td>
<td>6.22</td>
<td>6.46 B</td>
<td>6.95</td>
<td>218.3 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 cm</td>
<td>8.01</td>
<td>6.13</td>
<td>7.26A</td>
<td>7.13</td>
<td>789.5A</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\^ means in undivided columns separated by Tukey's New Studentized Range Test (upper case p(F)=.01, lower case p(F)=.05)

\^ cm spacings indicate distance in row between original plants. "50+r" indicates original plants planted at 50 cm with daughter plants placed at 13 cm.
4.2.3.3 Size

Fruit size was larger on plants grown on flat beds as compared to raised in 2 of 3 pickings (Table 24). Average size also followed this trend. In comparing spacings, the plants at 50 cm yielded large berries than those at 13 or 50 cm with runners on June 17.
Chapter V
DISCUSSION

The central findings of this research were the increased root depth and altered root distribution, and the earlier (Spring) increase in metabolic activity and yield of strawberry plants grown on raised as compared to flat beds. These responses were due to differences between the raised and flat bed plant's photosynthetically active radiation (PAR) interception, soil matric potential and/or soil temperature (Figure 29).

In Experiment II, the higher PAR penetration at 1/2 canopy height on the raised beds in April may have been due to a more open canopy in the raised bed, since leaf area was equivalent on the two bed types the previous October. A more open canopy offers the potential for higher photosynthetic rates, since more leaves are apt to be saturated with PAR. This more open leaf habit could be due to an alteration in root synthesized growth substances, or simply to the physical space available to the plant on the raised bed. If the increased light penetration increased the rate of photosynthesis significantly in the less PAR competitive raised beds, the increased early photosynthetic flow could be responsible for the earlier metabolic activity. The greater, lighter colored (drier) surface area of the raised bed could have reflected more PAR than the flat bed, contributing enough additional heat and diffuse radiation to further speed the plant's metabolic activity in the Spring.

- 92 -
Earlier solubilization of carbohydrates in Spring and earlier yield.

Lower leaf Ca concentration

More open leaf canopy in early Spring resulting in a higher percentage of PAR saturated leaves

Higher crown numbers/area at closer spacings

Larger lighter colored (drier) soil surface reflecting more diffuse PAR and heat

Higher soil matric potential

Higher percentage of roots in deeper (cooler) soil

-roots further from crown
- more growing tips?

Figure 29. The strawberry plant on raised beds as compared to flat beds.
In Experiment I, 'Bedchief' had higher PAR penetration at one location on raised beds as compared to flat, while 'Scott' had no differences due to bedtype. This evidence, coupled with the fact that only 'Bedchief' had higher PAR penetration at the 50 cm spacing supports the hypothesis that 'Scott' was a more vegetative plant, since it filled either bed completely enough to equalize light penetration between spacing and bedtype treatments.

The raised bed in Experiment II consistently registered higher matric potentials at 15, 30 and 45 cm depths. When differences in percent moisture were detected in the top 20 cm of soil, the higher moisture content was consistently in the flat beds. Matric potential data from Experiment I did not support this data, presumably due to the unusually wet season. Collins and Smith (1970) reported a soil moisture tension of 2.03 bars as being conducive to good strawberry root growth, however, the matric potential at which soil water is marginally deficient or excessive is unknown. The lack of moisture in the top layer of soil on the raised bed was substantial enough to impede daughter plant establishment, as evidenced by the runneled treatments' lower root mass in the surface 7.5 cm of soil, however soils at this depth were too dry to assess matric potential using tensiometers.

The difference in root distribution between the raised and flat bed plants suggests that the matric potential differences were biologically significant. Plants in the flat beds had 76, 21 and 3 percent of their total dry root mass in the 0-7.5, 7.5-15, and 15-22.5 cm depths, respectively. Those in the raised beds had 60, 29 and 10
percent at those same depths, indicating a deeper, more uniform root distribution on the raised bed as compared to the flat bed plants. This difference indicates a shift in the most favorable environment for root growth in the raised as compared to the flat beds. This favorable environment consists of having optimal moisture availability (according to the tensiometer data, between 20 and 40 centibars matric potential) and presumably some air-filled pore space for gas exchange.

Taylor and Ratliff (from Hsaio, 1973) found that root growth in peanut and cotton was not curtailed as much by increased matric potential as by increases in soil mechanical resistance. Water in the soil simply reduced soil strength, allowing root growth. This implies that the effects of the increased matric potential on the raised bed may not be as important to the plant's root growth as the reduction in soil compaction that the construction of the raised bed affords. It is not possible from the data from either experiment to determine whether water availability directly, or indirectly, by altering soil strength, is responsible for differences between plant root distribution on raised and flat beds.

Kinnanen and Sako (1979) established that drier conditions in August just prior to flower bud formation, elicited the highest number of flowers per plant the following year. The shift in root growth downward on the strawberry plants in raised beds in Experiment II may be the same phenomena that Kinnanen and Sako imposed when they stressed their plants; that is, the strawberry plants in raised beds may have been subject to a constant low level drought stress. Root growth generally reaches its highest
rate in the fall, which is also when flower buds are initiated (Darrow, 1966). Kinnanen and Sako's work, however, did not cite earlier flowering and/or yield as a consequence of drought stress.

Slatyer (1969) reported that both primordia initiation and cell enlargement was extremely sensitive to moderate water stress. However, while stress causes a rapid cessation in initiation and enlargement, development was renewed upon relief of the stress (provided that the stress had not been too severe). This renewed development often proceeds at a more rapid rate than in the controls, explaining the increased flower bud production in Kinnanen and Sako's work.

Hsaio (1973) defined levels of drought stress by the water potential of the plants' leaves. Mild stress is 8 or 10 percentage points below corresponding values in well-watered plants; moderate stress, 10-20 percentage points lower, and severe stress is more than 20 percentage points below the water potential of the well-watered plant. The reduction in leaf water potential is a product of osmoregulation, the plants' regulatory mechanism which allows it to increase the diffusion gradient between the soil solution and the plants' cells (Hellenkust, 1976). Breen et al. (1982) found that more negative leaf water potentials in strawberry did not correlate well to drought stress, though leaf elongation rate was an excellent indicator. This suggests that osmoregulation may not be as important to the strawberry plant's low level drought response as it is to most plants, exemplified by the apple tree in Drake, et al.'s work (1981). It has often been assumed that the strawberry plant's sensitivity to water
deficits and excesses was due to its shallow root system. The lack of correlation of leaf water potential to drought stress implies that the strawberry plant's osmoregulation response may account for this sensitivity.

When studying the influence of low level drought stress on apple, Drake, et al. (1981) found that trickle irrigated apple trees with soil moisture levels away from the emitter approaching permanent wilting percentage had earlier maturing apples and slightly more negative leaf water potentials throughout the season. The earlier maturity of the apples concurs with the results of Experiment II. However, root systems of the apple trees were not excavated, and the precise mechanism is a source of speculation. The trickle irrigated trees had a very saturated area around the emitter. In contrast, the strawberry raised bed had optimal water uptake conditions deeper in the soil. In both cases, there may have been a "containment" effect on the plant, brought about by the presence or absence of water in the soil. In addition, the surface area of the raised bed decreased throughout the season, progressing from 1000 cm squared/m to 690 cm squared/m (July) to 600 cm squared/m (September), further exaggerating the containment effect. This containment may have brought about more root branching, hence more sites of cytokinin production. Gess (in Feldman, 1984) found that 50 kPA of applied pressure on barley root tips resulted in more lateral roots per cm root as compared to nonimpeded roots. The strawberry root coming into contact with the drier soil of the periphery of the raised bed could have responded similarly, since matric potentials of that soil were most certainly equal to or greater than 50 kPA.
Cytokinins generally depress apical dominance, and exogenous applications result in wider crotch angles in apple (Williams and Billingsley, 1970). The increased cytokinin production in strawberry could reduce the apical dominance of the crown tip, thus forcing the leaves to have a wider angle, producing a plant with a more open canopy. The higher percentage of saturated leaves would result in higher rates of photosynthesis, hence a more rapid flow of photosynthates to the roots. This response would be magnified by the increased albedo on the raised bed, due to the increased surface area.

Soil temperatures interacted with matric potential in that soil temperatures decreased with soil depth, so that the favorable matric potential, combined with the cooler temperatures may have increased the root growth. Gannmore-Neumann and Kafkafi (1979) reported that as temperatures decreased between 32 and 10°C, root growth increased. The temperatures of the raised beds were not dramatically different from those on the flat beds. However, the raised bed temperatures were more extreme. This is probably a function of the greater water content of the soil in the flat bed, which exerts a moderating influence on the temperature. This increase in range of temperature in a given time frame may or may not be of consequence to the plant's growth and yield. Certainly, the plant on raised beds has greater potential to suffer cold injury by these larger fluctuations than a comparable plant on flat beds. In the winter, under dry, clear conditions the bed itself would also become warmer, since straw mulch does not remain on top of the beds, exposing the surface to more radiant energy. Convective heat loss
from the soil surrounding the plant on the bed is also more likely. Thus, the raised beds would be expected to have even greater temperature fluctuations under winter conditions.

Due to the method of temperature data collection (recorded daily at 8:00 am) the data does not reflect diurnal fluctuations in temperature. However, since fluctuations over days were greater on the raised beds, one can speculate that diurnal fluctuations may also be greater on raised beds that flat. It is the range of the diurnal temperature fluctuation that is often responsible for some physiological responses, such as cold injury. The June-bearing strawberry plant is thermoperiodic (Salisbury and Ross, 1978), specifically, it will set flowers during periods of cold night temperatures, indicating that the plant is physiologically responsive to temperature changes. It could be that plants responded earlier in the season to the wider temperature range, or simply that raised bed temperatures rose higher during the afternoon, when temperatures were not recorded.

Renguist et al. (1982a, 1982b) reported that strawberry beds under polyethylene mulch had higher temperatures and increased fruit numbers, but did not report earlier yields. This work implies that the earlier yield in Experiment II was not due to temperature increases alone.

Root excavation of apple trees (Golden delicious/M.9) has shown that trees at closer spacings develop a deeper root system, with more vertically oriented roots, and less spreading laterally (Atkinson, 1976), similar to the response of the strawberry plant on raised beds. This is, again, a containment effect. In the case of the apple
trees, the competition of the root systems of the adjacent plants force the roots to grow vertically to forage for water and nutrients. For the strawberry plant, the dry soil in the topmost layer of the raised bed served to contain the roots, so that growth occurs in the more favorable conditions deeper in the soil horizon.

It's possible that ethylene also plays a role in the plants' response to low level water stress. Torrey (1976) reported that the roots of a tomato mutant deficient in auxin-induced ethylene biosynthetic capacity failed to form lateral roots—a condition that was altered by foliar sprays with ethrel. Thus, for the tomato, the generation of more root tips requires ethylene.

The earlier yields on the raised beds were enhanced and extended when the plants were at the closest mother plant spacing. In contrast, the yield from plants on the flat beds was not influenced by spacing. This was directly related to the crown number per unit area. Plants on raised beds at 13 cm had higher crown numbers per unit area than the other two spacings. Because crown number is directly correlated with yield (Hancock et al., 1982), this increased crown number represents the potential for increased yields. The fact that the raised bed's effect on early yields was magnified by the closer spacing is due to one or both of the following:

1. There was a higher number of extension (mother) crowns, as opposed to branch crowns. The extension crowns initiate flowers earlier (Dana, 19__) and bloom earlier in the season (author's observation), thus shifting the raised bed plants' yield per unit area earlier.
2. The competition between the closer spaced plants was sufficient to further enhance the containment effect discussed earlier, resulting in more cytokinin production in the roots, wider leaf petiole angles, hence higher early photosynthetic rates, giving rise to earlier flowering and ripening.

Because there were more crowns on the raised bed plants at 13 cm than those at 50 cm, one would have expected greater total yields from this treatment, rather than only greater early yields. This discrepancy can be explained by the fact that the berries from the early raised bed yield were smaller, so that overall berry number was greater, but yield per unit area was the same. Thus, there was a potential for higher yields on the raised beds at closer spacings, but the plants did not transport adequate moisture through the xylem to enlarge all of the berries. This inability to enlarge the berries may have been due to a lack of available moisture or to the plant's inability to extract and transport enough water.

The smaller berry size on the raised bed further supports the notion of low level drought stress imposed on the raised bed plants, since berry size subsequent to initiation and pollination is heavily dependent on water (Darrow, 1966).

In both Experiments, on both cultivars, there was always a tendency for the plants at the 50 cm spacing to be larger, have more branch crowns, more fruit/plant and less fruit/area, however, these differences were often not statistically significant. In Experiment I, there was a high degree of variability, in part due to the lack of runner control, which may have masked many of the spacing
responses. Plant populations as reflected by leaf area in the two spacing treatments were very similar on both cultivars, explaining the lack of detectable physiological response to spacing on many of the estimated parameters.

Tree fruit literature indicates that closer tree spacings result in a lower yield/tree but a higher yield/unit area (Westwood, 1978). While yields/plant in both experiments were higher at the wider spacings, total yield was not different between spacings. This is due to the fact that the plants at 13 cm spacings were dense enough to compensate for the reduction in per plant yield on a per area basis, but not dense enough to increase total yield/area. The fact that average fruit size did not differ from spacing to spacing further supports this contention. Hancock, et al. (1982) reported that most of the twelve cultivars (including 'Redchief') had higher per hectare yields at closer spacings, however, the closest spacing tested was 30 cm. From this data and the data from Experiment II, it can be concluded that the optimal spacing for maximum 'Redchief' yields/hectare is more than 13 cm and less than or equal to 30 cm.

Experiment I was characterized by unusually severe climatic conditions (both heavy spring rains and an exceptionally cold winter in 1981), a soil which had water more readily available per unit moisture above 20 kPa pressure and no runner control. In contrast to Experiment II which was conducted under near optimal weather conditions with runners rigidly controlled. Many, if not all of the inequities between the results of the two experiments can be explained by these differences. Tensiometer data from Experiment I indicated little matric
potential difference between the raised and the flat bed, while the data from Experiment II indicated that the soil in the raised bed had a much higher matric potential than that of the flat at 15, 30 and 45 cm depths. This factor alone could well account for the many disparities between the results of the two experiments. Because Experiment I had only 3 replications and many treatments which interacted with one another, it was difficult to interpret the results. Future research should have more replications and/or fewer treatments.

The fact that 'Scott' and 'Bedchief' responded differently to all treatments in Experiment I was not surprising, since strawberry variability from clone to clone is well documented (Hancock, et al., 1984; Hancock, 1983; Breen and Martin, 1981; Allreghs and Howard, 1980).

The trickle/nitrogen treatments in Experiment I generally had very little effect on any of the measurements analyzed. Though the strawberry has been described as being "sensitive" to nitrogen (Waltham, 1951), van Eysinga and van Caem (1977) reported no yield differences in 'Ostara' strawberry plants when nitrogen fertilizer was increased from 0 to 5 kg/100 m squared, even when plants at the lowest level showed deficiency symptoms.

Boyce and Matlock (1966) reported on strawberry that

The literature dealing with responses to N is generally contradictory. Some investigators have reported increased yields with N applications, others no significant increases, while others have reported decreased yields. One investigator has reported conflicting results on the same well replicated plots. This serves to indicate that the N nutrition of the strawberry is complicated and governed by many other factors.
Roberts and Kenworthy (1956) noted that increasing nitrogen above the amount available in a .05 Hoagland nutrient solution had no significant effect on top growth of strawberry at temperatures of 55 F or below.

Ereen and Martin (1981) reported that for 'Hood' and 'Benton', nitrogen rates above 3.6 g/liter media were ineffective in eliciting any plant response. While this level is difficult to compare to the 46.7 ppm aqueous solution in the highest trickle/nitrogen treatment, it does establish that there is a level above which two strawberry cultivars cease to respond. Breen and Martin were, however, able to continually increase leaf nitrogen with increasing rates of root supplied nitrogen from 0.3 to 4.8 g nitrogen/liter media.

Because leaf nitrogen levels were not affected by the increasing N rates, it is most likely that the lack of response to the trickle/nitrogen treatments was due to the unusually wet growing seasons of 1980 and 1981. Under these very wet conditions, much of the nitrogen could have been leached, or undergone ammonification.

In Experiment II, 'Redchief' grown on raised beds had higher leaf K and lower leaf Ca concentrations than plants on flat beds. In Spring, 1981, 'Redchief' root fresh weight was also higher on raised bed plants, giving it a larger root surface area with which to forage for K, assuming moisture and nutrient levels were adequate. The lower Ca in raised bed plant leaves was consistent through both experiments and all three years. Since Ca is moved largely by mass flow through the plant (Mengel and Kirkby, 1979, Hsiao, 1973), the difference is probably due to more
drying out of the raised beds, resulting in less transpiration of the plant. Even mild water stress directly effects the rate of water transport through the plant (Slatyer, 1969). The fact that the tensiometers in Experiment I showed no difference between raised and flat bed matric potentials conflict with this hypothesis, while the increased matric potentials on raised beds in Experiment II support it. In Experiment I, there may have been differences in the matric potential between less than 0 and 10 centibars where the tensiometer is less reliable. Zero on the tensiometer should represent field capacity, however soils were often moist beyond field capacity, approaching saturation. The raised beds probably dried out more, due to a greater exposed surface area than the flat beds. Matric potential was recorded in early morning when potentials would be expected to be at their lowest level. There may have been more drying out in the afternoon on the raised beds, which was equalized by water movement from deeper soil during the night. This would also account for the greater root mass and different yield responses of plants on raised and flat beds in Experiment I.

Calcium is an important nutrient involved in cell wall integrity, particularly important with respect to fruit quality. There was no indication, however, that the difference in calcium between raised and flat bed plants had any effect on fruit quality as reflected by the cull weight data. While cull weight is somewhat indicative of the fruit's membrane integrity, it is not a conclusive measure of fruit quality. Specific fruit quality tests were not conducted.
In Experiment I, leaves had higher P concentrations on raised beds. Phosphorus availability in the soil, and subsequent translocation to the leaves is limited by the rate at which it is released from the soil colloid to the soil solution to maintain an equilibrium (Mengel and Kirkby, 1979). The site at Experiment II had abundant P reserves compared to the site at Experiment I (638 compared to 160 kg/ha), so that the raised bed plant, with a higher root:crop ratio had more soil surface area/leaf area available to it for foraging P, resulting in a higher leaf P concentration. In Experiment I, however, leaf P concentration was equivalent in plants on both bed types, since P was in abundant supply.

In the second year of Experiment I, both 'Redchief' and 'Scott' plants had lower leaf N concentrations on raised as compared to flat beds. The rainy seasons may have played a role in this, since the water probably drained more completely from the more porous root zone of the raised bed plants, carrying the soluble nitrogen with it, whereas water would not drain as rapidly from the flat bed, leaving some nitrogen in the flat bed plant's root zone.

Internal drainage, that is, the amount of water which exits via gravity from the soil porespace is difficult, if not impossible to measure in a field experiment. One assumes that a relationship exists between the soil matric potential and drainage, however water lost by evaporation may be more substantial given the larger surface area of the raised bed. Conservatively calculated, every meter of row in the raised bed in Experiment II had 10,000 square centimeters of surface area compared with 8000 in the flat bed. Though the raised bed did deteriorate over time, its
surface area was consistently between 19 and 20 percent greater than that of the flat, assuming the same bed width. The fact that the matric potentials as deep as 45 cm were higher on raised beds in Experiment II would also indicate that evaporation, not drainage, was responsible for a large portion of the soil water reduction on raised beds.

There were some differences in Experiment I in the leaf micronutrient concentration data, particularly in the form of trickle/nitrogen/bedtype interactions. The data has been presented in the previous chapter, however very little is known about the response of strawberry plants to, for example, copper. Literature pertaining to micronutrient responses of strawberries growth in the field are extremely limited, and micronutrient deficiencies are seldom a problem in growing strawberries in the East and Midwest. For these reasons, the discussion will not delve further into the micronutrient data, which is documented in the "Results" and "Appendix" portions of this dissertation.

Overall, 'Scott' did not have the differences in leaf nutrient concentrations that 'Redchief' displayed. The 'Scott' plants tended to be more vigorous and vegetative, and the root system responded to the raised bed by increasing in mass. It is concluded from this that 'Scott' is able to compensate vegetatively to alterations in the root environment more readily than 'Redchief'. This may be done, however, at the expense of the reproductive responses, since 'Scott' also had lower yields on raised as compared to flat beds.

In Experiment I, 'Redchief' yields were not influenced by bedtype, while 'Scott' had lower overall yields on
raised beds compared to flat. 'Scott' also had a larger root and total plant dry weight on raised beds as compared to flat. In addition, while the difference was not statistically significant, 'Scott' plant's root:crown ratio was substantially larger on raised beds. Again, this suggests that the plants on raised beds partitioned the resources available to them into vegetation, particularly root mass, while those on flat beds had relatively more resources partitioned into fruit. It also may be extrapolated that very vigorous strawberry cultivars such as 'Scott' may not respond to raised beds by yielding higher. This hypothesis is further supported by the fact that the strawberry plants in California and Florida which yield so well on raised beds are not very vigorous cultivars (e.g. 'Tufts', 'Douglas').

The shift in the root:crown ratio in 'Scott' indicates that the genetic makeup of 'Scott' is such that the roots become a stronger sink than shoots or fruit for resources on raised bed conditions. The cause of this shift in Experiment I may have been due to less saturated conditions on the raised bed, as discussed earlier. However, the differences between plants on raised and flat beds may have been due to a low level cold injury to plants on raised beds. Boyce and Reed (1982) have reported lower crown temperatures and more injury on strawberry plants on raised or unmulched beds. 'Scott' relative to 'Bedchief', is untested concerning cold sensitivity. Because winter injury was not assessed in Experiment I, it is only speculation that the 'Scott' plants may have suffered more cold injury on the raised as compared to the flat bed.
Chapter VI
SUMMARY AND CONCLUDING REMARKS

6.1 EXPERIMENT I

1. There were no differences detected in soil matric potential between raised and flat beds at 15, 30 or 45 cm depths.
2. Soil temperature at the 10 cm depth was slightly warmer on raised as compared to flat beds.

6.1.1 Bedchief

1. PAR penetration was higher on raised beds and at 50 cm spacings.
2. In 1980, leaf P concentration was higher and leaf Ca concentration lower in plants on raised as compared to flat beds.
3. In 1981, leaf N and leaf Ca concentrations were lower in raised as compared to flat bed plants.
4. Leaf area (1981) was higher on raised bed plants at 13 cm as compared to 50 cm spacings.
5. Plant root fresh weight was higher on plants from raised as compared to flat beds.
6. In 1981, berry size was larger on raised bed plants.
7. In 1981, there was a higher yield/unit area from plants at 13 as compared to 50 cm mother plant spacings.
8. In 1982, plants at 13 cm yielded higher per unit area than those at 50 cm spacings.

- 109 -
6.1.2 Scott

1. There were no differences in PAR penetration for plants at either bedtype or at either mother plant spacing.

2. In 1980 (planting year) plants receiving trickle irrigation and no nitrogen had lower Mg and B on raised beds as compared to those on flat beds.

3. In 1981 plants at 50 cm had higher leaf K concentration than those at 13 cm mother plant spacings.

4. Leaf area (1981 and 1982) was equivalent between bedtypes and spacings.

5. Root and crown dry weight was greater on plants at 50 cm as compared to 13 cm spacings.

6. In 1981, yield/unit area was less, and berry size greater on plants grown on raised as compared to flat beds.

6.2 Experiment II

1. Matric potential was higher at 15, 30 and 45 cm depths on raised as compared to flat beds.

2. Soil temperature at 15 cm fluctuated more on raised as compared to flat beds.

3. Plants on raised beds had higher PAR penetration than those on flat beds.

4. Plants at 50 cm had higher PAR penetration than those at 13 cm spacings.

5. Plants had higher K and lower Ca on raised as compared to flat beds.

6. Plants in the runnered treatment had more roots in the top 7.5 cm of soil on raised beds as compared to those on flat beds.
7. There were more roots in the 15.0-22.5 cm depth on plants from raised as compared to flat beds.

8. The plants on raised beds had a more uniform root distribution through the 3 layers of soil excavated (0-7.5, 7.5-15.0 and 15.0-22.5 cm) compared to those on flat beds.

9. Raised bed plants yielded higher earlier in the season than those on flat beds.

10. Close plant spacing (13 cm) extended the raised bed plants' higher early yield, while spacing had no effect on the flat beds yield.

11. Yield/plant was highest on plants at 50 cm as compared to plants at 13 cm or 50 cm plus runners.

12. Berry size was smaller from plants on the raised as compared to the flat beds.

Concluding Remarks.

On the silt loam soils on which these two experiments were conducted, raised bed systems did not substantially improve 'Scott' or 'Bedchief' overall yields in 1980-1983. Early yields of 'Redchief' were increased in Experiment II as a result of altered PAE interception, soil matric potential and/or soil temperature. These systems are not presently recommended for commercial use under the conditions tested. There is a potential for higher overall yields with 'Redchief' at 13 cm spacings on raised beds, evidenced by the increased number of small fruit, and higher crown number per unit area. However, the problem of manipulating the irrigation on raised beds to obtain the
deeper rooted plant and enough moisture just prior to harvest for berry enlargement needs to be addressed. Further, more research is necessary to determine water use, cold injury and plant stress responses before raised bed systems can be advocated for strawberry production in the East and mid-West.

**AREAS FOR FUTURE RESEARCH**

1. Strawberry genotypic and phenotypic interactions with the environment
2. Chronic low-level water stress response in strawberry
3. Factors influencing earliness of yield in strawberry.
### Appendix A
#### REGRESSION SUMMARIES, EXPERIMENT I

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(root and crown mass, branch crown #: granular)

| Redchief  | raised  | 50           | br. crn.# | .67       | .03         |

(injected)

| Redchief  | raised  | 50           | rt. fw    | .56       | .03         |
| Redchief  | raised  | 50           | rt dw     | .56       | .02         |
| Redchief  | raised  | 50           | br. crn.# | .62       | .01         |
| Redchief  | raised  | 50           | fr. r:c   | .42       | .08         |
| Redchief  | raised  | 50           | tot fw    | .54       | .03         |
| Redchief  | raised  | 50           | tot dw    | .51       | .04         |

(yield, 1981: granular)

| Redchief  | raised  | 50           | 2nd har   | .67       | .003        |
| Scott     | raised  | 13           | cull wt   | .56       | .005        |
| Scott     | flat    | 50           | cull wt   | .29       | .07         |
| Scott     | flat    | 50           | size 1    | .58       | .03         |
| Redchief  | raised  | 50           | size 2    | .32       | .05         |

(injected)

| Redchief  | raised  | 50           | 3rd har   | .72       | .003        |
| Scott     | raised  | 13           | cull wt   | .56       | .005        |
| Scott     | flat    | 50           | cull wt   | .29       | .07         |
| Scott     | flat    | 50           | size 1    | .58       | .03         |
| Redchief  | raised  | 50           | size 2    | .32       | .05         |
Appendix A (cont'd)

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(yield, 1982: granular)

Note: for parameters estimated, "fw"=fresh weight, "dw"=dry weight, "har"=harvest, "size 4"=berry size, 4th harvest.
Appendix A (cont'd)

Regression relationships between granular nitrogen treatments and leaf analysis statistics:
2nd growing season, 1981.
Appendix A (cont'd)

Redchief/raised/13 cm

\[ y = 110.99 - 83.11x + 106.84x^2 \]

\[ r^2 = .52, \ p(F) = .04 \]

Redchief/raised/13 cm

\[ y = 4.96 + 4.79x - 3.67x^2 \]

\[ r^2 = .55, \ p(F) = .04 \]

Redchief/raised/13 cm

\[ y = 19.84 + 10.83x - 7.48x^2 \]

\[ r^2 = .52, \ p(F) = .04 \]

(cont'd)
Regression relationships between injected trickle/nitrogen treatments and leaf analysis statistics: 1st growing season, 1980.
Appendix A (cont'd)

Regression relationships between granular nitrogen treatments and yield statistics: 1st harvest, 1981.
Appendix A (cont'd)

Regression relationships between granular nitrogen treatments and leaf analysis statistics: 1st growing season, 1980.
Regression relationships between injected trickle/nitrogen treatments and yield statistics: 2nd harvest, 1982.
Regression relationships between injected trickle/nitrogen treatments and yield statistics: 1st harvest, 1981.
Regression relationships between injected trickle/nitrogen treatments and plant mass statistics: 2nd growing season (spring), 1981.
Regression relationships between granular nitrogen treatments and yield statistics: 2nd harvest, 1982.

\[
y = 1821.5 - 1654.6x \\
\text{r}^2 = .86, \ p(F) = .02
\]
Regression relationships between injected trickle/nitrogen treatments and leaf analysis statistics: 1st growing season, 1981.

Scott/flat/13 cm

\[ y = 2.53 - 0.23x \]
\[ r^2 = 0.33, \ p(F) = 0.05 \]

Nitrogen rate

Redchief/raised/13 cm

\[ y = 2.39 - 0.23x \]
\[ r^2 = 0.33, \ p(F) = 0.05 \]

Nitrogen rate
Appendix A (cont'd)

Regression relationships between injected trickle/nitrogen treatments and yield statistics: 2nd harvest, 1982.
## Appendix B
### Weather Data, Experiment I

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- 128 -
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## Appendix C

### PESTICIDE SCHEDULE, EXPERIMENT I

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*Rates listed on a per Acre basis.*

*GA=ground application, IR=through overhead irrigation, S=by field sprayer.*
### Appendix C. (cont'd)

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The influence of trickle irrigation, nitrogen rate and bedtype on 'Scott' dry weight root:crown ratio,
The influence of trickle irrigation, nitrogen rate and bedtype on 'Scott' leaf zinc concentration.
The influence of trickle irrigation, nitrogen rate and bedtype on leaf copper concentration of 'Redchief' strawberry.
### Appendix E

#### Weather Data, Experiment II

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- 136 -
## Temperature and Precipitation

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### Appendix F

**PESTICIDE SCHEDULE, EXPERIMENT II**

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\(^2\)unless otherwise state, rates are in lbs/A.
Appendix F (cont'd)

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The influence of bedtype and spacing on root dry weight (level A: 0-7.5 cm) of 'Redchief' strawberry plants.
The influence of bedtype and spacing on root dry weight (level B: 7.5-15 cm) of 'Redchief' strawberry plants.
The influence of bedtype and spacing on marketable yield (6/10) of 'Redchief' strawberry plants.
The influence of bedtype and spacing on marketable yield (6/14) of 'Redchief' strawberry plants.
The influence of bedtype and spacing on marketable yield (6/21) of 'Redchief' strawberry.
The influence of bedtype and spacing on total marketable weight of 'Redchief' strawberry plants.
The influence of bedtype and spacing on total cull weight of 'Redchief' strawberry plants.
LITERATURE CITED


