EFFECT OF NITROGEN AND CANE DENSITY ON CANE ARCHITECTURE, FRUIT AND FRUIT YIELD COMPONENTS IN PRIMOCANE BEARING RED RASPBERRIES

by

Joseph Ngwela Wolukau

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DEDICATION

To my grand parents Rosa Nakhumicha and the late Maruti whose love for me saw me through high school, to the late Nasilalas who I never had a chance to know, to my parents and mother-in-law (Mrs Apiri) for their unselfish support. To my very wonderful family for all the caring they showed.

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List of Abbreviations

C	Celsius
C.V.	Coeficient of variation
cm	Centimeter
diam.	Diameter
f.	Fruits
g	grams
ha	Hectare
kg	kilograms
lab	Laboratory
lat.	Laterals
LSD	Least significant difference
m	Meter
mequiv	Milli-equivalent
mm	Millimeters
No.	Number
N	Nitrogen
P	Probability
perc.	Percentage
repr.	Reproductive
SAS	Statistical analysis systems
s.e.	Standard error
St.	Saint
tot.	Total
wt.	Weight

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Abstract

Effect of nitrogen and cane density on cane architecture, fruit and fruit yield components in primocane bearing red raspberries.

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Nitrogen fertilization and cane density management are the most critical factors in the commercial production of red raspberries. In general, little is known about these factors in relation to primocane bearing red raspberries and their effect on fruit yield. In two separate experiments, four levels of nitrogen and four levels of cane density were investigated on 2 primocane bearing red raspberries, Rubus strigosus, selections '8008' and '8114', respectively. The experiments were conducted at three sites in Manitoba: a clay soil at St. Adolphe, a clay-loam soil at Morden, and a sandy soil at Souris. In the second year of the study (1991), only the latter two sites were used. A nitrogen response experiment was repeated in a soilless medium in a green house in 1991.

Parameters investigated included number of flowers per lateral and per cane, fruit set, fruit yield (per cane and per plot), number of fruits per lateral, fruit size, fruit dry weight, cane height, cane diameter, number of nodes per cane, internode lengths, number of laterals per cane, length of laterals and lateral branch angle. High nitrogen and low cane density had similar effects on fruit yield components: canes were larger in diameter, and the canes had more laterals which were progressively longer towards the bottom of the cane. At high cane density the relationship of lateral length from the tip to the bottom of the cane was curvilinear. The lateral branch angle increased with cane density. Similarly, both high nitrogen and low cane density increased the number of laterals and the proportion of cane that fruited. High nitrogen increased cane height while low cane density decreased cane height. Nitrogen and low cane density increased the number of fruits per lateral and per cane, fruit size and fruit yield per cane. Nitrogen increased the overall fruit yield by as much as 3 times on the sandy soils but had less effect on clay-loam soils. In the cane density study, although overall fruit yield increased with increasing cane density, the increases were not significant due to the greater productivity of individual canes at low cane density. The increase in overall fruit yield stabilised at high cane density and there was a tendency for it to decrease after an optimum number of canes per meter row was reached. The application of nitrogen increased fruit yields significantly.

It can be concluded that nitrogen fertilization and cane density management could improve yield component performance and the yield potential of primocane bearing red raspberries.

1. INTRODUCTION

Red raspberries are grown widely in Northern temperate climates. Red raspberries are popular for fresh fruit in desserts, processed by freezing for retail markets, and processed into purees, preserves, jellies, concentrates, juices, yoghurt and recently into table wine. Fresh fruit sales are limited to u-pick and local markets. As packaging and freighting become more efficient, there is increasing interest in shipping to distant fresh market sale points.

Red raspberries provide a range of nutrients. One hundred and twenty three (123) grams of red raspberries provide 50 % of vitamin C daily intake requirement, 10 % of iron requirements and 70 calories. Other nutrients include proteins, calcium, phosphorus, sodium, potassium, magnesium, vitamin A, thiamine, riboflavin and niacin.

Nitrogen and cane density management are the most critical factors in the commercial production of red raspberries. There are numerous studies on fertilization and cane density management of summer bearing red raspberries in other areas. Commercial production in Manitoba uses cultural practices adapted from elsewhere, practices that are not standardised and their effects on fruit yield and yield components may not be clearly understood. The best package of standardised cultural practices would be those established under natural pedogenetic and microclimatic conditions of Manitoba.

Primocane bearing selections have become available in Manitoba lately through the work of Dr. C. Davidson of Agriculture Canada Research Station, Morden. Selections '8114' and '8008' have been tested for performance and are due for release in Southern Manitoba. Studies to examine cultural factors and close attention to details of husbandry and management of such selections are essential in efforts to improve the efficiency of fruit production. It is also important to adapt management methods at economic costs, although this was beyond the scope of the present study. Research on summer rearing red raspberries in other locations has shown that varying cane density and nitrogen fertilizer affects fruit and fruit yield components. In general, little is known about primocane bearing red raspberries especially in terms of fertilization and cane management and their effect on fruit yield. Nothing is known about such factors in Manitoba and no studies on cane density and nitrogen fertilizer requirements have been carried out on selections '8114' and '8008'.

The objectives of the present study were:

(i) to determine the effect of various cane densities on cane architecture, fruit yield and fruit yield components of primocane bearing red raspberries,

(ii) to elucidate the effect of various nitrogen fertilizer levels on fruit yield and fruit yield components of primocane bearing red raspberries, and

(iii) to establish guidelines on site specific nitrogen requirements for primocane bearing red raspberries.

2. LITERATURE REVIEW

2.0. Distribution and Commercial Production

There are well over **200** species of red raspberries (Jennings, 1988). Several of these species have been domesticated especially in Europe, Asia and North America. The species occur on all five continents but are more diverse in temperate and subtropical regions of the northern hemisphere. They are well distributed in all temperate regions of Europe, Asia and North America.

In Canada, the most intensive commercial production red raspberry occurs in British Columbia. Limited production also occurs in Ontario and Quebec. Manitoba has a small but expanding acreage (200 acres) of red raspberries most of which are summer bearing cultivars such as 'Boyne', 'Latham', 'Killarney', 'Chief', 'Wyoming'. The expansion in acreage is related to the growing interest in fresh fruit.

Currently most of the raspberries produced in Manitoba are marketed through the u-pick system where consumers go to the farm, pick fruit and pay the grower by volume. Some fruit finds its way to grocery stores, food processors and some growers process their own fruit (Rigby, 1991).

2.1. Red Raspberry Biology

Red raspberries belong to the Rosaceae family, genus Rubus and subgenus Idaebatus. Their origin is believed to be Mt. Ida in Greece or Mt. Ide in Turkey (Jennings, 1988). Cultivated red raspberries belong to two types, groups, species or subspecies: Rubus idaeus, believed to be native to Europe and R. strigosus, native to North America (Jennings, 1988; Scheer, 1988). The two groups intercross readily (Jennings, 1988) and their hybrids are fertile.

Red raspberry plants have perennial root systems but the canes or stems are biennial in that they live only for two years (Jennings and McCregor, 1989; Crandall and Daubeny, 1990). A cane is defined as an erect shoot or stem developing from root or basal stem buds of 2 year old growth. A plant may be made up of single or many canes. Canes are erect, spiny or spineless.

New canes are produced each spring from buds on underground roots or on the base of the cane (Crandall and Daubeny 1990; Williams, 1959b). In young plantations, many canes originate from root buds but as the plantation matures, they are less confined to the root buds, more of them develop from basal buds of canes. Shoots from root buds begin growth in late summer. Additional shoots arise from basal buds of other canes in the spring when growth begins.

Leaves are trifoliate, ovate and deciduous (Scheer, 1988). The fruit is aggregate, made up of drupelets that vary in number depending on cultivar and growing conditions. The fruit separates from the receptacle when mature - this characteristic identifies the species from the rest in the genus (Jennings, 1988).

Flowers and fruit may be produced on first year canes termed primocanes or on canes in the second year termed floricanes. Plants which bear fruit on canes in the second year are called June, summer or floricane bearing raspberries. The biennial canes which grow vegetatively in the first season (Jennings and McCregor, 1989), go dormant in winter because of short days and low temperatures (Jennings and Dale, 1982; Williams, 1959a). Following winter chilling, some axillary buds on canes (now called floricanes) grow out in the spring to produce lateral shoots which may or may not bear summer ripening fruit in the second season of growth. Up to 71 % of the axillary buds have been reported to grow into lateral shoots, the rest fail to grow out. Canes may also continue elongation from terminal buds in early spring if the buds have not been winter killed (Williams, 1959b). Floricanes die to the base after cropping. Floricane bearing red raspberries initiate flowers in response to short days at low temperatures. The overwintering canes are vulnerable to low winter temperatures.

Red raspberries which bear fruit on first year canes are termed primocane bearing. They are also called fall, tip or ever-bearing (Jennings, 1988; Jennings and McCregor, 1989; Keep, 1961; 1988; Knight, 1987; Lawrence, 1980a and b). They are morphologically similar to those bearing fruit on floricanes except that the growth habit differs: the primocanes mature each year, producing fruit bearing laterals during the first season. It has been suggested that genetic factors which determine the number of fruit bearing laterals differ from those for floricane fruiting (Jennings and McCregor, 1989; Keep, 1961). Generally, primocane bearers only produce flowers and fruit on upper portions of current season canes (primocanes). The fruit ripens in late summer or fall. Buds on the lower portion of the canes may remain dormant to produce a spring crop of fruit if canes are retained until the following spring (double cropping) (Lawrence, 1980b). The part of the cane that bears fruit dies. The proportion of a cane that fruits in the first season depends on a number of factors such as cultivar, cultural practices and environmental conditions (Dale, 1990; Jennings, 1988). In contrast to floricane bearers, primocane bearing red raspberries are photoperiod and temperature neutral (Keep, 1961) although flowering can be precociously induced experimentally by low temperature treatment (Vasilakakis et al., 1980). Nevertheless, flower induction in primocane bearing raspberries is not considered to be temperature dependent.

2.2. Economics of Primocane Bearing Red Raspberries

Interest in primocane bearing red raspberries has arisen lately because of a number of factors:

The fruit is produced outside the normal season (Crandall and Daubeny, 1990; Steers, 1985 cited in Keep, 1988). Fruit of primocane bearers ripens late in summer or in fall when strawberry and June bearers are already off-season. For example cultivar 'Heritage', a primocane bearer, has been shown to bear fruit for two months beyond the normal season in the Pacific north west (Braun et el., 1984b; Hoover et al., 1988).

Reduced maintenance and management costs (Crandall and Daubeny, 1990; Lawrence, 1980a; Lockshin and Elfving, 1981). Most primocane bearers have self-supporting canes and therefore do not need expensive supporting structures such as trellises and other training systems commonly used with floricane bearing types in many locations. In addition, the spent canes are cut down (mowed) at the end of each cropping season and therefore the tedious labour intensive process of identifying, separating and pruning spent canes in the fall or spring as in June bearing types does not arise. The potential for mechanised cultural practices such as pruning back spent canes and fruit harvesting are practicable (Lawrence, 1980b; Ourecky, 1976). Because there are only the spent canes at the end of the cropping (single) season, they can be cut down in one single operation mechanically. This is not possible with June bearers since at the end of any one season, there is always a mixture of canes: spent canes and primocanes. Similarly primocane bearing raspberries are also suited for mechanised fruit harvesting. This feature may also be attractive for u-pick customers since they don't have to contend with spiny primocanes.

Avoidance of winter injury (Crandall and Daubeny,1990; Hoover et al., 1988; Ourecky, 1976). Because all canes are cut back at the end of each cropping season the hazards of sub-zero winter temperatures are avoided. In contrast, primocanes of June bearers overwinter and they often suffer winter injury.

There is no conveyance of disease and pests from canes of one season to the next season as occurs in biennial canes (Keep, 1988; Lawrence, 1980a). Moreover some pest and disease pathogen inoculum cycles overwinter in standing canes.

Low temperature may not be a requirement for flower bud initiation in some primocane bearing cultivars (Vasilakakis et al., 1980). This phenomenon can be a great asset when considering raspberries for southern and tropical climates which don't have sufficient chilling hours required for june bearers.

Despite the advantages, fall bearing cultivars also have some problems. The current cultivars available do not yield as well as the summer/June bearing cultivars (Keep, 1988); in many cases, not all mature fruit is recovered before freeze up and full yield potential of primocane bearing cultivars is rarely realised. For example, the cultivar 'Heritage' is the most popular and most successful primocane bearing red raspberry (Braun and Garth, 1986; Hoover et al., 1988; Luby et al., 1987). However, 'Heritage' flowers late and fruit loss due to early fall freeze up is inevitable (Hoover et al., 1988).

2.3. Cane Management Techniques

There are several aspects of raspberry culture which could be defined as pertaining to cane management:

Row spacing. Row spacing defines the distance from one row to another. Over a five year period, Waister et al. (1980) obtained the highest fruit yields per meter row from a 90 cm row spacing. In earlier studies, Wood (1960) and Wood et al. (1961) had reported similar results. They also tested inter-stool spacing and found that the effect of inter-row spacing on overall fruit yield exceeded that of inter-stool spacing. Raspberry plantations can be maintained on stool basis (Wood, 1960; 1976; Wood et al., 1961) or as a hedgerow. In the stool system of management, new canes are restricted to a limited area around the original plant while in the hedgerow system of management, canes are allowed to grow out and fill the entire row.

Row width. Row width determines the extend that new canes are allowed to grow into the alleys from either stools or hedgerows. Row width will affect many cultural operations such as disease control, pruning, fruit harvesting (Mason, 1981). Ellis et al. (1982) found that as row width increased, spray deposition into the row centres decreased and canker length per cane increased significantly. However, total yield per meter row was greater (25 % more) for the 137 cm row width than for either 91 or 46 cm row widths.

Cane tipping height. In floricane bearing raspberries dormant canes are generally pruned to a height of 1.6 m (tipping height) above ground in the fall or spring before growth resumes. Many workers (Crandall, 1980; Crandall et al., 1974a; De Gomez et al., 1986; Martin et al., 1980; Waister et al., 1980) have shown that cane tipping height influences yield components and fruit yield. High topping (tipping) increases fruit yield over lower topping but the higher topping limits hand harvesting (Crandall, 1980). Odyvin (1986) obtained highest yields at 1.8 m tipping, but most pickers could not reach this height.

Training and trellising systems. Apart from the newer primocane bearing raspberry cultivars, the conventional raspberry cultivars usually require some form of training. Training systems are designed to maximise the capture of photosynthetic energy and support structures or trellises keep the canes from lodging. Systems of training and trellising vary from region to region. Odyvin (1986) has described the 'Gjerde' method for training raspberries in Norway. He reports that this method gives higher fruit yields than previous methods tried. A similar system has been described by Crandall (1980) of weaving canes on a cross-arm trellis with two top wires. The system allows canes to be left in the farm longer and increases yields. However, with this system, fruit size is reduced, berries are crumbly and fruits are more susceptible to rot. No explanation is given for these observations. Similar training and trellising systems with slight variations and their effects on performance of raspberries have been discussed (Martin, 1985; Martin and Nelson, 1987; Nehrbas and Pritts, 1988b; Palmer 1987).

Primocane suppression. Control of first year growth or primocane suppression has received considerable attention. As indicated earlier, there are both primocanes and floricanes after the first year of growth in June bearing raspberries. The techniques of primocane suppression check the vigour or rate of growth of the primocanes (first year growth). Primocane vigour control is done either mechanically or chemically. Control is done repeatedly until some time after fruiting when some primocanes are allowed to develop fully to become the following season's floricanes. Primocane control has been shown repeatedly to increase fruit yield significantly (Freeman and Daubeny, 1986; Freeman et al., 1989; Lawson, 1980). The timing of suppression is critical and it has been found that the optimum time for suppressing canes is when they reach 10 to 20 cm. Up to 70 % yield increase has been reported with cane vigour control practices (Crandall et al., 1980). Increased yields are due to increased fruit numbers, fruit size and cropping nodes per cane in the absence of competition from primocanes. Similar observations have been made by other workers (Brierley, 1934; Crandall et al., 1980; Lawson and Wiseman, 1983; Nehrbas and Pritts, 1988a; Norton, 1980; Waister et al., 1977; Williamson et al., 1979).

Cropping system. June bearing raspberries can be cropped either annually or biennially. Cropping systems are designed to increase fruit yields. Lawson and Wiseman (1983) showed that resting plots in alternate years (biennial cropping) gave higher cumulative yield (31 % greater) than the annually cropped plots. Biennial cropping is accomplished by complete suppression of all primocanes in the cropping year. After mowing spent floricanes in the fall, a new crop of primocanes is allowed to grow the following year. Biennial cropping has also been shown to prolong the potential life of the plantation. These observations are supported by Cormack and Waister (1989), Waister et al. (1980) and Wright and Waister (1984) who reported more canes, increased number of cropping nodes and increased fruit size under biennial cropping systems. Wright and Waister (1984) went further and explained that yields in annual systems were lower because of heavy self or mutual shading which leads to reduction in actual yield compared to the potential yield indicated by flower numbers. Loss of potential yield may also result from leaf loss on lower fruiting laterals caused by primocane shading. Nehrbas and Pritts (1988a) have also reported yield increases under biennial cropping systems.

Fruiting cane density. Fruiting cane density refers to the number of canes (floricanes or primocanes) allowed to fruit at any one time. Fruiting cane density is related to cane vigour control and cropping system in the sense that the three cultural practices operate on cane numbers. In primocane bearing raspberries, it is more appropriate to consider fruiting cane density as the other two practices (cane vigour control and cropping system) don't apply or they have not been tried. In primocane bearing raspberries therefore the most important aspect of cane management is the primocane (which are also fruiting canes) density per unit area of land (Buszard, 1986; Gundershein and Pritts, 1991; Wood, 1960).

The preceding list of cultural practices related to or affecting cane quality and fruit yields in raspberries is not exhausitive. Soil cultivation techniques (Lawson and Waister, 1972a), mulching (Childs and Hoffman, 1941) are equally important. There are also indications that date to first bloom can be advanced and the amount of early picked fruit increased by growth regulators applied during flower initiation in primocane fruiting red raspberries (Braun and Garth, 1984b; Crandall and Garth, 1981; McCregor, 1987). Total yield may also be increased (Braun and Garth, 1984b).

2.4. Fruit Yield and Yield Components

2.4.0 Fruit yield

Fruit yield increase is the continual goal of every raspberry grower (Orkney and Martin, 1980). In primocane bearing red raspberries, most fruit is borne on the laterals in the upper third of the cane. Many factors contribute to fruit yield and it is not possible to quantify the precise contribution of each factor because they interact (Oydvin, 1969; Wood, 1960; 1976). Besides cultivar differences, environmental and cultural factors greatly influence fruit yield (Crandall et al., 1974a; 1974b; Jennings, 1988; Jennnings and Dale, 1982; Wood, 1960; 1976). Such factors operate on yield components to define potential and actual fruit yield.

2.4.1. Fruit Yield Components

The major yield components in both floricane and primocane bearing raspberries include the number of flowers and berries per lateral shoot, berry size, and the number of fruiting laterals per cane, which consititute the number of berries per cane; vigour of primocanes/cane length, cane diameter, the number of canes per unit area, number of buds/nodes per cane (Crandall, 1980; Crandall et al., 1974a; 1974b; Dale, 1979; 1990; Dale and Topham, 1980; Darrow and Waldo, 1934; Daubeney et al., 1986; Fejer and Spangelo, 1973; Gundershein and Pritts, 1991; Jennings and Dale, 1982; Jennings And McCregor, 1989; Hoover et al., 1988; Nehrbas and Pritts, 1988a; Orkney and Martin, 1980; Waister et al., 1980; Wood, 1960). The relative contribution of each yield component to total yield varies among genotypes and under different conditions (Crandall et el., 1974a; Nehrbas and Pritts, 1988a).

2.4.2. Number of Flowers and Fruit per Lateral

Daubeny et al. (1986) and Nehrbas and Pritts (1988a) showed very high correlation between flowers per lateral and actual harvested fruit yield. In a path analysis study, Hoover et al. (1988) found that berries per lateral had the strongest direct effect on fruit yield in four primocane bearing genotypes. Darrow and Waldo (1934) reported emphatically that the number of fruits per lateral of any cultivar was a measure of its vigour and capacity for yielding. Crandall (1980) also indicated that fruitfulness in red raspberries is strongly related to the number of fruits per lateral. On the other hand Crandall et al. (1974a) found fruit number per lateral to have only a partial effect on overall fruit yield.

2.4.3. Number of Fruiting Laterals per Cane

Wood et al. (1961) indicated that the number of laterals per cane was one of the most important yield components for cultivars 'Royalty' and 'Titan'. Nehrbas and Pritts (1988a) reported that one of the greatest effects of cane thinning on fruit yield was the increased number of laterals per cane. On the other hand, it has been reported that canes with many laterals may have fewer fruits per lateral (Crandall, 1980; Dale, 1990).

Attempts have also been made to relate the occurrence of multiple laterals (more than one lateral at a node) to fruit yield. Jennings (1979) found that most multiple laterals occurred in the upper portions of the cane. The ability of more than one lateral to develop at a node is influenced by genetic and non-genetic factors. Occurrence of multiple laterals increased with cane diameter. However the occurrence of double laterals in the work of Jennings (1979) did not affect fruit number or fruit yield significantly.

2.4.4. Fruit Size

Fruit size (weight per fruit) is another variable that has been shown to affect fruit yield positively. Crandall (1980), Hoover et al. (1988) and Nehrbas and Pritts (1988a) all found that large fruit size improved the fruitfulness of red raspberries.

2.4.5. Number of Nodes per Cane

The number of nodes (axillary buds) per cane have also been shown to be positively correlated with fruit yield. Gundershein and Pritts (1991) found the number of nodes per cane to have the greatest single influence on fruit yield in purple raspberry cultivar 'Royalty', while Hoover et al. (1988) found number of nodes per cane to occupy third place in contributing to fruit yield in four genotypes. Jennings and Dale (1982) and Jennings and McCregor (1989) indicate that high node number per cane is important because it is closely related to the number of fruiting laterals and can actually be used for selection in breeding programs. Besides the total number of nodes, the percentage of nodes which bear fruiting laterals is positively correlated with fruit yield (Hoover et al., 1988; Nehrbas and Pritts, 1988a; Lawson and Wiseman, 1983). It was also shown by Dale and Topham (1980) that canes with many nodes tend to have vigorous lower laterals with a higher yielding potential. Canes with a large number of nodes per cane have also been associated with late fruiting.

2.4.6. Cane Vigour

Cane vigour can be defined in terms of total cane growth or height. There are reports in the literature to indicate that cane vigour has an effect on fruit yield. Crandall et al. (1974a) found that cane vigour had only a partial effect on fruit yield but concurred with Wood et al. (1961) that more vigorous canes have more berries per lateral and that taller canes are more productive than shorter canes. Darrow and Waldo (1934) and Crandall et al. (1974a) reported similarly that taller canes had more berries per lateral than shorter canes. Darrow and Waldo concluded that more productive raspberry fields had taller canes but at the same time contradicted their conclusions by saying that taller canes have fewer nodes in the cropping zone than shorter canes.

2.4.7. Cane Diameter

There is considerable evidence to show that cane diameter is positively correlated with fruit yield. Darrow and Waldo (1934) were the first ones to show that the most reproductive canes had a greater basal diameter. Crandall et al. (1974a) showed in the primocane bearing cultivar 'Willamette', that cane diameter was correlated with an increase in the total number of berries per lateral and therefore per cane. Crandall et al. (1974a) further showed in cultivar 'Washington' that fruit yield for individual canes and laterals was greatest with increased cane diameter and that large diameter canes had a greater percentage fruit set. Thick canes have more nodes regardless of their height (Jennings and McCregor, 1989) and high node number increase the potential for the production of fruiting laterals. However,Crandall et al. (1974a) and Jennings and Dale (1982) found that, although cane diameter was positively correlated with cane height, it was negatively correlated with the number of nodes below 150 cm which is the minimum recommended tipping height in floricane bearing red raspberries. This agrees with Darrow and Waldow's (1934) findings that thick, tall canes have fewer nodes in the cropping zone and hence fewer fruiting laterals. An explanation in this apparent dicrepancy may come from the conclusion of Jennings and McCregor (1989) that thick canes have high numbers of nodes with multiple laterals which compensates for fewer nodes on such canes. They also suggest that the highest number of nodes with fruiting laterals occur on canes of moderate thickness. Jennings (1979) proposed a mid cane diameter of 1 cm as optimum. Nevertheless, it has been variously reported that thick and tall canes give the highest yields because of the longer fruiting laterals and greater food reserves (Crandall et al., 1974a; Darrow and Waldow, 1934; Pepin et al., 1980). Dale and Daubeny (1985) suggested that cane diameter be used for identifying high yielding plants.

2.4.8. Fruit Yield and Cane Number

Cane number per unit area of land is perhaps the most commonly reported fruit yield component in the literature. This component has been found to be the most consistent under varying cultural and environmental conditions for most cultivars (Wood, 1960). Overall fruit yield per unit area of land is increased by increasing the number of canes (Buszard, 1986; Crandall, 1980; Crandall et al., 1974a; 1974b; Darrow and Waldo, 1934; Gundershein and Pritts, 1991; Hoover et al., 1988; Nehrbas and Pritts, 1988a; Orkney and Martin, 1980; Odyvin, 1986; Wood, 1960; Wood et al., 1961). Crandall (1980) indicated that fruitfulness of red raspberries was strongly related to number of canes as well as the yield components of individual canes. Odyvin (1986) always obtained higher fruit yields at 10 than at 8 canes per meter of row. Gundershein and Pritts (1991) found that cane number per unit area had a strong direct effect on yield and that fruit yield increased significantly with higher floricane densities up to 12 canes per meter of row in the purple raspberry cultivar 'Royalty'. Similar results were discussed by Buszard (1986), Odyvin (1986) and Orkney, Martin (1980) and Nehrbas and Pritts (1988a). Hoover et al. (1988) found cane number to have the second strongest direct effect on fruit yield after number of fruits per lateral in four genotypes. Freeman et al. (1989) reported that the effect of cane numbers above 12 canes per meter of row is not known.

Because of the interaction between cane density and other fruit yield components, there is an optimum number of canes that can be maintained per unit area without compromising fruit yield and increasing disease incidence (Buszard, 1986; Gundershein and Pritts, 1991; Fejer, 1979; Mason, 1981; Wood, 1960; 1976; Wood et al., 1961). These authors indicate that high cane numbers increase cane death rate and disease incidence. Wood (1960) and Wood et al. (1961) have also shown that losses and poor performance are heaviest in dry conditions at high cane numbers. It has also been demonstrated that optimum cane number varies with cultivar due to cultivar differences and the many interacting factors (Dale, 1990; Freeman et al., 1989; Gundershein and Pritts, 1991; Mason, 1981; Wood, 1960). Cultivar is probably the most important factor because of genotypic differences in vigour and stature. In the primocane bearing cultivar 'Glen Clova', Mason (1981) found that initial increase in cane number per meter of row resulted in increased fruit yield, but beyond 8 canes per meter of row, further increase in cane number produced no additional fruit yield. Wood (1960) found cultivars 'Malling Promise' and 'Lloyd George' to perform differently at the same level of cane numbers under the same environmental conditions. Similarly Gundershein and Pritts (1991) proposed that the optimum cane number for cultivar 'Royalty' and the other vigorous large fruited cultivars are different from those of less vigorous smaller fruited cultivars. Cultural practices and environmental conditions will interact to determine optimum cane numbers for any one cultivar and Gundershein and Pritts (1991) have suggested the need for further work in this area. Dale (1990) has cited the age of the plantation as another important factor to consider in arriving at optimum cane numbers.

The following summarise experimental optimum cane densities with several cultivars:

(i) in North America and Tasmania, 15 canes per meter of row gave optimum fruit yields (Crandall, 1980),

(ii) Orkney and Martin (1980) have reported 8-12 canes per meter of row as being optimum in Europe,

(iii) in Holland (in Europe), Keep (1988) has cited 16 canes per meter of row for cultivar 'Heritage',

(iv) while in Scotland (also in Europe), Wood (1976) indicated that fruit yields reached a plateau at 8-9 fruiting canes per meter of row for most cultivars and

(v) in Quebec Buszard (1986) found 10 canes per meter of row to be appropriate for cultivars 'Festival', 'Latham' and 'Newburg'.

Despite the overall increase in yield with cane density, a larger number of canes per unit area reduces fruit yield of individual canes (Crandall et al., 1974b; Gundershein and Pritts, 1991; Hoover et al., 1988; Nehrbas and Pritts 1988a). In some primocane bearing red raspberry cultivars, increasing the number of canes per unit area has a negative effect on all other yield components (smaller fruit size, fewer fruitful laterals near the bottom and middle of canes, fewer reproductive nodes and fruits per node). This may be attributed to inter-cane competition and poor light penetration. Conversely, reducing the number of canes per unit area has the effect of improving individual cane performance. Crandall et al. (1974b) found that a reduction in the number of canes per unit area in cultivars 'Washington' and 'Puyallup' had the effect of increasing cane diameter, and the canes had longer laterals and more fruitful nodes per cane. The canes also had more fruits per flowering lateral and per cane, and the fruits were larger and of higher marketable quality (Freeman et al., 1989). However, the improved individual cane performance at low cane numbers does not always compensate for the loss of canes (Freeman et al., 1989; Wood, 1960).

General observation reveals that although there are guidelines regarding the optimum number of canes, growers always tend to retain the maximum (Wood, 1960). In fact, some authors have suggested that growers should leave all good fruiting canes regardless of the number per meter of row (Crandall and Carstens 1962, cited in Crandall, 1980; Hoover et al., 1988). Hoover et al. (1988) point out that in primocane bearing red raspberries, retaining all primocanes should have a positive effect on fruit yield without affecting fruit size. They argue that for this type of raspberry, higher cane numbers and large fruit size are required in order to compete with the June bearing type. The lack of a negative effect on fruit size and yield with high cane density in Hoover et el. (1988) is unsubstantiated.

2.2. Fertilization of Raspberries

Soil applied fertilizers improve plant growth and fruit yield and quality in fruit crops (Claypool, 1975). In raspberries, specific fertilizer programs will depend on type of raspberry, cultivar, age of plantation, climate, inherent soil fertility and cultural practices (Dale, 1990; Strong 1936). It has been suggested that primocane bearing red raspberries require more nitrogen than the floricane bearing types (Dale and Daubeny, 1990). Because of these many and interacting factors, fertilizer programs used presently have not been definitively established, and tend to be imprecise and inconsistent (Hoffman and Schlubatis, 1929; Chaplin and Martin, 1980; Kowalenko,1982; Ramig and Vandecaveye, 1950; Crandall et al., 1974a; Lawson and Waister, 1972b; Stene, 1933).

Different effects of mineral nutrients on the growth and fruiting of raspberries have been demonstrated in a number of studies. Studies have been carried out under varying conditions and the responses to added single nutrient elements have also been variable (Cheng, 1982; Smolarz et al., 1982; Stene, 1936; Wood, 1960; Woods, 1935). Nevertheless, several nutrient elements have been shown to impact raspberry growth and yield.

2.2.1. Phosphorus

Phosphorus fertilization of commercial raspberries is not generally very common (Smolarz, et al., 1982). Except in Quebec (Cheng, 1982) and Rhode Island (Stene, 1933) where phosphorus had a more positive effect on fruit yield than nitrogen, phosphorus added alone is generally not very effective (Hoblyn, 1931 cited in Stene, 1936; Stene, 1936) although few cases have been reported. Stene (1933) reported a 28 % yield increase due to added phosphorus fertilizer. Positive phosphorus effects have also been reported with pot experiments (Ramig and Vandecaveye, 1950). On the other hand, Wallace (1938) found that omission of phosphorus from fertilizer treatments did not depress fruit yields. Smolarz et al. (1982) also did not find any significant effects of phosphorus fertilizer application on fruit yields. These observations indicate that either soil phosphorus resources are often sufficient or that raspberries have a low phosphorus requirement.

2.2.2. Potassium

Adding potassium to red raspberries does not give consistent results (Harris, 1936; Ljones, 1967 cited in Dale, 1990; Woods, 1935). Cheng (1982) obtained a positive potassium response only where farm yard manure was applied. Stene (1933), Smolarz et al. (1982) and Wallace (1938) also reported better response to potassium in combination with nitrogen. Wallace (1938) and Tomkins and Boynton (1959) showed better fruiting with added potassium but Woods (1935) reported a negative response. Kowalenko (1982) also reported no response.

2.2.3. Trace Elements

Boron is the only trace element that has shown fruit yield response in red raspberries (Kowalenko, 1982; Askew et al., 1951; Chaplin and Martin, 1980). In Manitoba, boron has not been shown to be deficient for raspberries. However, the Manitoba Soil Testing Lab recommends the addition of zinc sulphate during the growing season as the plants generally show zinc deficiency symptoms. Three foliar applications during the growing season are recommended.

2.2.4. pH

Besides mineral nutrition, the pH is important in fruit production as it affects the availability of mineral elements. Harris (1936) stated that pH is extremely important as many nutrients will be held in unavailable forms at less or more than appropriate PH. Soil pH will also affect function and activity of soil microorganisms. Little information is available on the effect of soil pH on growth and fruiting of raspberries. Hoffman and Schlubatis (1929) say that good raspberry fruit yields are obtained when soil pH is 5.1 to 7.0 while Harris (1936) considered a pH of 5.7 to be the best for raspberry growing.

2.2.5. Nitrogen and Fruit Yield Response

Nitrogen is probably the single most important factor limiting crop yields, as most plants require large quantities (Pantastico and Subramanyam, 1975). The beneficial effects of nitrogen fertilizer on the growth, fruiting and quality of fruits is widely recognized (e.g., Claypool, 1975; Smolarz et al., 1982). Fruit bud formation and fruit set can be greatly influenced by soil nitrogen levels (Claypool, 1975). In raspberries, nitrogen is considered the principal and most limiting element to which red raspberries respond (Childs and Hoffman, 1933; Crandall, 1980; Martin et al., 1980; Wallace, kilograms of nitrogen per hectare gave higher yields consistently over a five year period compared to when the control or the higher rate of 134 kilograms per hectare, implying that 67 kilograms per hectare was close to the optimum for the cultivar tested under the conditions of the experiment. In contrast, Childs and Hoffman (1933) found 136 kg per acre to give higher yields than 91 kg per acre. Similarly, De Gomez et al. (1986) showed a 14 % fruit yield increase at a higher (135 kilograms nitrogen per hectare) than at 67 kilograms of nitrogen per hectare. Kowalenko (1982) recorded a yield increase over a four year period at 134 kilograms nitrogen per hectare while Lawson and Waister (1972b) found that a higher rate of nitrogen only increased yield in the first two years then subsequently yields were either unaffected or depressed altogether. Martin et al. (1980) obtained 1.5 metric tonnes of fruit more at 68 kilograms per hectare than at 0 kilograms per hectare. Over a 7-year-period, Smolarz et al. (1982) found that the lowest yielding plots were always those without added nitrogen in cultivar 'Latham'. Plots without nitrogen yielded 30 % lower than those with nitrogen. Similar yield reductions under conditions of nitrogen deficiency have been reported by Stene (1933, 1936).

Childs and Hoffman (1933) and Iwanika (1966) cited in Smolarz et al. (1982) did not find fruit yield response to added nitrogen when the experiments were conducted on highly fertile soils. Goode (1970) reported that, although nitrogen application increased fruit yields, high nitrogen rates were also associated with high incidences of spur blight disease.

2.2.6. Nitrogen and Yield Components

Several raspberry yield components have been shown to be affected by nitrogen fertilizer application. Nitrogen is also required for rapid vegetative development. De Gomez et al. (1986) and Lockshin and Elfving (1981) found that raspberry canes of cultivars 'Amity' and 'Heritage' supplied with nitrogen grew more rapidly and reached the number of nodes associated with the switch to reproductive growth (flowering). Generally, 20 to 25 nodes are required for the switch from vegetative to reproductive growth. This was also reported by Kowalenko (1982) for cultivar 'Willamete'. However, in Kowalenko's case nitrogen delayed fruit ripening.

Lockshin and Elfving (1981) also found that nitrogen promoted the formation of more flowering nodes per cane and increased the number of flowers per unit of vegetative growth. Similarly Childs and Hoffman (1933) and Cheng (1982) reported that "well fertilized" raspberries produced more flowers.

The size of berries has also been shown to be affected by added nitrogen. In both black and red raspberries, a linear relationship between fruit size and added nitrogen has been demonstrated frequently (Chaplin and Martin 1980; Collison and

Slate; 1943; Kowalenko, 1982). A similar relationship was shown by De Gomez et al. (1986) in which fruit size increased with nitrogen application over a 5 year period. On the other hand, Martin et al. (1980) indicated that fruit size was unaffected by rate of nitrogen fertilization.

In terms of vegetative growth, Lockshin and Elfving (1981) and Smolarz et al. (1982) found that nitrogen promoted greater total growth (i.e. increased vigour as measured by cane height, total dry weight, total nodes and increased internode length) in cultivar 'Heritage'. Woods (1935) indicated that cultivar 'Cuthbert' canes branched more (had more laterals) when fertilized than when not fertilized but he did not relate this to fruit yield. On the other hand, Lawson and Waister (1972b) reported no nitrogen effect on the number of laterals per cane.

Lawson and Waister (1972b) found a higher rate of nitrogen increased the number of canes per unit area of land in early years of a plantation. First year canes, canes growing in alleys and between stools and within stools were also increased. In a nitrogen, phosphorus and potassium experiment, Smolarz et al. (1982) found that any combination with nitrogen always had more canes than those combinations without nitrogen. Morever the number of trainable canes (canes over 1.5 meters tall) have been shown to increase (Crandall and Daubeny, 1990). Conversely, Martin et al. (1980) did not show any increase in cane numbers with high nitrogen rates.

Martin et al. (1980) reported an increase in cane diameter due to added nitrogen on canes topped to a standard height in the cultivar 'Meeker'. Chandler (1920) reported that with the cultivar 'Cuthbert', nitrogen caused the canes to grow more in diameter. Similarly, Childs and Hoffman (1933) and Cheng (1982) also alluded to the fact that "well fertilized" red raspberries produce thicker canes. With clean cultivation, even low nitrogen was shown to increase cane diameter in the cultivar 'Malling Jewel' (Lawson and Waister, 1972b).

The literature indicates that raspberries require nitrogen but that requirements vary with many factors. It is this variability that makes it difficult to make generalised recommendations with respect to fertilizer application rate. Woods (1935) noted that general recommendations are often misleading.

2.2.7. Time of Nitrogen Application

Little information is available in the literature regarding time of nitrogen application in raspberries. Harris (1940) suggested two applications in early spring and early May but he did not quantify the beneficial effects of this split application. Crandall (1980), however, does emphasize that early spring nitrogen applications are more efficient than fall applications. He concluded that split applications have no advantage and that slow-nitrogen release formulations are no more effective than early spring doses.

3. MATERIALS AND METHODS

3.0. Experimental sites

Field experiments were initiated in 1990 at three previously established sites in Manitoba- near the towns of Morden, Souris and St. Adolphe, Manitoba (Figure 1). St. Adolphe is located 20 kilometres South of Winnipeg, Morden is located 100 kilometres South-West of Winnipeg while Souris is located 270 kilometres South-West of Winnipeg. The Morden site was located at the Agriculture Canada Research Station, Morden while Souris and St. Adolphe were both located on grower's fields. St. Adolphe was deleted in the second year because of management problems.

Each year, before application of the treatments, soil samples were taken at a depth of 0 to 60 and 0 to 75 cm respectively. Soil samples were taken from as close to the experimental plots as possible. The soil was analyzed for characterisation of general soil types and inherent mineral nutrient status. St. Adolphe and Morden were classified as clay and clay-loam respectively while Souris was categorised as fine sand. A detailed presentation of mineral nutrient status before application of treatments is given in appendix 1, Tables A1.1 and A1.2. For a detailed soil characterisation of the experimental sites refer to appendix 5, Table A5.1. Agroclimatics statistics for the three sites are also given in appendix 5, Table A1.2. All the three sites had facilities for supplemental irrigation and were irrigated moderately when conditions became dry.

3.1. Experimental Materials

For the experiments two primocane bearing red raspberry selections, '8114' and '8008' were used. The experiments were previously planted for cultivar performance trials by Dr. C.G. Davidson of Agriculture Canada Research Station, Morden, Manitoba. The selections have been tested and are considered of sufficient quality for naming and release to growers in Southern Manitoba.

3.2. History of Experimental Materials

The cultivar performance plots were established in 1987. Originally 10 plants were planted at equal spacing in single row blocks 6 m long. The blocks were replicated four times and were oriented south-north. The inter-block spacing was 3.6 m. The plants were allowed to fill out the inter-plant spaces of 0.6 m so that at the time the present management experiments were initiated, hedge-rows had been established. Row width was maintained at 0.46 m manually and by rotovating. Cane numbers were maintained at a maximum (only dead, broken and diseased canes were removed). Guard rows of the cultivar 'Boyne' were grown on all sides of the plots.

Weeds were controlled by rotovating between the rows and hand hoeing within the rows. Prior to the present study, the plots received a soluble form of nitrogen, phosphorus and potassium fertilizer annually in mid-June (see appendix 2, Table A2 for rates). Zinc was also applied three times during the growing season as a foliar feed. Each year, canes were removed to ground level after cropping in mid to late October.

3.3. Cane Density Experiment

To investigate the effects of cane density on yield and cane characteristics, the previously established primocane fruiting red raspberry selection '8114' was used. Before application of the treatments, the 6 m blocks were subdivided into 4-1 m plots seperated by 0.3 m shared borders and similar sized borders at the ends of the block (Figure 2). The plots were maintained at a width of 0.46 m. Cane density treatments of 6, 12, 18 and 24 canes per meter of row were replicated four times in a randomized complete block design. The densities were achieved by thinning out excess canes with secateurs. Canes retained were as equally spaced as possible. Cane numbers were subsequently maintained by thinning throughout spring and summer whenever new growth attained a height of 10-15 cm. In 1990, thinning was initiated in mid-June when the canes were 25 cm high. In 1991, thinning was initiated in mid-May when canes were 10-15 cm high.

All plots were subjected to cultural practices similar to those of the previous cultivar trial. The Morden site did not have any disease or pest problems in either year. Grasshoppers were observed at both St. Adolphe and Souris in 1990 and 1991 respectively, and were controlled with malathion. Cane blight was also observed on some canes at Souris in 1991 and to prevent any possible spread, canes were sprayed with captan every 10 days from the onset of symptoms to the end of the season.

In 1990, four canes were randomly selected from each plot and tagged for detailed study of cane architecture characteristics, in particular those related to yield components. In 1991, two canes per plot were analyzed. Fruit was harvested from 26 August to 3 October in 1990 and from 10 August to 20 September in 1991.

3.4. Nitrogen Experiment

3.4.0. Field Nitrogen Study

An experiment to investigate the effects of nitrogen on yield and cane characteristics was initiated at the same time as the cane density study. This experiment was superimposed on another primocane bearing selection '8008' in Davidson's cultivar evaluation trial. The plot layout was similar to that of the cane density experiment except that the plots were separated by cutting a furrow 60 cm deep at the centres of each shared border. This was done to minimise any contamination between plots.

In 1990, four levels of nitrogen: 0, 75, 150 and 300 kilograms nitrogen per hectare as ammonium nitrate were applied. In 1991, the rates were revised upward to 0, 150, 300 and 450 kilograms nitrogen per hectare and were applied over those of 1990 in the same ascending order. The revision was based on the 1990 results in which it was observed that yields were increasing even at the highest rate of nitrogen. The rates were applied in a single dose in mid-June in 1990; in 1991, the nitrogen was split into two equal portions and applied in mid-May and early-June. The fertilizer was broadcast adjacent to the row and rinsed in 1990 while in 1991, the fertilizer was covered by soil after broadcasting and then rinsed in.

A uniform cane density of 24 canes per meter row was maintained by regular removal of new growth when it reached 10-15 cm in height. The density was based on the observation that, over all locations, the minimum number of canes produced under standard cultural conditions was 24. Other cultural practices were standard for commercial red raspberry production as practised on the plots before initiation of the experiment. Cane selection and tagging for detailed study was as for the cane density experiment. Fruit was harvested from 15 August to 3 October in 1990 and 10 August to 20 September in 1991.

3.4.1. Green house Nitrogen Study

Plants of various fall bearing red raspberry selections were established in the green house in December 1989 to assess their suitability for container growing. The primocane bearing selection '8008' used for the field nitrogen study, was found to perform well in containers and was therefore adopted.

Planting material of this selection was obtained from a site near Portage La Prairie (Figure 1) in October 1990. This location had been part of the original cultivar trial. The spent canes were cut back to stumps at 10 cm above ground and the plants lifted with their roots. After one and a half months in cold storage, they were potted in metromix™ in three gallon plastic nursery containers (containers were 26 cm high and 23 cm in diameter). A single stump consisting of a piece of stem and old trimmed roots was set in each container. A total of 27 plants were so containerised. Twenty four containers with uniformly growing plants were selected for nitrogen treatments.

Rates of 0, 0.435, 0.870, 1.740 and 3.480 grams nitrogen as ammonium nitrate were applied per container in a single dose. The treatments were applied in completely randomized design: 4 containers functioned as controls and received no nitrogen; the other treatments were applied to 5 containers each. Primocanes were thinned to two per pot prior to the fertilizer treatments. Canes were staked with wires for support. Plants were given equal amounts of water twice a week. Kelthane was used every 10 days to control spider mite. The plants were grown at 20-30° C and 16 hours of light.

One cane per pot was selected at random and tagged for detailed study. The period of fruit harvesting was from 19 April to 10 June 1991.

3.5. Observations

Detailed records were taken as follows for all experiments in both years except as otherwise indicated:

Fruit yield - a) grams per meter row/container. This was based on the whole plot or per container for the green house nitrogen study. Harvesting was done every 4-6 days. The number of harvest dates ranged from 5 to 9 per study depending on the site and the experiment. Harvested fruits were placed into zip-lock plastic bags and transported back into the lab in coolers and weighed on a scale. The yields of each harvest date were summed up to give total cumulative yield per plot or container.

b) grams per cane (cane density experiment only). This was derived by dividing the yield per meter row and the number of canes in the meter row.

Fruit size - grams per 10 fruits. Ten fruit were selected randomly on each of three harvest dates and weighed. The first and last picks were not used for sizing because they tend to give unusually large and small fruit respectively. Therefore early, mid and late picks were sized and averaged. Fruit size was not determined for the nitrogen experiment at Morden in 1990.

Flowers per lateral/cane. These data were obtained for the green house nitrogen study only. Open flowers were counted every day on each lateral of a tagged cane. The flowers on each lateral were then summed to give flowers per cane.

Fruit set (greenhouse study only). The number of fruit expressed as a percentage of the total number of flowers per cane.

Fruits per lateral/cane. Ripe harvestable fruit were counted on each lateral of tagged canes prior to harvesting and summed to give fruits per cane.

Number of laterals per cane. Primary laterals on every tagged cane were counted at three different times: at flowering, mid-harvest and at the last harvest date to ensure that late developing laterals were counted. Laterals were categorised as fruiting (reproductive) or vegetative.

Lateral length (cm). Length from the base of the lateral to the tip of the terminal fruit or terminal leaf bud for vegetative laterals for every counted lateral was measured on tagged canes.

Height to lowest lateral (cm). If the first lateral was not reproductive, the distance to the first fruiting lateral was also measured.

Cane diameter (mm). After harvest, stem or cane diameter of each tagged cane was measured with vernier callipers at 5, 15 and 30 cm from the soil level. The three measurements were then averaged to give the cane base diameter.

Cane height (cm). The height of tagged canes was taken from soil level to the tip of the terminal fruit. The proportion of cane that fruited was determined as a percentage by the difference between total cane length and the height to lowest fruiting lateral.

Number of nodes per cane. Number of nodes above the soil was counted for tagged canes. The total number of leaf nodes was counted after the canes had bloomed. The number of reproductive nodes was derived as a percentage of the total number of nodes on the cane.

Internode length (cm). The distances between nodes were measured on tagged canes in the green house and on field plots in 1991 only.

Lateral branch or crotch angle. The angle between the horizontal and the primary lateral was measured using a carpenters' tool for calculating angles and roof pitch with respect to gravity. The angle between the cane and the lateral was then determined by the difference between 90 and the measured value. This was done for the cane density study only.

Fruit dry weight (g). In 1991, 10 gram samples from every harvest date were weighed out into paper bags and oven dried at 80° C for 24 hours to determine the dry matter content.

Biomass study (gm). For the green house study, the tagged spent canes were harvested, chopped into paper bags and weighed to determine the spent cane fresh weight. They were oven dried like the fruit to determine the spent cane dry weight.

3.6. Statistical Analysis

Analysis of variance was performed on all variables measured and Least Significant Difference (LSD) used to test the differences between means of the variables. Years were analysed seperately in both experiments. Regression analysis was used to analyze cane architecture characteristics. Slopes of simple linear regressions were compared and both simple and quadratic equations were used to describe the relationships along the cane. All procedures were done by Statistical Analysis Systems (SAS, 1985).

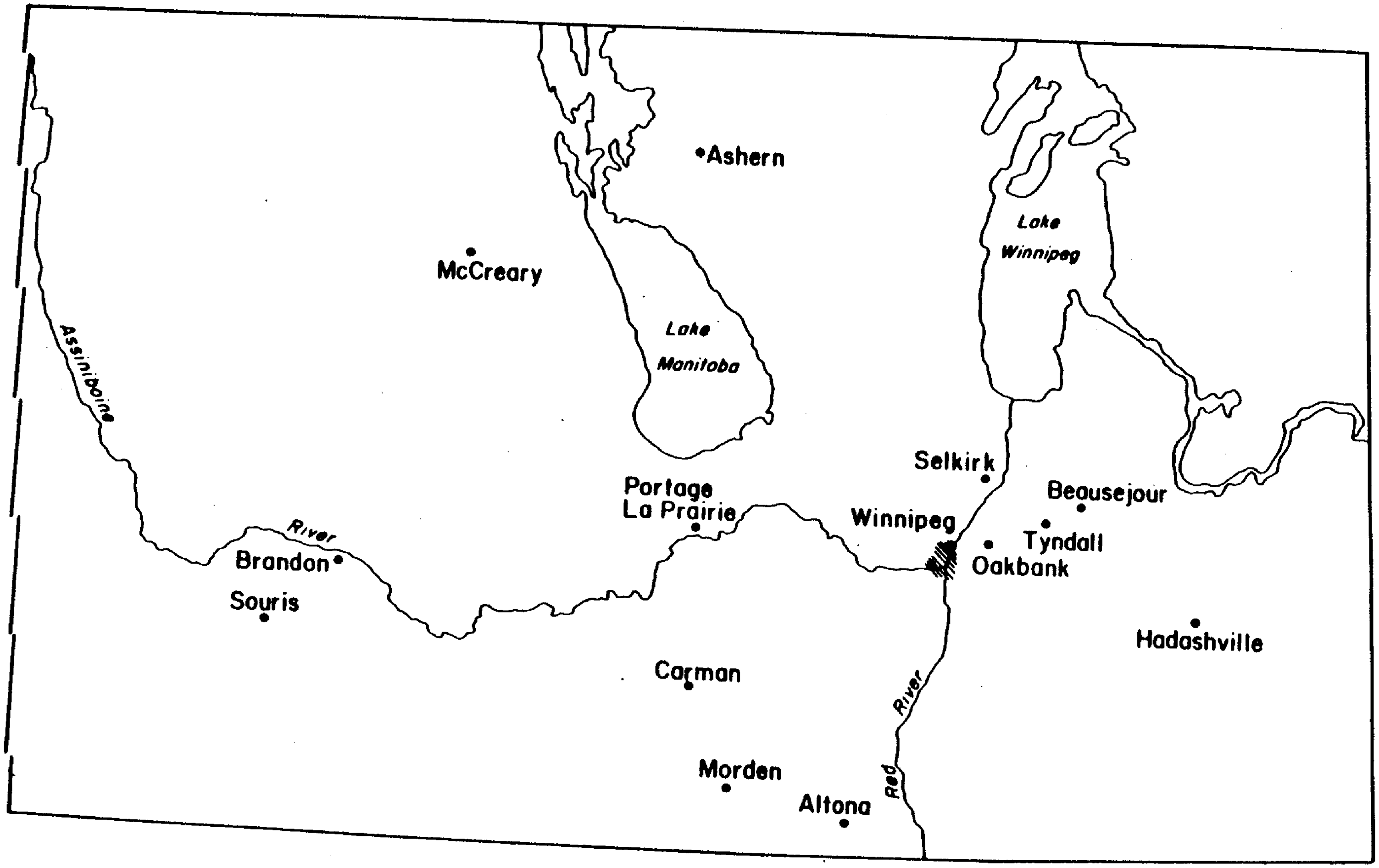


Figure 1. Locations in Manitoba, designated by the nearest town, of raspberry experimental sites

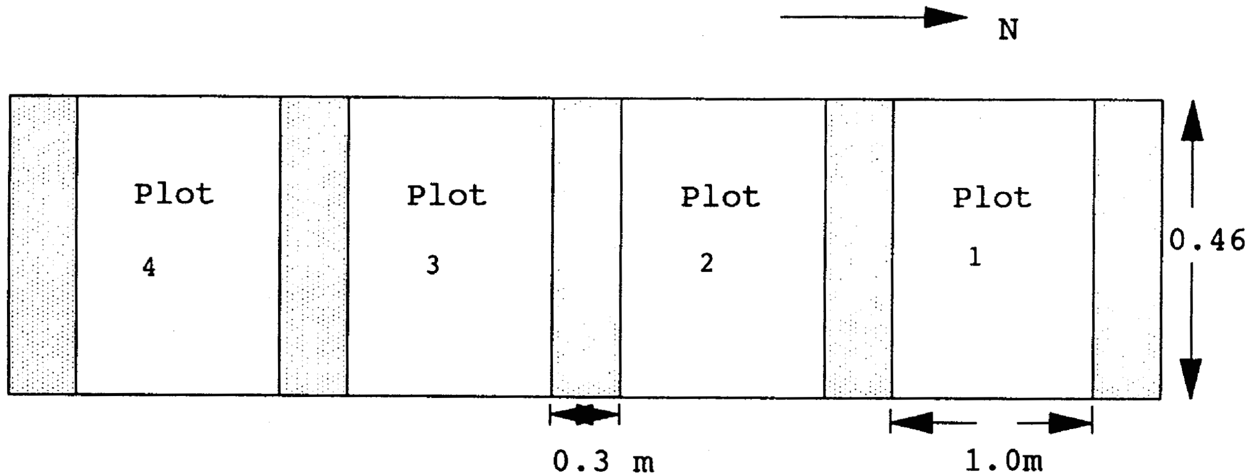


Figure 2. Plot layout for cane density and nitrogen experiments at all experimental sites, with only one replication shown.

4. RESULTS AND DISCUSSION

4.0. Cane Density Experiment

4.0.1. Fruit yield

In both years, the highest yields overall were recorded at the Morden site and the lowest yields at the St. Adolphe site. The pattern of fruit yield response to cane density was similar at all sites in both seasons (Figure 3). Yield tended to increase with cane density, but the differences were only significant at Morden and Souris in 1991. Moreover, the relationship was not necessarily linear and the density at which maximum yield was obtained differed among sites and between years for Morden. There were no site*treatment interactions in either year ($p = 0.7519$ and $p = 0.1071$, respectively).

Considering fruit yield by harvest date showed that low cane density treatments tended to advance fruit yields in the season i.e., at low cane density, high yields were realised early in the season than at high cane density (Figures 4 to 8). Peak fruit yields were realised late in the season at high cane density. Delaying peak yields towards the end of the season could lead to fruit yield loss due to fall freeze. Fall freeze has been frequently blamed for the low fruit yields realised in primocane bearing red raspberries (Hoover et al., 1988; Lawrence, 1980a).

Fruit yield per cane responded in reverse to yield per m row. Yield per cane decreased significantly with increasing cane density at all sites in both years (Tables 1 to 5). The lowest cane density treatment always had the highest fruit yield per cane while the highest density had the least. The 6 cane treatment yielded three times or greater per cane over the 24-cane treatment. There were site*treatment interactions in both 1990 and 1991 ($p = 0.0316$ and 0.0001, respectively). The range of variation in yield per cane between low and high densities was much greater at Morden with low densities giving considerably higher yields than the other sites, especially in 1991. The reduced response to thinning at Morden in 1990 may have been due to the lateness of treatment application, that is there was less time for the yield components to respond. The relatively high yields per cane at low density for all sites in each year appears to have contributed to the relatively flat response in yield per meter row, particularly evident in relation to increasing cane density. Improved individual cane yield at low cane density has been reported frequently. Buszard (1986) showed a yield increase per cane of 4 times or greater at the low than the high cane numbers. Crandall et al. (1974a), Hoover et al. (1986) and Wood (1960) reported that at low cane numbers individual canes yielded better in both the June and primocane bearing red raspberries. Similarly, Freeman et al. (1989) found that when canes were maintained at low density, higher yield of marketable quality was obtained per cane. However, Crandall et al. (1974a) and Wood (1960) pointed out that the improved individual cane performance at low cane numbers seldom compensated for the yield of lost canes so that larger cane numbers per unit area still resulted in high yields.

Although the result of the present study agreed with the general observations of previous work (e.g., Crandall et al., 1974a), it contradicts the conclusion that the improved cane yield at low cane numbers seldom made up for the yield of the lost canes. The present investigation clearly demonstrated that improved cane yield at low cane numbers could effectively compensate for the yield of canes lost in thinning.

The contribution of cane number to overall fruit yield has been quantified mainly in the June bearing red raspberries. The cane number at which optimum fruit yields are obtained varies and this has been attributed to genotype, environmental and age differences. Buszard (1986) found that in the June bearing red raspberry cultivars 'Festival', 'Latham' and 'Newburg', fruit yield increased with cane number per meter row and reached optimum at 10 canes per meter of row. Similar results were reported by Oydvin (1986) for the June bearing red raspberry cultivar 'Veten'. Mason (1981) reported that in cultivar 'Glen Clova', maximum yields were obtained at 8 canes per meter of row. Others (Crandall, 1980; Crandall et al., 1974a, Freeman et al., 1989, Gundershein and

Pritts, 1991; Orkney and Martin, 1980; Wood, 1976) have reported a similar trend of results with varying cane numbers for different genotypes in June bearing red raspberries. Freeman et al. (1989) indicated that nothing is known about the effects of cane numbers higher than the 12 canes per meter of row/stool recommended for commercial growers.

In the primocane bearing red raspberries, it has been acknowledged that cane number per unit area is an important yield component (Hoover et al., 1986; 1988) but it has been rarely quantified. Hoover et al. (1986) analyzed yield components in three primocane bearing red raspberries, but they did not show clearly how cane number affected overall yield. Hoover et al. (1988) proposed that for primocane bearing red raspberries with a limited lateral bearing capacity, high cane densities were required. Similarly, Crandall (1980) recommended that growers maintain all good fruiting canes regardless of the number per unit area. The present investigation found that although cane number contributed to overall fruit yield in the primocane bearing red raspberry selection '8114', the range of cane numbers over which a significant yield gain was realised was limited. Below 12 and (or) 18 canes per of row, yield depended to a large extent on the number of canes per meter of row. The highest increases in fruit yield per meter of row, significant or not, occurred at the lowest cane densities. Above the 12 or 18 cane densities, further increases in cane numbers did not increase overall fruit yield significantly and there was evidence that fruit yield stabilised or decreased after 12 or 18 canes per meter row were reached. Mason (1981) found that increasing the number of canes per meter of row above 8 did not produce significant additional fruit yield. Buszard (1986) showed that increasing or reducing cane numbers from 5 to 10 and vice versa affected yields significantly, however, any cane increases per meter of row above 10 or 15 up to 30 did not affect fruit yields. In '8114', therefore, a density of 12 and 18 canes per meter of row were considered to be the critical optimum.

The present work also showed that in primocane bearing red raspberries, cane number per meter row or stool could be increased, depending on the site location, above the currently recommended 12 canes with beneficial yield gains. Nevertheless, the recommendations by Crandall (1980) and Hoover et al. (1988) that growers leave as many canes as there are good canes per stool or per meter of row is misleading. Clearly, it would be uneconomical to maintain more than 12, 18 or whatever optimum cane number per meter row that applied to a genotype or grower region if there was no yield benefit. Besides, a cane number higher than necessary only increases maintenance costs and is likely to reduce the economic life of a plantation. Mason (1981) reported that increase in cane numbers per unit area could result in a greater incidence of cane diseases such as cane spot and cane blight. In the June bearing red raspberries, increased cane numbers also means increased inter-cane and inter-lateral competition both between the fruiting canes and between the fruiting canes and the primocanes (Waister et al., 1977).

The results of the present study showed that the critical optimum numbers varied with site and with years. Year and site differences have been cited frequently (Dale, 1990; Fejer, 1979; Mason, 1981; Wood, 1960). For example, Fejer (1979) found high cane density to increase fruit yields in some years but not in others.

4.0.1.0. Number of Fruits per Lateral and per Cane

The response of the number of fruits per lateral and per cane corresponded with that of yield per cane indicating that these components played a major role in overall cane yield. The number of fruits per lateral and per cane was significantly higher at the lower than at the higher cane density (Tables 1 to 5). Although there were site differences, there were no site*treatment interactions for both number of fruits per lateral and per cane. Plants grown at Morden had consistently more fruit per cane and per lateral than the other two sites in both years.

Along the cane, the number of fruits per node increased from the tip to the bottom (Figures 9 and 10). Nevertheless, the pattern was different at each site and between years

(Figures 9 and 10). For example, at Morden in 1991, there were more fruits per node in the upper regions of the cane at high density but there were about 10 fewer nodes bearing fruit. At low cane density, the increase in number of fruits per node was very strongly linear, while at high cane density, the relationship was curvilinear except at Morden in 1991 (Figure 10). At high cane density, the r^2 values were generally lower indicating the number of fruit in relation to position of the lateral on the cane is more variable.

The relationship between the number of fruits and length of lateral (see section 4.0.2.5) was somewhat similar to that of the number of fruits and node number in that, at low cane density, the relationship was strongly linear (Figures 11 and 12). At high cane density, the relationship between number of fruits and lateral length was curvilinear resulting from a fewer fruits per lateral towards the bottom of the cane. The reduced number of fruits per lateral may be due to poor light penetration resulting from mutual shading. It has been shown that the number of fruits per node varies with cultivar (Dale, 1979) with the greatest variation occuring 30 cm below the tip. The number of fruits per node in the lower portion of the cane can be increased by reducing the number of canes per unit area i.e., reducing competition during the spring growth (Crandall, 1980; Dale and Daubeny; 1990).

The importance of the number of fruits per lateral and per cane as a yield component in relation to density has been

4.0.1.1. Fruit Size

Fruits were significantly larger in size at the low than at the high cane densities (Tables 1 to 5) and probably contributed to the high individual cane fruit yields at low cane density. The larger fruits at low cane density also contributed to the overall yield per m row. Cane density affected fruit size similarly at all sites in 1991 but in 1990 there was a significant interaction between site and treatment. At St. Adolphe, low cane density did not result in as great an increase in fruit size as the other two sites. The fruits were consistently larger at Morden than any other site in both years. Fruits were also numerically smaller in 1991 than in 1990.

The importance of fruit size as a yield component in red raspberries has been well documented (Crandall, 1980; Hoover et al., 1986; 1988; Nehrbas and Pritts, 1988a), but few studies have related fruit size to cane density particularly in the primocane bearing types. Freeman et al. (1989) found that primocane removal in several June bearing red raspberry cultivars enhanced fruit size. Buszard (1986) showed that fruit size in the June bearing cultivars 'Festival', 'Latham' and 'Newburg' decreased with increasing cane density but the differences were very small. In other fruit crops such as peaches, tree pruning which is similar to cane thinning in red raspberries, increased fruit size (Schneider and McClung, 1957).

The results of the present study showed that fruit size is sensitive to each level of cane density. Fruit size was as much as 3 times greater at 6 canes per m row compared to 24 canes per m row, again showing the potential for yield increase per cane at low cane numbers. The small significant differences observed by Buszard (1986) may be largely due to genotype differences or differences in the age of the plantations. Hoover et al. (1988) suggested that in primocane bearing red raspberries, all primocanes could be retained with a positive effect on fruit yield without affecting fruit size. The results of the present study indicate that it is probably inappropriate to make such generalized conclusions.

4.0.1.2. Fruit Dry weight

Fruit dry weight increased with cane density to a maximum at 12 canes per meter row then decreased at both sites (Tables 4 and 5). Although the differences were small, they were significant at Morden. There was no evidence of site*treatment interaction. A combined analysis did not show any site differences. There was a trend for fruit dry weight to vary directly with fruit yield and fruit size, but the relationship was not as apparent as observed with other components. Literature regarding dry weight changes with varying cane numbers is limited. The present study indicated that there was a trend for fruit dry weight to decrease with increasing cane numbers. Fruit dry weight is largely made up of soluble solids (e.g., sugars) important in determining the quality of canned or processed fruit (Hendrix et al., 1977). For example, the relative sweetness or tartness of a fruit juice is determined by the ratio of soluble solids (brix) to acidity. Total solids also indicate the maturity level of the fruit (Pantastico and Subramanyam, 1975).

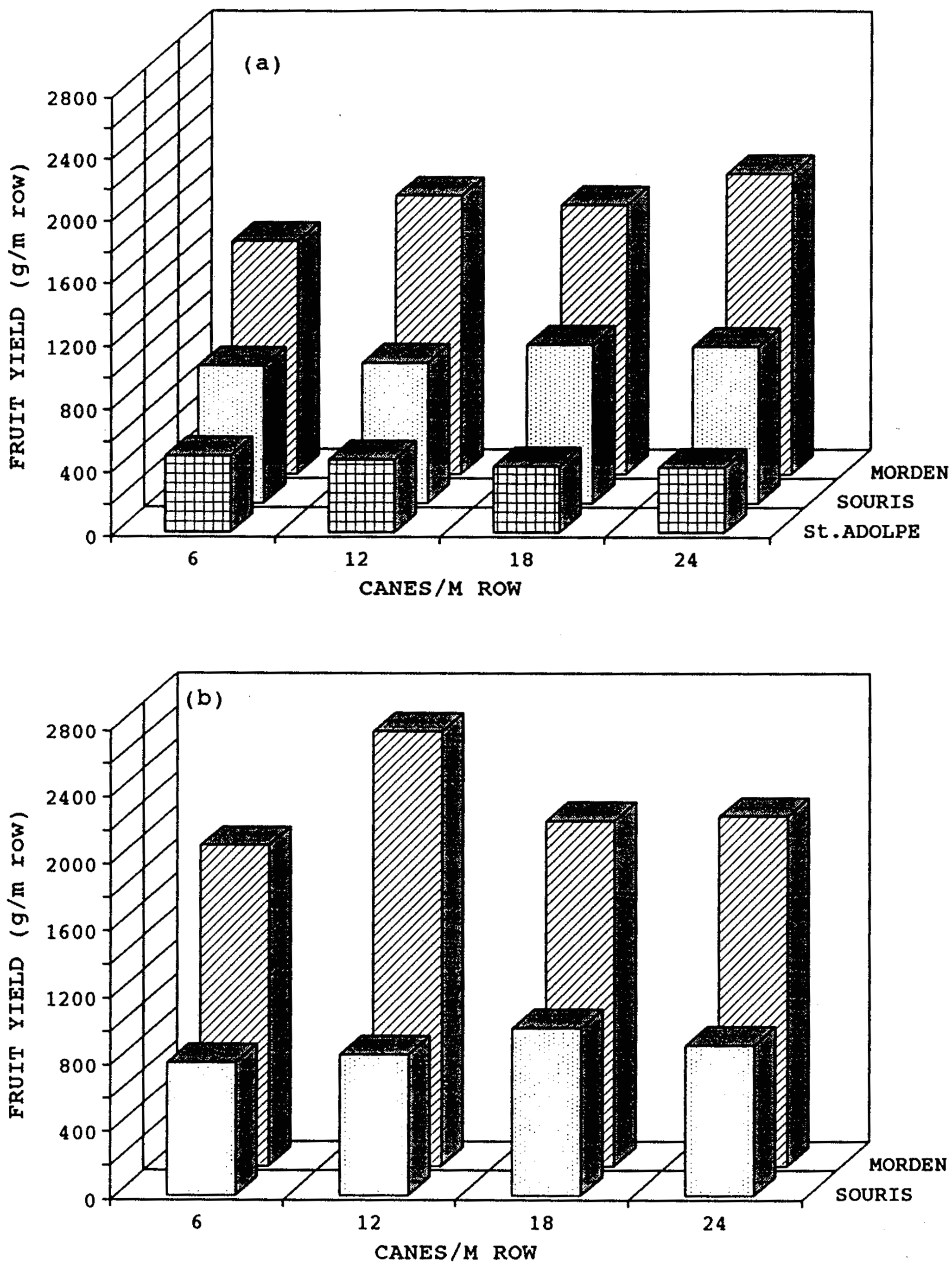


Figure 3. Effect of cane density on total fruit yield in the primocane bearing red raspberry '8114' in 1990 (a) and 1991 (b)

Table 1. Effect of varying cane density on the productivity of the primocane bearing red raspberry '8114' (St. Adolphe 1990)

canes per m row	fruit yield (g/cane)	number of fruits (per cane)	(per lat.)	fruit size (g/10 fruits)
6	69.4a	163.0a	7.9a	32.7a
12	40.1b	97.5b	5.4b	28.3b
18	25.6b	63.8c	3.8c	25.6c
24	19.0c	46.7c	3.6c	22.4d
C.V. (%)	24.5	18.9	11.9	4.4

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 2. Effect of varying cane density on the productivity of the primocane bearing red raspberry '8114' (Morden 1990)

canes per m row	fruit yield (g/cane)	number of fruits (per cane)	(per lat.)	fruit size (g/10 fruits)
6	245.7a	269.1a	11.4a	46.4a
12	147.7b	180.8b	8.1b	38.9b
18	95.3ab	145.9bc	7.3bc	31.7c
24	80.0ab	127.3c	6.3c	28.8d
C.V. (%)	24.8	18.4	10.5	4.6

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 3. Effect of varying cane density on the productivity of the primocane bearing red raspberry '8114' (Souris 1990)

canes per m row	fruit yield (g/cane)	number of fruits (per cane)	(per lat.)	fruit size (g/10 fruits)
6	144.4a	215.0a	9.7a	44.6a
12	73.9b	142.6b	7.1b	35.3b
18	55.6b	116.2b	6.3bc	31.5c
24	41.4b	94.8b	4.9c	27.9d
C.V. (%)	51.7	28.2	15.2	4.1

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 4. Effect of varying cane density on the productivity of the primocane bearing red raspberry '8114' (Morden 1991)

canes per m row	fruit yield (g/cane)	number of fruits (per cane)	(per lat.)	fruit size (g/10 fruits)	fruit dry weight (g/10 g)
6	318.3a	830.0a	27.8a	39.6a	1.50ab
12	216.6b	558.1b	20.4b	34.6a	1.63a
18	114.4c	350.0c	15.2c	30.1ab	1.53b
24	88.0c	325.0c	14.5c	26.5b	1.46b
C.V. (%)	15.7	10.4	9.0	35.4	5.9

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 5. Effect of varying cane density on the productivity of the primocane bearing red raspberry '8114' (Souris 1991)

canes per m row	fruit yield (g/cane)	number of fruits (per cane)	(per lat.)	fruit size (g/10 fruits)	fruit dry weight (g/10 g)
6	131.4a	454.3a	16.8a	35.3a	1.56a
12	70.4b	305.4b	12.9b	30.9b	1.62a
18	55.7bc	71.9c	4.2c	24.2c	1.55a
24	37.4c	63.3c	3.9c	20.2d	1.53a
C.V. (%)	15.6	15.8	17.8	6.3	7.8

values followed by the same letter are not significantly different at P<0.05 (LSD).

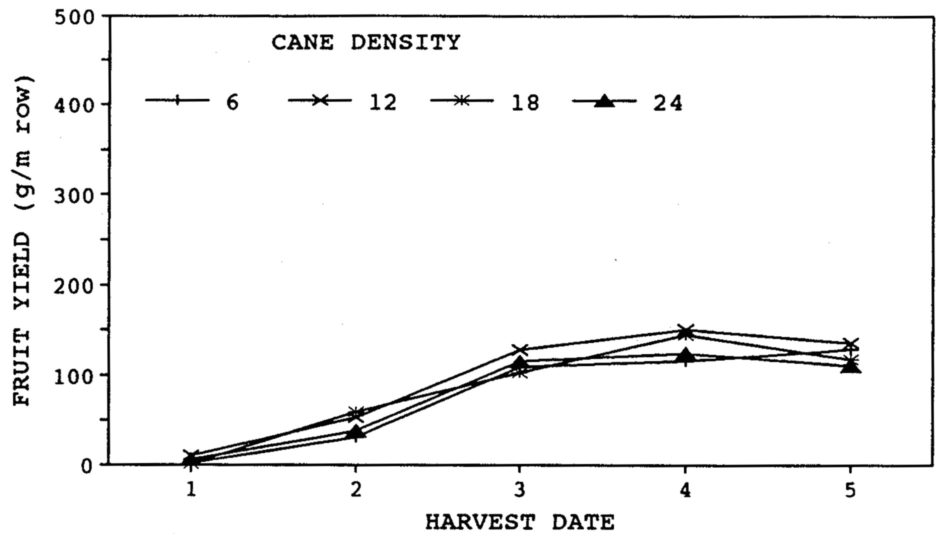


Figure 4. Effect of cane density on fruit yield by harvest date in the primocane bearing red raspberry '8114' at St. Adolphe, 1990

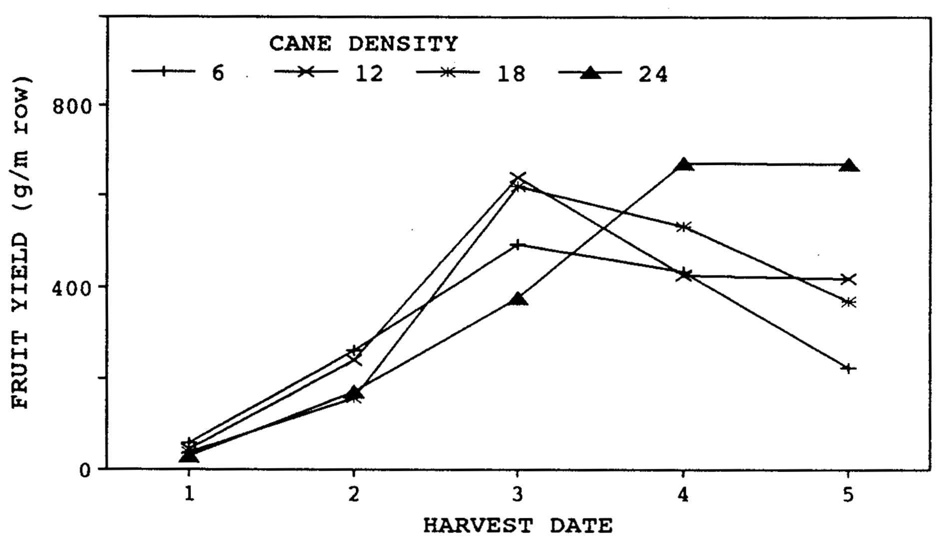


Figure 5. Effect of cane density on fruit yield by harvest date in the primocane bearing red raspberry '8114' at Morden, 1990

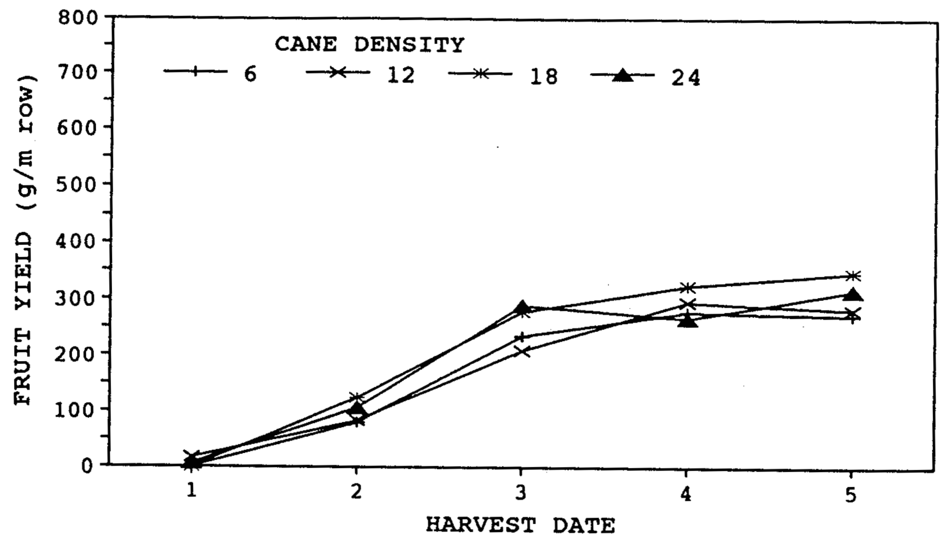


Figure 6. Effect of cane density on fruit yield by harvest date in the primocane bearing red raspberry '8114' at Souris, 1990

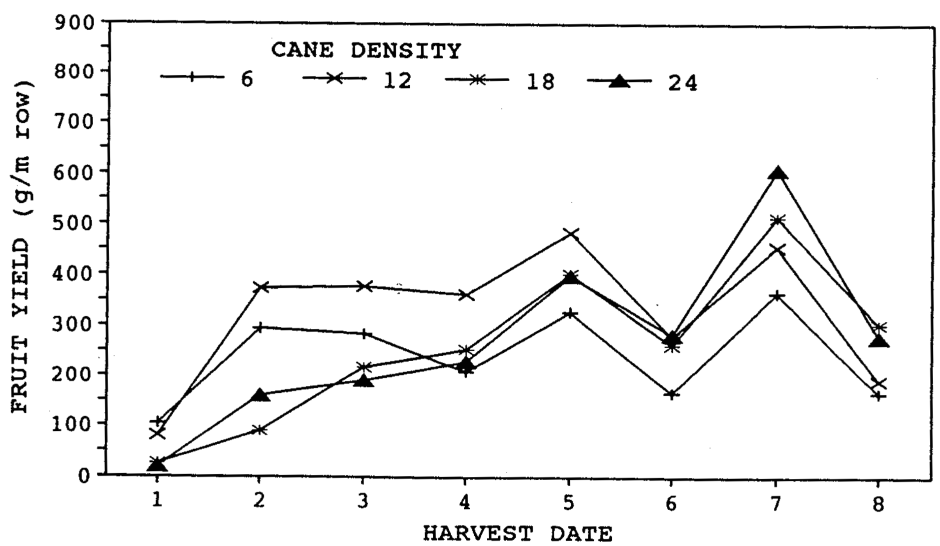


Figure 7. Effect of cane density on fruit yield by harvest date in the primocane bearing red raspberry '8114' at Morden, 1991

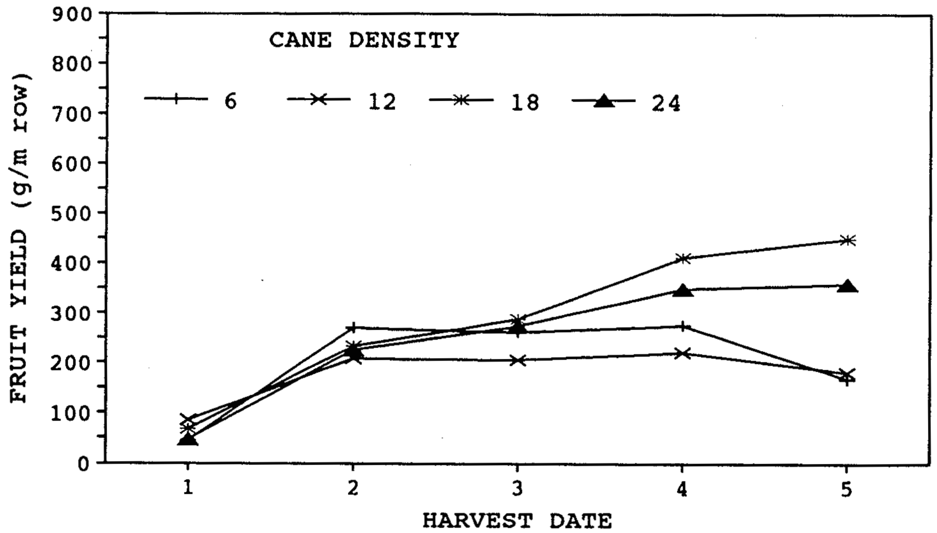


Figure 8. Effect of cane density on fruit yield by harvest date in the primocane bearing red raspberry '8114' at Souris, 1991

4.0.2. Cane Characteristics

4.0.2.0. Number of Nodes per Cane, Internode Length and Cane Height

Cane height increased with increasing cane density (Tables 6 to 10). The differences were significant except for St. Adolphe in 1990. In 1991, cane height was highest at 18 canes per meter row, then decreased at the 24 canes per meter row density. Cane height growth was affected similarly at all sites in both years but the sites differed. Morden tended to have more cane height growth than the other sites in both years.

Corresponding with cane height, internode length increased significantly with cane density up to a maximum at the 18 canes per meter row (Tables 9 and 10). Because internode length and cane height were positively related, internode length was clearly involved in the determination of cane height (Tables 9 and 10). Morden had longer internodes than Souris and there was a site*treatment interaction, partly because of the much longer internodes at Morden at high densities.

The number of nodes per cane was not consistently influenced by cane density. In 1990, the analysis by site and with sites combined showed that the number of nodes per cane was independent of density although cane height differed.

Therefore, although internodes were not measured in 1990, internode length appeared to be largely responsible for differences in cane height in that year. However, in 1991, the number of nodes per cane was significantly influenced by cane density (Tables 9 and 10). Moreover, the number of nodes per cane varied inversely with cane height in that the shorter canes had more nodes than the taller ones. The sites differed in both years with Morden having more nodes per cane than either St. Adolphe or Souris.

Both the internode length and cane height had an inverse relationship with yield per cane; conversely the number of nodes per cane was positively related with yield. The shorter canes out yielded the taller ones partly because of the greater number of nodes they developed. The result of this study confirmed those of others (Gundershein and Pritts, 1991; Hoover et al., 1988; Jennings and Dale, 1982) who indicated that canes with a large number of nodes yielded more than those with less. In a related study, Buszard (1986) found that the number of nodes per cane decreased with increasing cane density, but cane height was not affected by the number of canes per unit area. Convesrely, Fejer (1979) found that cane height increased with cane density. However, previous work has not shown how internode length varies with cane density and how canes with long internodes tend to be less productive.

The relationship between cane height and fruit yield is not clearly understood. On one hand, taller canes have been reported to be more productive than shorter ones (Crandall et al., 1974a; Darrow and Waldo, 1934; Wood et al., 1961), a result which contradicts that found in '8114'. On the other hand, tall canes have been shown to have fewer nodes in the cropping zone than short ones (Dale, 1990; Darrow and Waldo, 1934). The higher yielding ability of the taller canes has been attributed more fruits per lateral (Crandall et al., 1974a; Darrow and Waldo, 1934; Pepin et al., 1980). The results of the present study indicate that tall canes have neither more fruits per lateral nor higher yield per cane than the short ones. On the contrary, the shorter canes with more nodes per cane clearly out yielded the taller ones. The taller canes at high cane density performed poorly because they had fewer fruits per lateral. The shorter canes would only be a problem in the June bearing red raspberries where a sufficient height is required for a management process called tipping which is reputed to increase cane productivity (Crandall et al., 1974a; Jennings and Dale, 1982).

4.0.2.1. Cane Diameter

There was a decrease in diameter with increasing density resulting in an inverse relationship between cane diameter and cane height (Tables 6 to 10). In contrast, fruit yield per cane was directly related to cane diameter with thicker canes yielding better than thinner ones (Tables 6 to 10 and 1 to 5).

As cane diameter increased, the number of nodes per cane also increased. Canes at Morden tended to be thicker in both years than at the other sites.

A number of studies have attempted to show a direct relationship between cane diameter and fruit yield in red raspberries (Crandall et al., 1974a; 1974b; Darrow and Waldo, 1934; Pepin et al., 1980). The improved yielding ability of the thicker canes has been attributed to the fact that they store more available carbohydrate reserves per node compared to the thinner canes (Crandall et al., 1974a). However, only Buszard (1986) reported that cane diameter decreased with increasing cane density in 3 June bearing red raspberry cultivars 'Festival', 'Latham' and 'Newburg'. The relationship between cane number and cane diameter in the primocane bearing red raspberry selection '8114' is similar to that of Buszard (1986). One of the most attractive features of certain primocane bearing red raspberry cultivars is that they have sturdy, self supporting canes which reduces maintenance and management costs because they do not require expensive supporting structures such as trellises (Crandall and Daubeny, 1990; Lawrence, 1980a; Lockshin and Elfving, 1981). Therefore, the manipulation of cane numbers could improve not only the yield but the sturdiness of the canes.

Crandall et al. (1974b) and Jennings and Dale (1982) found that cane height and cane diameter were positively correlated in June bearing red raspberries. In the primocane bearer, '8114', cane height and cane diameter were inversely related in that the taller canes were thinner than the shorter canes. Thinning of forest stands has been shown to result in increases in diameter growth of remaining trees (Kramer and Kozlowski, 1979). At high densities, proportionately more reserves appear to go into height growth instead of diameter. The apparent contrary results of Crandall et al. (1974b) and Jennings and Dale (1982) to those of the present study may be related to the nature of the treatments imposed. Both Crandall et al. (1974b) and Jennings and Dale (1982) randomly selected canes from a population that had previously been treated uniformly and not subjected to any density pressure.

Table 6. Effect of varying cane density on cane characteristics of the primocane bearing red raspberry '8114' (St. Adolphe 1990)

canes per m row	cane height (cm)	nodes per cane	cane diam. (mm)	lateral branch angle	lateral length (cm)
6	90.2a	38.2a	9.8a	63.9a	18.8a
12	94.3a	39.7a	9.6a	54.6b	16.5a
18	96.7a	38.0a	7.9b	44.9c	11.7b
24	99.5a	39.8a	6.9b	36.3c	8.3c
C.V. (%)	7.9	4.6	7.4	13.8	15.3

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 7. Effect of varying cane density on cane characteristics of the primocane bearing red raspberry '8114' (Morden 1990)

canes per m row	cane height (cm)	nodes per cane	cane diam. (mm)	lateral branch angle	lateral length (cm)
6	106.5a	43.2a	13.2a	67.1a	30.6a
12	117.4b	44.1a	11.4b	56.0b	27.7a
18	121.3ab	43.8a	9.7c	45.5c	16.9b
24	127.7c	45.0a	9.3c	41.9c	14.0c
C.V. (%)	5.1	4.5	8.6	11.0	17.2

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 8. Effect of varying cane density on cane characteristics of the primocane bearing red raspberry '8114' (Souris 1990)

canes per m row	cane height (cm)	nodes per cane	cane diam. (mm)	lateral branch angle	lateral length (cm)
6	91.4ab	37.5a	11.8a	69.4a	26.2a
12	88.2a	36.9a	9.9b	60.3b	20.2b
18	99.9ab	38.4a	8.9c	48.8c	17.5b
24	104.1b	38.0a	8.3c	43.2d	12.2c
C.V. (%)	8.4	4.1	6.5	9.3	13.9

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 9. Effect of varying cane density on cane characteristics of the primocane bearing red raspberry '8114' (Morden 1991)

canes per m row	cane height (cm)	nodes per cane	internode length (cm)	cane diam. (mm)	lateral branch angle	lateral length (cm)
6	112.4a	46.5a	2.4a	14.6a	71.0a	37.7a
12	124.0ab	45.3a	2.7b	13.2b	65.5b	31.6b
18	136.8b	41.1b	3.3c	9.9c	49.0c	20.0c
24	126.6ab	39.1b	3.2c	8.6d	40.2d	14.1d
C.V. (%)	7.2	4.0	5.6	4.8	16.1	8.2

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 10. Effect of varying cane density on cane characteristics of the primocane bearing red raspberry '8114' (Souris 1991)

canes per m row	cane height (cm)	nodes per cane	internode length (cm)	cane diam. (mm)	lateral branch angle	lateral length (cm)
6	102.9ab	44.6a	2.2a	13.5a	71.5a	26.6a
12	95.8b	42.0ab	2.3a	10.7a	62.1b	24.6a
18	109.4a	39.5bc	2.7b	7.4b	44.5c	9.5b
24	104.4ab	37.9c	2.7b	6.6b	39.0d	9.5b
C.V. (%)	7.8	4.3	6.5	6.9	5.5	12.4

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 11. Effect of varying cane density on cane characteristics of the primocane bearing red raspberry '8114' (St. Adolphe 1990)

canes per m row	no. of lats. per cane (tot.)	(repr.)	(veg.)	percentage of repr. nodes	percentage of cane fruiting
6	22.0a	21.4a	0.7a	55.9a	86.9a
12	18.9a	17.1b	1.8ab	43.1b	83.7a
18	18.0b	13.9c	4.1bc	36.3bc	54.9b
24	16.5c	11.1c	5.4c	28.1c	37.5c
C.V. (%)	3.1	12.4	61.3	13.8	16.5

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 12. Effect of varying cane density on cane characteristics of the primocane bearing red raspberry '8114' (Morden 1990)

canes per m row	no. of lats. per cane (tot.)	(repr.)	(veg.)	percentage of repr. nodes	percentage of fruiting cane
6	23.3a	22.0a	1.3a	51.0a	89.8a
12	22.5a	20.2a	2.3a	45.2a	86.8a
18	20.4a	14.9b	5.3b	33.9b	65.9b
24	20.2a	14.4b	5.9b	32.2b	64.2b
C.V. (%)	10.2	11.8	45.4	11.1	11.6

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 13. Effect of varying cane density on cane characteristics of primocane bearing red raspberry '8114' (Souris 1990)

canes per m row	no. of laterals per cane (tot.)	(repr.)	(veg.)	percentage of repr. nodes	percentage of cane fruiting
6	22.1a	21.2a	0.9a	55.4a	95.1a
12	20.3ab	18.7a	1.6a	50.9a	93.8a
18	19.3b	13.9b	5.4b	36.6b	78.8b
24	18.6b	10.9c	7.7c	26.6c	75.9b
C.V. (%)	8.7	10.5	29.5	9.8	6.4

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 14. Effect of varying cane density on cane characteristics of primocane fruiting red raspberry '8114' (Morden 1991)

canes per m row	no. of lats. per cane (tot.)	(repr.)	(veg.)	percentage of repr. nodes	percentage of cane fruiting
6	29.9a	27.8a	2.1a	60.6a	93.8a
12	27.4ab	24.5b	2.9ab	54.3ab	75.4ab
18	24.0bc	20.0c	4.0b	48.9bc	74.5ab
24	21.4c	17.3c	4.1b	44.1c	60.2b
C.V. (%)	8.3	8.5	26.2	9.0	17.2

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 15. Effect of varying cane density on cane characteristics of the primocane bearing red raspberry '8114' (Souris 1991)

canes per m row	no. of lats. per cane (tot.)	(repr.)	(veg.)	percentage of repr. nodes	percentage of cane fruiting
6	27.5a	25.6a	1.9a	57.8a	94.4a
12	23.6a	21.4a	2.2ab	51.0a	90.4a
18	17.3b	13.6b	3.7c	34.5b	49.6b
24	15.5b	12.3b	3.2bc	32.4b	44.6b
C.V. (%)	11.8	15.1	24.6	16.8	10.3

values followed by the same letter are not significantly different at P<0.05 (LSD).

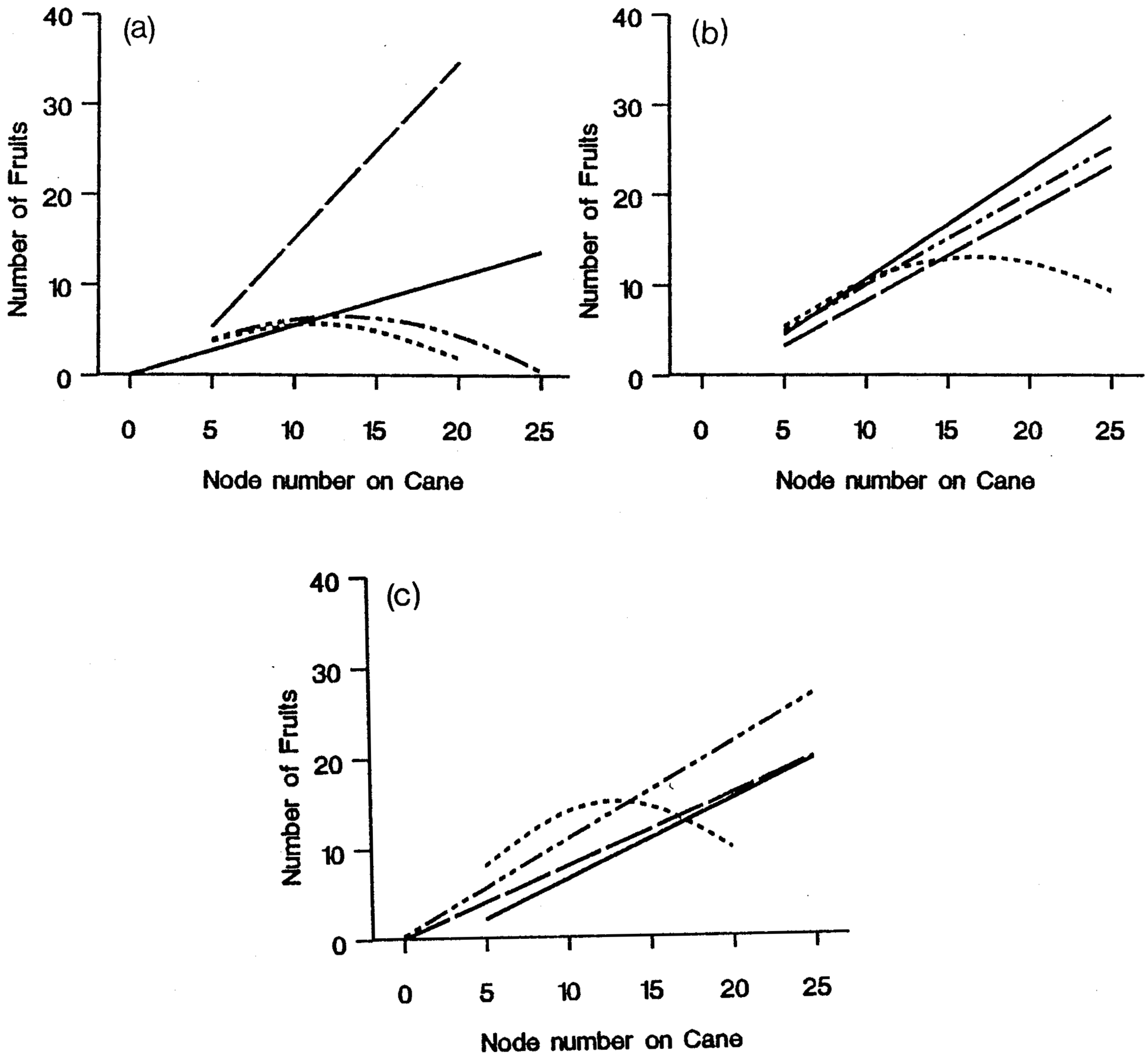


Figure 9. Regression lines for the number of fruits against the node position on the cane for primocane red raspberry '8114' in 1990 **(a) St. Adolphe:** 6 canes (______, Y = 0.0620+0.5481, r^2 = 0.67), 12 canes (___ ___ ___, Y = -4.4382+1.9613, r^2 = 0.57), 18 canes(___ _ _ ___, Y = -0.1813+1.0416-0.0405, r^2 = 0.34), 24 canes (_ _ _ , Y = -0.2332+1.0558-0.0474, r^2 = 0.42) **(b) Morden:** 6 canes (_ _, Y = -1.4295+1.2113, r^2 = 0.74), 12 canes (___ ___ _ , Y = -1.6172+0.9925, r^2 = 0.74), 18 canes(__ _ _ __, Y = -0.1348+1.0196, r^2 = 0.64), 24 canes (_ _ _ , Y = -2.3754+1.8419-0.0547, r^2 = 0.50) **(c) Souris:** 6 canes (___, Y = -0.2127+0.8728, r^2 = 0.68), 12 canes (___ ___ _ , Y = 0.0765+0.7875, r^2 = 0.65), 18 canes(__ _ _ __, Y = 0.3848+1.0515, r^2 = 0.60), 24 canes (_ _ _ , Y = -3.0873+2.7532-0.1054, r^2 = 0.58)

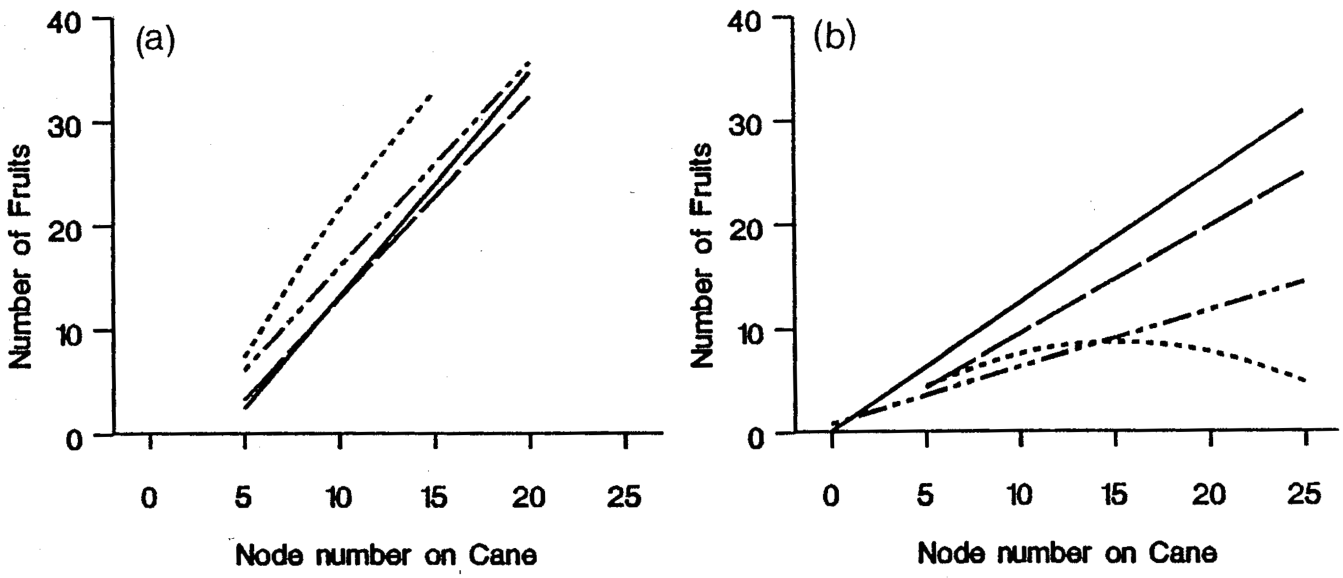


Figure 10. Regression lines for the number of fruits against the node position on the cane for primocane red raspberry '8114' in 1991 **(a) Morden:** 6 canes (_______, Y = -8.3136+2.1514, r^2 = 0.75), 12 canes (___ ___ ___, Y = -6.4245+1.9427, r^2 = 0.63), 18 canes(__ _ _ __, Y = -3.7071+1.9706, r^2 = 0.69), 24 canes (_ _ _ , Y = -9.4785+3.6393-0.0545, r^2 = 0.61) **(b) Souris:** 6 canes (_ _, Y = 0.1732+1.2336, r^2 = 0.58), 12 canes (___ ___ ___, Y = -0.8509+1.0346, r^2 = 0.48), 18 canes(__ _ _ __, Y = 0.8644+0.5456, r^2 = 0.47), 24 canes (_ _ _ , Y = -0.5073+1.1999-0.0394, r^2 = 0.31)

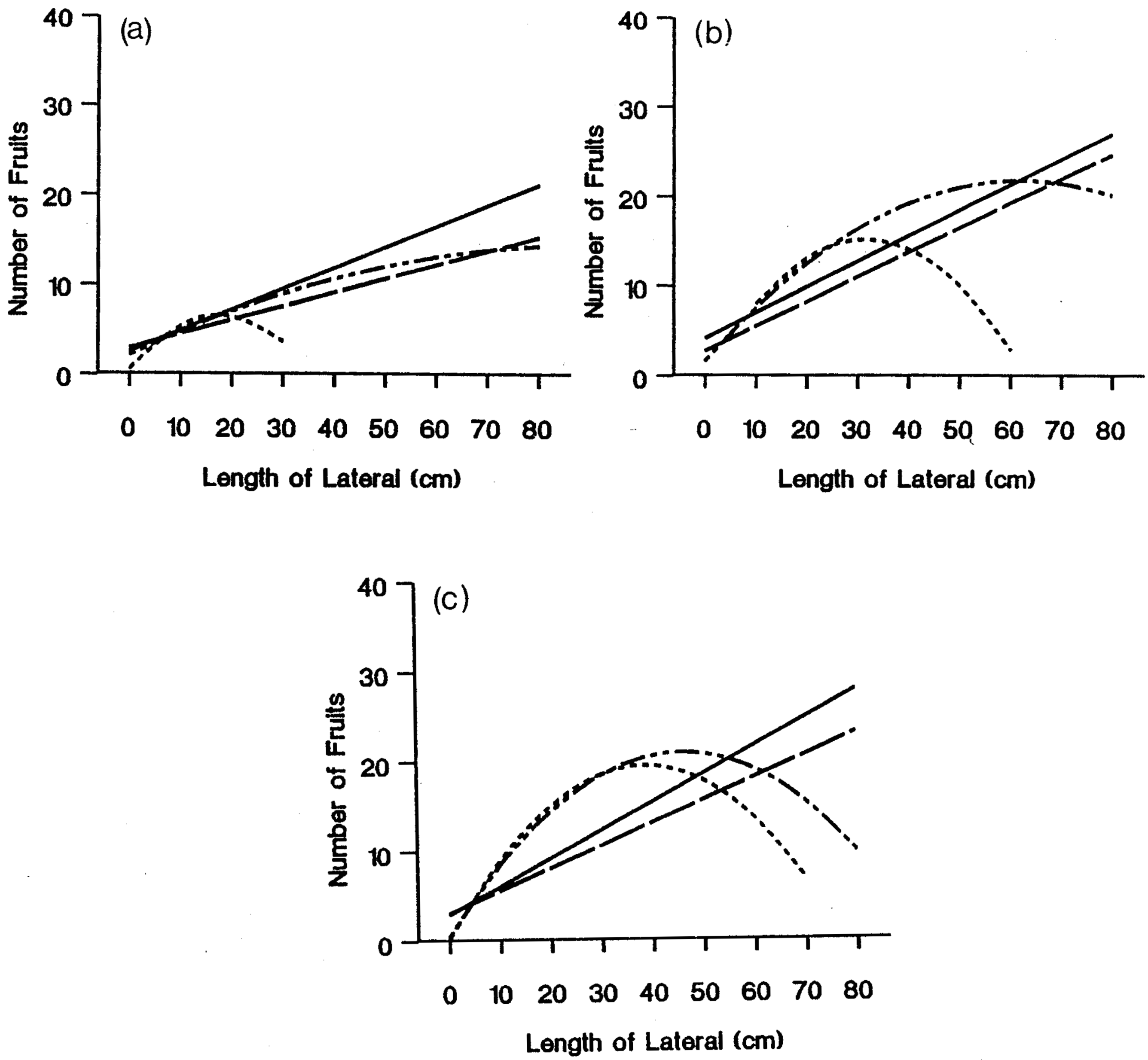


Figure 11. Regression lines for the number of fruits against lateral length for primocane red raspberry '8114' in 1990 **(a) St. Adolphe:** 6 canes (____, Y = 2.5092+0.2334, r^2 = 0.71), 12 canes (____ ____ ____, Y = 2.9611+0.1541, r^2 = 0.57), 18 canes(___ _ _ ___, Y = 2.1564+0.2695-0.0032, r^2 = 0.25), 24 canes (_ _ _ , Y = 0.5811+0.6619-0.018, r^2 = 0.45) **(b) Morden:** 6 canes (____, Y = 4.2206+0.2860, r^2 = 0.70), 12 canes (____ ____ ____, Y = 2.7746+0.2755, r^2 = 0.79), 18 canes(___ _ _ ___, Y = 1.6352+0.6484-0.0062, r^2 = 0.62), 24 canes (_ _ _ , Y = -0.1077+0.9675-0.0153, r^2 = 0.47) **(c) Souris:** 6 canes (____, Y = 2.9314+0.3127, r^2 = 0.82), 12 canes (____ ____ ____, Y = 3.0494+0.2511, r^2 = 0.72), 18 canes(___ _ _ ___, Y = 0.4889+0.8848-0.0096, r^2 = 0.68), 24 canes (_ _ _ , Y = -0.2162+0.9960-0.0129, r^2 = 0.68)

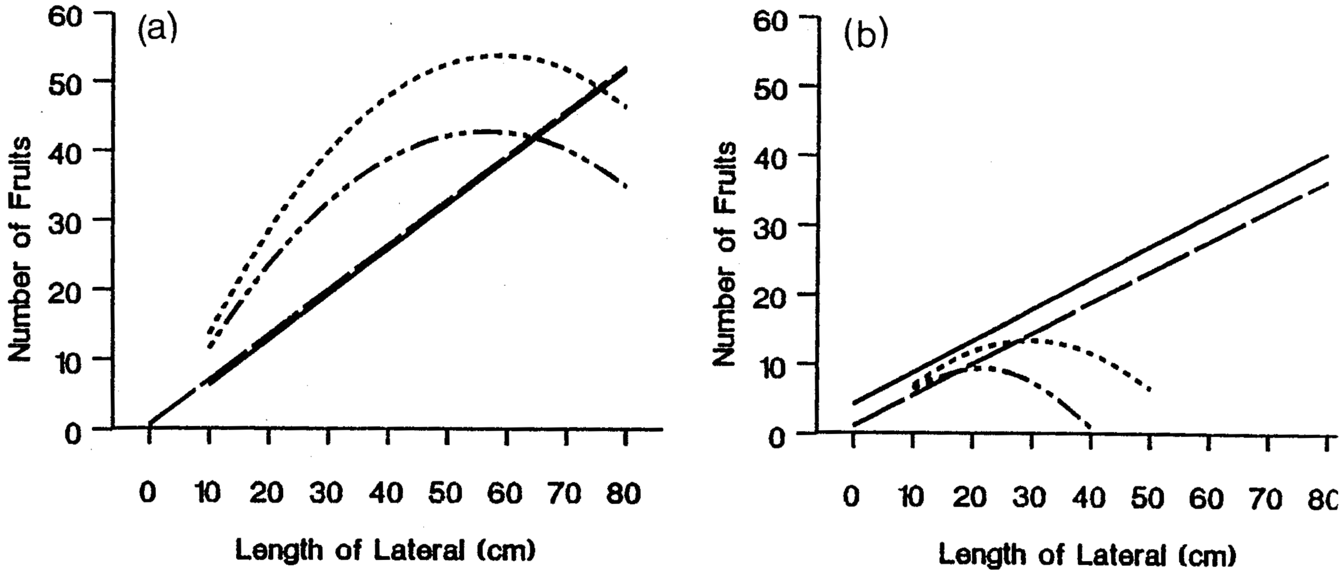


Figure 12. Regression lines for the number of fruits against lateral length for primocane red raspberry '8114' in 1991 **(a) Morden:** 6 canes (______, Y = -0.0993+0.6511, r^2 = 0.84), 12 canes (____ ____ ____, Y = 0.6518+0.6469, r^2 = 0.82), 18 canes(__ _ _ __, Y = -3.1684+1.6226-0.0143, r^2 = 0.72), 24 canes (_ _ _ , Y = -4.5172+1.9828-0.0168, r^2 = 0.74) **(b) Souris:** 6 canes (____, Y = 4.2934+0.4563, r^2 = 0.72), 12 canes (____ ____ ____, Y = 1.1425+0.4455, r^2 = 0.72), 18 canes(__ _ _ __, Y = -0.8499+0.9739-0.0232, r^2 = 0.47), 24 canes (_ _ _ , Y = -1.1811+0.9853-0.0166, r^2 = 0.43)

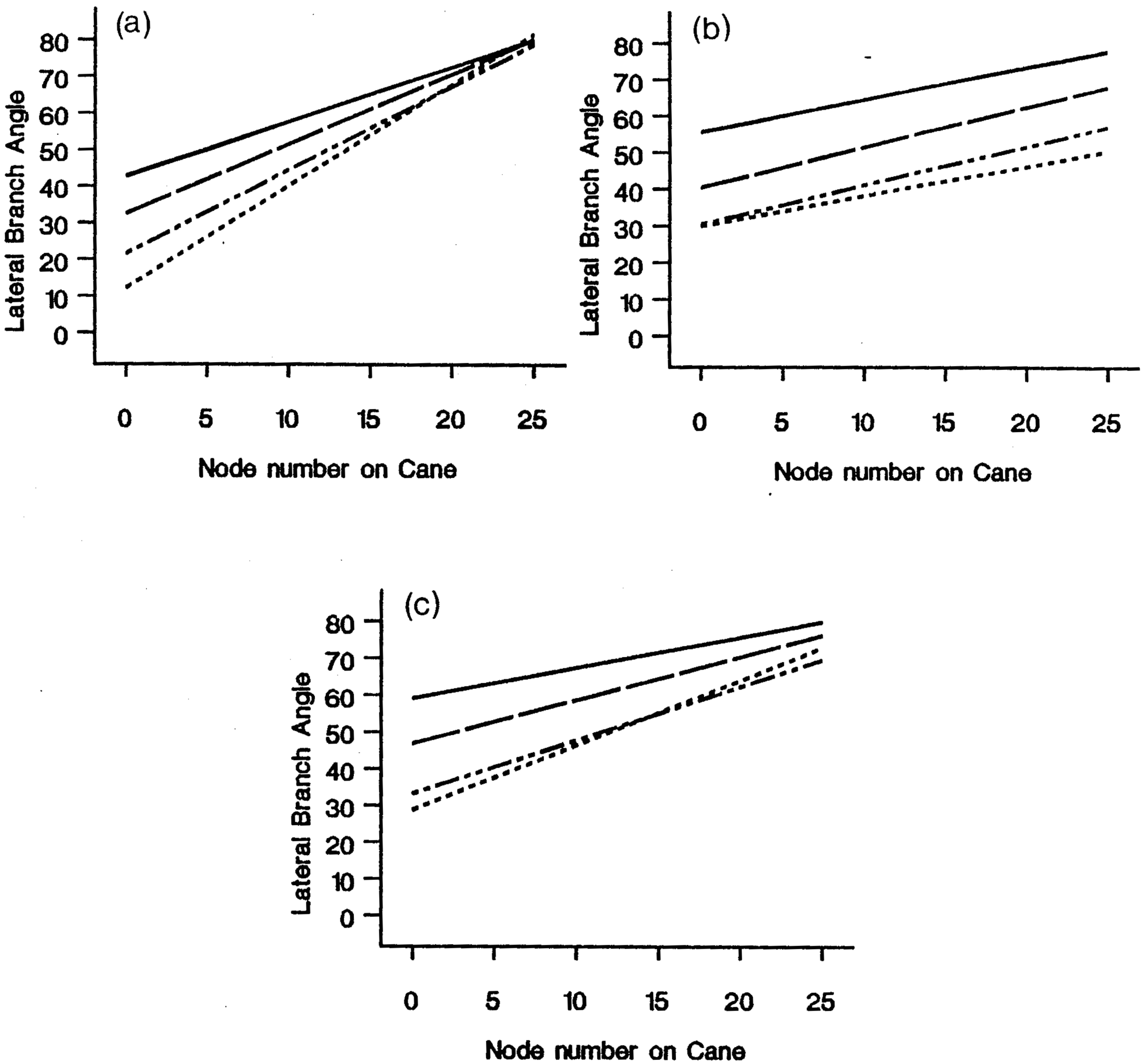


Figure 13. Regression lines for lateral branch angle against the node position on the cane for primocane red raspberry '8114' in 1990 **(a)** St. Adolphe: 6 canes (______, Y = 42.6058+1.5005, r^2 = 0.66), 12 canes (___ ___ ___, Y = 32.3662+1.9196, r^2 = 0.55), 18 canes(___ _ _ ___, Y = 21.4983+2.2977, r^2 = 0.68), 24 canes (_ _ _ , Y = 12.1808+2.2789, r^2 = 0.83) **(b)** Morden: 6 canes (_____, Y = 55.5058+0.9052, r^2 = 0.68), 12 canes (___ ___ ___, Y = 40.4131+1.1142, r^2 = 0.60), 18 canes(___ _ _ ___, Y = 30.4104+1.0770, r^2 = 0.61), 24 canes (_ _ _ , Y = -29.9645+0.8293, r^2 = 0.42) (c) Souris: 6 canes (_____, Y = 58.9960+0.8400, r^2 = 0.65), 12 canes (___ ___ ___, Y = 46.7803+1.1842, r^2 = 0.54), 18 canes(___ _ _ ___, Y = 33.0998+1.4651, r^2 = 0.71), 24 canes (_ _ _ , Y = -28.6906+1.7704, r^2 = 0.74)

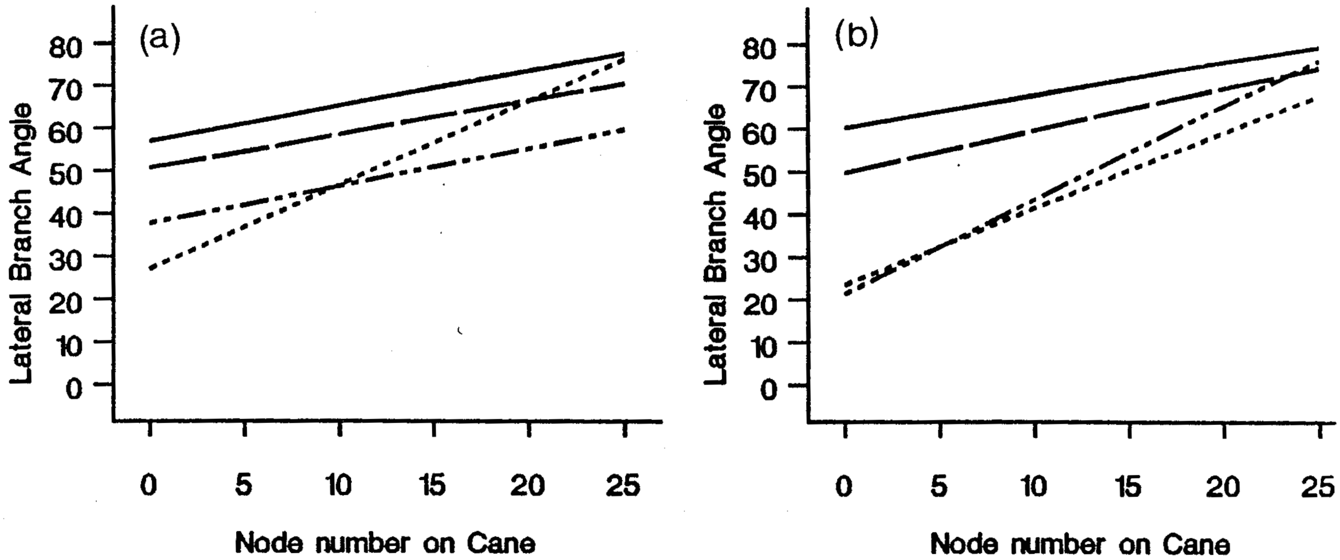


Figure 14. Regression lines for lateral branch angle against the node position on the cane for primocane red raspberry '8114' in 1991 **(a) Morden:** 6 canes (________, Y = 56.9373+0.8339, r^2 = 0.67), 12 canes (___ ___ ___, Y = 50.6077+0.7991, r^2 = 0.64), 18 canes(___ _ _ ___, Y = 37.6265+0.8824, r^2 = 0.58), 24 canes (_ _ _ , Y = -27.4829+1.1049, r^2 = 0.67) **(b) Souris:** 6 canes (_____, Y = 60.2068+0.7874, r^2 = 0.73), 12 canes (___ ___ ___, Y = 49.7229+1.0035, r^2 = 0.71), 18 canes(___ _ _ ___, Y = 21.4065+2.2141, r^2 = 0.80), 24 canes (_ _ _ , Y = -23.5764+1.7886, r^2 = 0.65)

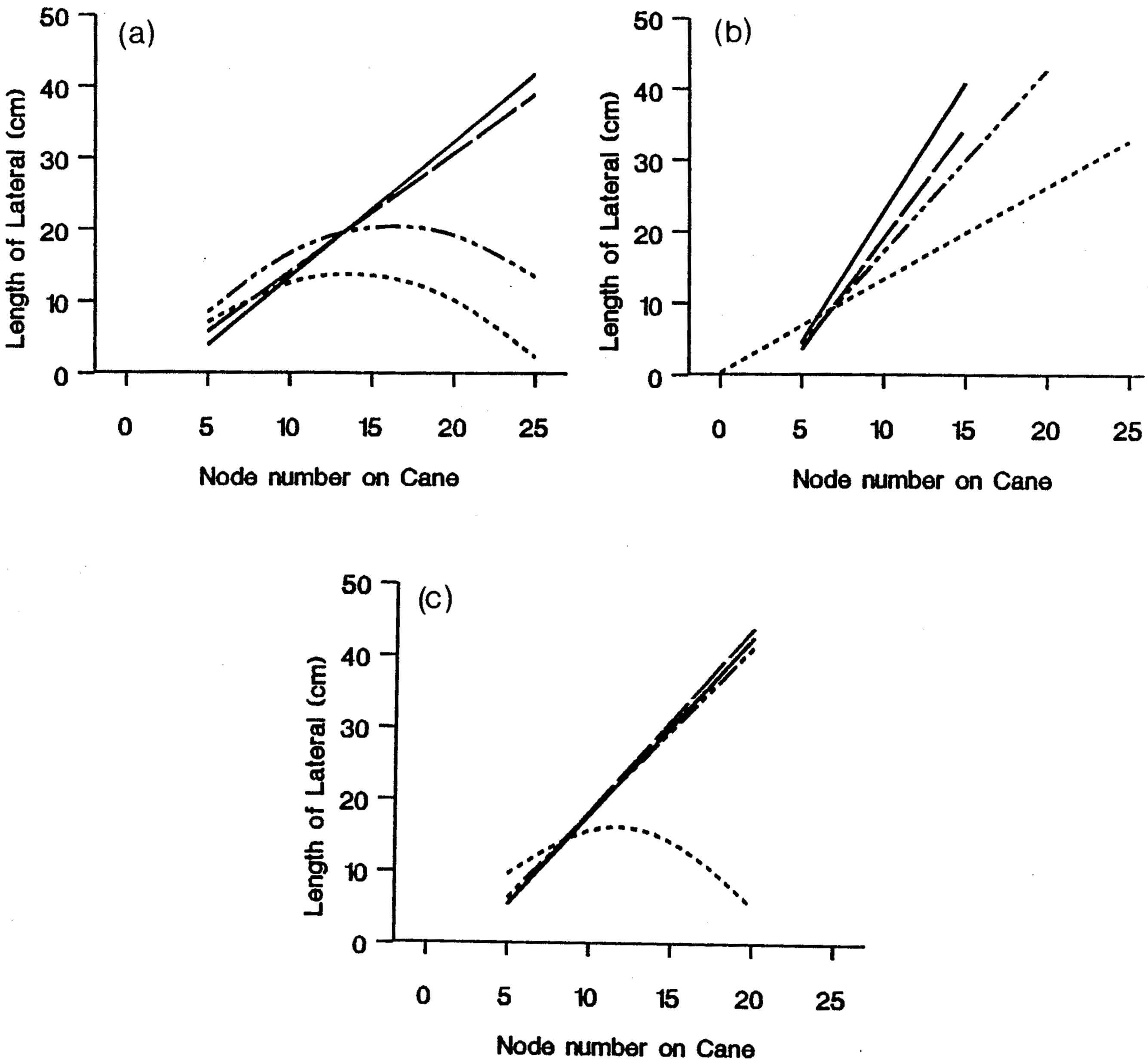


Figure 15. Regression lines for lateral length against node position on the cane for primocane red raspberry '8114' in 1990 **(a) St. Adolphe:** 6 canes (________, Y = -5.5609+1.8956, r^2 = 0.64), 12 canes (___ ___ ___, Y = -2.5007+1.6597, r^2 = 0.48), 18 canes(___ _ _ ___, Y = -4.3732+3.0325-0.0927, r^2 = 0.38), 24 canes (_ _ _ , Y = -2.8741+2.4307-0.0889, r^2 = 0.42) **(b) Morden:** 6 canes (_ _, Y = -13.5159+3.6380, r^2 = 0.78), 12 canes (____ ____ _ , Y = -11.9189+3.1084, r^2 = 0.73), 18 canes(__ _ _ __, Y = -8.4524+2.5729, r^2 = 0.57), 24 canes (_ _ _ , Y = 0.3591+1.3063, r^2 = 0.39) **(c) Souris:** 6 canes (_____, Y = -7.1848+2.5053, r^2 = 0.68), 12 canes (___ ___ ___, Y = -7.4919+2.5848, r^2 = 0.66), 18 canes(___ _ _ ___, Y = -5.3480+2.3452, r^2 = 0.42), 24 canes (_ _ _ , Y = -3.9611+3.4792-0.1508, r^2 = 0.31)

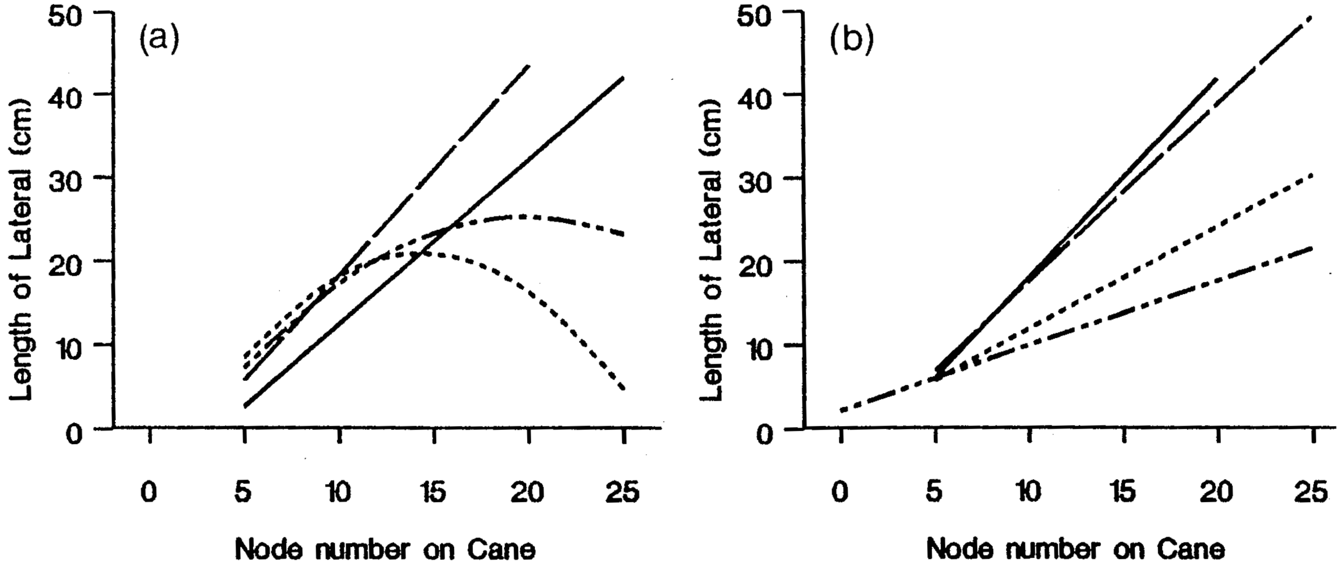


Figure 16. Regression lines for lateral length against node position on the cane for primocane red raspberry '8114' in 1991 **(a) Morden:** 6 canes (____, Y = -7.2301+1.9712, r^2 = 0.68), 12 canes (___ ___ ___, Y = -6.8602+2.5180, r^2 = 0.61), 18 canes(__ _ _ __, Y = -6.1662+3.2230-0.0808, r^2 = 0.27), 24 canes (_ _ _ , Y = -8.3684+4.0793, r^2 = 0.37) **(b) Souris:** 6 canes (______, Y = -5.8292+2.3917, r^2 = 0.61), 12 canes (____ ____ ____, Y = -3.6789+2.1294, r^2 = 0.62), 18 canes(__ _ _ __, Y = 2.1536+0.7761, r^2 = 0.48), 24 canes (_ _ _ , Y = -0.3515+1.2273, r^2 = 0.35)

4.0.2.2. Branching Angle of Primary Laterals

The branching angle of primary laterals or crotch angle differed significantly with the number of canes per meter row (Tables 6 to 10) and location on individual canes within treatments (Figures 13 and 14). Overall, the angle decreased with increasing number of canes per meter row but increased within each treatment from the tip to the bottom of the cane. The pattern was similar at all sites in both years. The lack of significant variation in lateral angle between sites suggests that spacing was probably the most important factor affecting branch angle. The relationship of branching angle of primary laterals to cane density in red raspberries is not well understood. Nevertheless, in some trees and other fruit crops, spacing has been shown to influence lateral branch angle and in turn patterns of fruit maturity on individual branches. Nelson et al. (1981) found that in Populus, when spacing between the trees was increased, the branching angle of the laterals increased. In peach fruit trees, Dann et al. (1990) showed that fruit from trees that were trained at more horizontal positions had higher Hunter 'a' values indicating better fruit colour than those trained at more vertical positions. In the same experiment, Dann et al. (1990) found that the more horizontal trees had more flowers per shoot, earlier fruit maturity and a higher fruit weight. Dann et al. (1990) attributed the observations to responses in endogenous rather than environmental factors.

In '8114', both branch angle and yield were correlated with cane density. Nevertheless, it was not possible to determine whether yield components were responding directly to branch angle changes. It has been shown in red raspberries that light penetration is better in horizontal than in vertical canopies (Palmer et al., 1987). An increase in light penetration and interception has been correlated with increased reproductive development (Hoover et al., 1988). It is probable that canes at low density may yield better because of the branching angle as it relates to light penetration and fruiting relationships but this would need to be specifically investigated.

4.0.2.3. Length of the Laterals

Plants grown at the Morden site had longer laterals overall at any level of cane density in both years than the other two sites. The St. Adolphe site had the shortest laterals. At all sites, laterals were much longer at the low than at the high cane density (Tables 6 to 10). However, the pattern of the response to density varied at the various sites resulting in significant interactions between site and treatment. For example, at Souris in 1991 (Table 10), the laterals were 3 times as long at the 6 cane density as they were at the 24 cane density. The interaction was mainly due to the fact that, at Morden, there were significant differences in lateral length at all levels of cane density (Table 9), while at Souris the differences were mainly between the two low and two high cane density treatments (Table 10). Conversely, the relationship among cane treatments with length of laterals was more linear at the Souris site in 1990. In 1991, treatment effects were more clearly seperated between the low and high cane density due to the early application of treatments. Competition was removed early allowing time for the full expression of yield components at low cane density i.e., yield component compensation.

Along individual canes, laterals increased in length progressively from the tip to the bottom (Figures 15 and 16). At low cane density, the increase in lateral length from the tip to the bottom of the cane was strongly linear, while at the high cane density, the relationship was more curvilinear resulting from the occurrence of many vegetative laterals towards the bottom of the cane which were relatively short. Where the relationship was linear at the high cane density, the r^2 values were low again due to the occurence of many vegetative laterals towards the bottom of the cane. In '8114', reducing cane numbers had the effect of increasing the length and improving the potential yield of the lower laterals of the fruiting canes which resulted in the different regression curves.

The linear and curvilinear observations in the length of laterals along the cane agree with those of Dale (1979) who found that, although most raspberry genotypes exhibited the basipetal increase in lateral length towards the base of the cane, there were exceptions. In some genotypes, lateral length increased basipetally but declined near the base giving a curvilinear relationship. The possible cause of the curvilinear relationship is not clear. Variation in the management, environment or age of the genotype may affect the relationship between lateral characteristics, their expression and position on the cane (Dale, 1979). Removal of primocanes, which is equivalent to decreasing cane density resulted in an increase in the length of the lower laterals on fruiting canes in a number of June bearing red raspberry cultivars (Dale, 1979). Similarly, in comparing an annual and a biennial cropping system in the June bearing red raspberry cultivar 'Glen Clova', Dale (1979) found canes in the less crowded biennial system to have longer lower laterals. Crandall et al. (1974a) maintained 6, 9 and 12 canes per hill in the June bearing red raspberry cultivar 'Washington' and found that canes from the 6 canes per hill treatment always had laterals that were longer than those from either the 9 or the 12 canes per hill treatment. It is not clear whether the canes were all fruiting or they were a mixture of both primocanes and fruiting canes. In any event, it is possible that such responses are related to an increase in available light (Lawson and Wiseman, 1983).

4.0.2.4. Number of Laterals per Cane, Percent Reproductive Nodes and Percent Fruiting Cane

Cane density influenced the number of laterals per cane at all sites in both years except for the total number of laterals at Morden in 1990 (Tables 11 to 15). At high cane numbers, both the total number of laterals and the number which became reproductive decreased. Moreover, canes from the high cane density treatments had more vegetative laterals (Tables 11 to 15). In other words, the percentage of reproductive nodes decreased. Concomitantly, the proportion of cane occupied by reproductive laterals varied with density. There was more cane fruiting at low than at high cane density. The number of laterals, percent reproductive nodes, and percent fruiting cane varied directly with yield per cane and cane diameter. As was the case for total nodes per cane, the thicker canes had more laterals overall and more reproductive laterals.

The number of laterals and percent reproductive nodes have been acknowledged as important yield components in both the June and primocane bearing red raspberries (Crandall, 1980; Dale, 1988; Nehrbas and Pritts, 1988a; Wood et al., 1961; Hoover et al., 1986; 1988; Lawson and Wiseman, 1983). Crandall et al. (1974a) demonstrated that at 6 canes per hill, the canes had more fruiting laterals than canes at either 9 or 12 canes per hill in two June bearing red raspberry cultivars

'Washington' and 'Puyallup'. The effect of cultural practices such as cane density on the proportion of vegetative and reproductive laterals, total and reproductive nodes and proportion of fruiting cane has not been demonstrated previously in the primocane bearing red raspberries. The present study demonstrated that increasing cane numbers increased the number of laterals that remained vegetative and decreased the number that became reproductive. The small number of reproductive laterals at high cane numbers have been attributed to the low amount of light reaching the cane (Hoover et al., 1988). According to Hoover et al. (1988), sufficient light levels are necessary for floral bud intiation. Moreover, light is necessary for the release and continued growth of lateral shoots.

Lack of prolific lateral branch development is one of the factors responsible for the poor yielding ability of primocane bearing red raspberries as compared to the June bearing types (Hoover et al., 1986). In the present study, it was possible to increase not only the total number of laterals per cane but also the number that became reproductive and minimise the number that remained vegetative by manipulation of cane numbers. High numbers of laterals that remain vegetative are considered a wasted allocation of dry matter (Waister and Wright, 1989).

4.1. Nitrogen Experiment

4.1.0. Fruit Yield

Except for Morden in 1990, added nitrogen significantly increased fruit yield per meter row in the primocane bearing red raspberry selection '8008' at all sites in both years (Figure 17). In containers, fruit yield also increased with nitrogen level (Table 21). The result in containers corresponded with field observations under conditions of low nitrate-nitrogen (e.g., Souris). Added nitrogen affected fruit yield similarly at all sites in both years. The sites differed significantly in both years. It was apparent that the pattern of response was the same in both years although the nitrogen rates were different. Souris appeared to be more responsive than either Morden or St. Adolphe. This result is supported by the soil test results which showed that Souris had consistently lower levels of nitrate-nitrogen (Appendix 1, Tables A1.1 and A1.2).

At Morden, the response to added nitrogen was generally less than the other two sites and this corresponded with the overall greater nitrate-nitrogen at this site (Appendix 1, Tables A1.1 and A1.2). Fruit yield response to the application of nitrogen was better in 1991 when nitrogen was applied in May than in 1990 when nitrogen was applied in mid June. The result would support Crandall's (1980) conclusion that early spring nitrogen applications were more efficient than any other options in increasing fruit yield. A close examination (Figure 17) reveals that there was a trend for fruit yield to increase with increasing nitrogen level at Morden in 1990 but the differences were not significant indicating considerable variability in the data. The standard error was large at the 0 level of nitrogen (s.e. 396). Two plots at the 0 level of nitrogen yielded just as high as the high nitrogen level. Thus, other factors such as variability in inherent soil nitrate-nitrogen at the Morden site may have influenced fruit yield in addition to the delayed application of nitrogen (see Appendix 1, Tables A1.1 and A1.2). There is evidence in other fruit crops that late application of nitrogen may reduce treatment effects of added nitrogen. Fisher et al. (1948) found that late application of nitrogen in apples reduced treatment effects and in peaches, Harris and Boynton (1952) and Schneider and McClung (1957) found that fruit response to the application of nitrogen was non significant in the first year but showed significant responses in the following years. In the June bearing red raspberry cultivar 'Willamette', Kowalenko (1982) obtained lower fruit yields at the high than at the low level of nitrogen in the first year. It was suggested that in the first year, no differences were observed because of natural heterogeneity in soil nitrate-nitrogen and that the plants needed a period of time to acclimatise to the nitrogen treatments (Harris and Boynton, 1952; Schneider and

McClung, 1957). Generally, however, the application of nitrogen has been shown repeatedly to increase fruit yields in red raspberries (Cheng, 1982; Kowalenko, 1982; Martin et al., 1980; Smolarz et al., 1982).

Primocane bearing red raspberries respond differently to nitrogen application under different pedogenetic conditions even for the same genotype. The plants of the selection '8008' were most responsive to nitrogen on the light sandy soils low in nitrate-nitrogen (see Appendix 1, Tables A1.1 and A1.2) and in soilless medium in containers. For example there was an almost three fold increase in yield between the lowest and the high nitrogen treatments in both years at Souris (Figure 17). In addition the optimum rates appear to vary with site. It appears that the 300 kg nitrogen rate at Morden may have been optimum while at Souris, the higher nitrogen rate of 450 kg still gave a yield increase. It is not clear from the present work if fruit yields would increase at a higher nitrogen rate at Souris. However, it has seldom been shown that fruit yield increases continuously over the entire range of nitrogen levels (Fisher and Cook, 1950), and Chandler (1920) showed that excess nitrogen could depress yields which was suggested by the trend at Morden in 1991. Generally, a medium or slightly above medium rate may be the most appropriate for optimum fruit yields (Benson et al., 1957). Oberly and Boynton (1966) also argued that when nitrogen was not so low as to limit vegetative growth, increased nitrogen fertilization would not increase fruit production. Other workers have indicated that with favourable cultural practices and climatic conditions, it is possible to increase fruit yields with the application of nitrogen if nitrogen is deficient (Claypool, 1975). For example, in peaches, Harris and Boynton (1952) reported a universal response to the application of nitrogenous fertilizers except on very fertile soils or where some other factor limited growth severely. It appears that at Souris, the optimum level may not yet have been reached and the levels applied still limited both vegetative growth and fruiting. It should be pointed out, however, that besides increasing fruit yields, high nitrogen could also lead to increased incidences of cane diseases such as spur blight (Goode, 1970). Nevertheless, it is clear that Morden and Souris require different levels of nitrogen for optimum fruit yields. In this regard, Strong (1936) and Woods (1935) indicated that the prescription of a general fertilizer rate was often misleading because of the wide range of soil types on which raspberries were grown and the many genotypes cultivated, a point which was supported by the results of the present study. It also appears that primocane bearing red raspberries may require more nitrogen for optimum fruit yields than the June bearing types (Crandall and Daubeny, 1990). In the latter, nitrogen levels of between 70 and 280 kg nitrogen per ha have been recommended (Crandall and Daubeny, 1990).

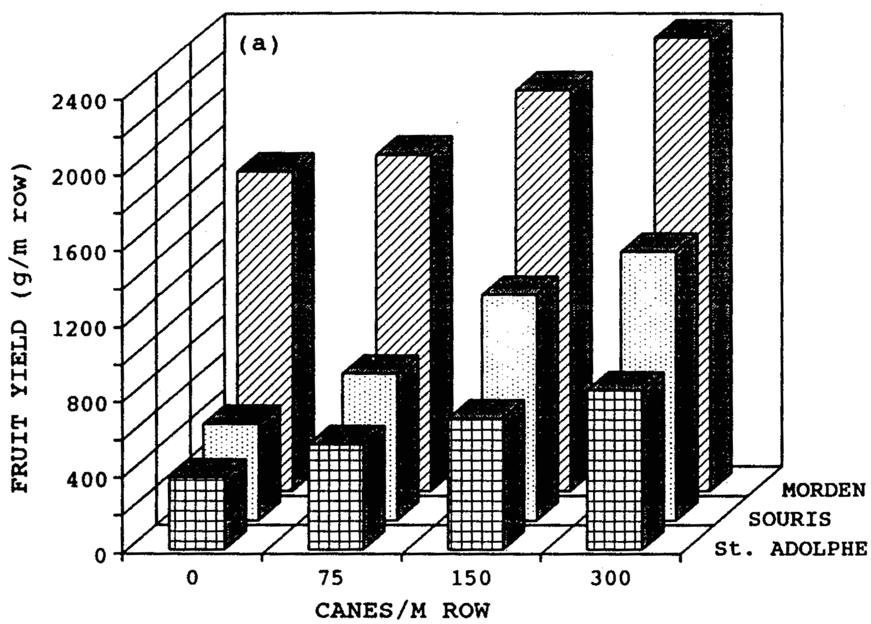
An examination of fruit yield by harvest date indicates that nitrogen increased initial yields (Figures 18 to 22). In other words, the application of nitrogen advanced fruit harvest in the season. Not only was fruit harvest advanced but fruit yield at each harvest date was constantly high throughout the season. In primocane bearing red raspberries, advancing the fruit season and maintaining high fruit yields throughout the season would mean growers realise high yields before the fall freeze.

4.1.0.1. Number of Fruits per Lateral and per Cane

The response in the number of fruits per lateral and per cane for both field and container experiments was similar to that for yield per meter row and per container (Tables 16 to 21) indicating that these components contributed significantly to overall fruit yield because cane number was held constant. Added nitrogen increased the number of fruits per lateral and per cane in both nitrogen experiments (Tables 16 to 21). The sites differed only in 1990, in which St. Adolphe had a very low number of fruits per lateral and per cane compared to the other sites. There was no site*nitrogen interaction in either year. Although the application of nitrogen to red raspberries has frequently been shown to increase fruit yields, relatively few studies show the yield components involved (Cherry, 1931; Lawson and Waister, 1972). In apples, Harley et al. (1933) found that the application of nitrogen caused the development of an early large leaf surface area which subsequently supported a larger crop. It can be argued that nitrogen influenced the development of a large and efficient leaf surface prior to flower initiation and fruiting which in turn may have influenced the number of flowers and fruit that developed to maturity.

A regression analysis of the number of fruits in relation to location of the lateral on the cane revealed a linear increase from the tip to the bottom of the cane (Figures 23 and 24). In some cases, the relationship at 0 kg nitrogen was curvilinear. Such relationships have been reported for some June-bearing cultivars (Dale, 1979) and indicates the importance of lower laterals in overall fruit production. The slope of the regressions indicates that the addition of nitrogen increased the productivity of lower laterals but had less effect on the fruit production of upper laterals. The pattern was similar for both years at all sites.

A similar analysis for the number of fruits in relation to lateral length was done and it was found that at high nitrogen level, the increase in the number of fruits with length of lateral was linear (Figures 25 and 26). At low nitrogen, the relationship was curvilinear indicating fewer number of fruits per length of lateral (Figures 25 and 26). The addition of nitrogen therefore improved the fruitfulness of lower laterals.



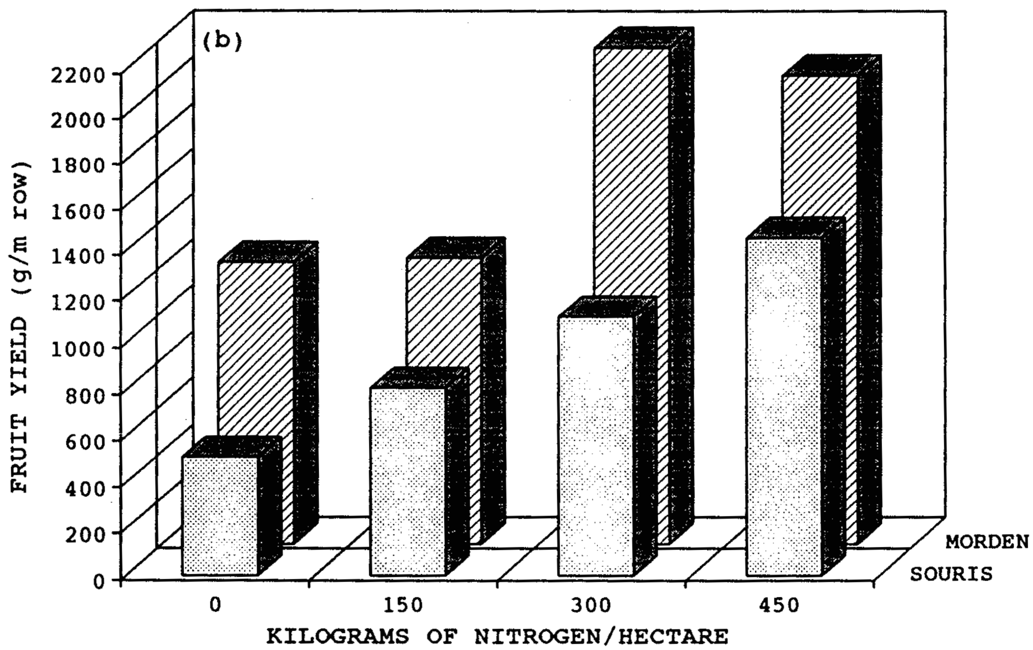


Figure 17. Effect of nitrogen level on total fruit yield in the primocane bearing red raspberry '8008' in 1990 (a) and 1991 (b)

Table 16. Effect of varying nitrogen levels on the productivity of the primocane bearing red raspberry '8008' (St.Adolphe 1990)

kg N per ha	number of fruits (per cane)	(per lat.)	fruit size (g/10 fruits)
0	30.3a	2.7a	13.5a
75	49.5ab	3.5a	18.8b
150	79.5b	5.7b	23.0c
300	122.1c	7.5b	27.4d
C.V. (%)	30.0	25.0	7.5

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 17. Effect of varying nitrogen levels on the productivity of the primocane bearing red raspberry '8008' (Morden 1990)

kg N per ha	number of fruits (per cane)	(per lat.)
0	103.1a	5.8a
75	115.4ab	6.9ab
150	133.7ab	7.5b
300	152.0b	8.3b
C.V. (%)	21.1	14.8

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 18. Effect of varying nitrogen levels on the productivity of the primocane bearing red raspberry '8008' (Souris 1990)

kg N per ha	number of fruits (per cane)	number of fruits (per lat.)	fruit size (g/10 fruits)
0	62.4a	4.6a	14.6a
75	92.4b	6.3b	18.1b
150	154.4c	9.1c	23.5c
300	190.7d	10.7d	28.3d
C.V. (%)	12.8	10.8	5.2

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 19. Effect of varying nitrogen levels on the productivity of the primocane bearing red raspberry '8008' (Morden 1991)

kg N per ha	number of fruits (per cane)	number of fruits (per lat.)	fruit size (g/10 fruits)	fruit dry weight (g/10 g)
0	51.0a	3.9a	16.7a	1.45a
150	62.3a	4.4a	18.4a	1.47a
300	397.5b	18.8b	28.9b	1.62a
450	388.5b	16.7b	27.7b	1.55a
C.V. (%)	32.8	30.0	9.5	9.3

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 20. Effect of varying nitrogen levels on the productivity of the primocane bearing red raspberry '8008' (Souris 1991)

kg N per ha	number of fruits (per cane)	(per lat.)	fruit size (g/10 fruits)	fruit dry weight (g/10 g)
0	30.5a	2.5a	11.4a	1.45a
150	53.1a	3.9a	13.0b	1.52a
300	237.8b	12.9b	21.5c	1.70b
450	387.9c	17.9c	26.6d	1.60c
C.V. (%)	32.8	18.2	5.0	3.2

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 21. Effect of varying nitrogen levels on the productivity of primocane fruiting red raspberry '8008' (Greenhouse 1991)

g N per cont.	yield (g/cont.)	no. of flowers (per cane)	(per lat.)	no.of fruits (per cane)	(per lat.)
0.000	62.2a	79.3a	5.6a	56.0a	4.1a
0.435	73.0a	93.6a	5.6a	70.2a	5.2a
0.870	131.3b	175.4b	8.6b	139.8b	6.8b
1.740	177.2c	264.0c	10.6c	230.6c	9.2c
3.480	230.9d	381.8d	14.3d	323.8d	12.2d
C.V. (%)	37.7	52.4	44.9	51.7	46.2

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 22. Effect of varying nitrogen levels on the productivity of primocane fruiting red raspberry '8008' (Greenhouse 1991)

g N per cont.	fruit size (g/ 10 fr.)	fruit dry wt. (g/ 10 g)	perc. fruit set	no. of lats. (tot.)	(repr.)	(veg.)	perc. repr. nodes
0.000	10.6a	1.91a	71.7a	13.5a	13.3a	0.3a	40.9a
0.435	11.0b	2.18b	75.4b	16.8b	15.2b	1.6b	43.7b
0.870	13.3c	2.20bc	78.7c	19.6c	17.2c	2.6c	46.6c
1.740	14.4d	2.28c	88.3d	24.6d	19.6d	3.8d	49.9d
3.480	16.6e	2.13b	85.7d	26.6e	22.8e	5.0d	57.1e
C.V. (%)	4.3	10.0	7.3	16.9	16.2	79.9	12.0

values followed by the same letter are not significantly different at $P<0.05$ (LSD).

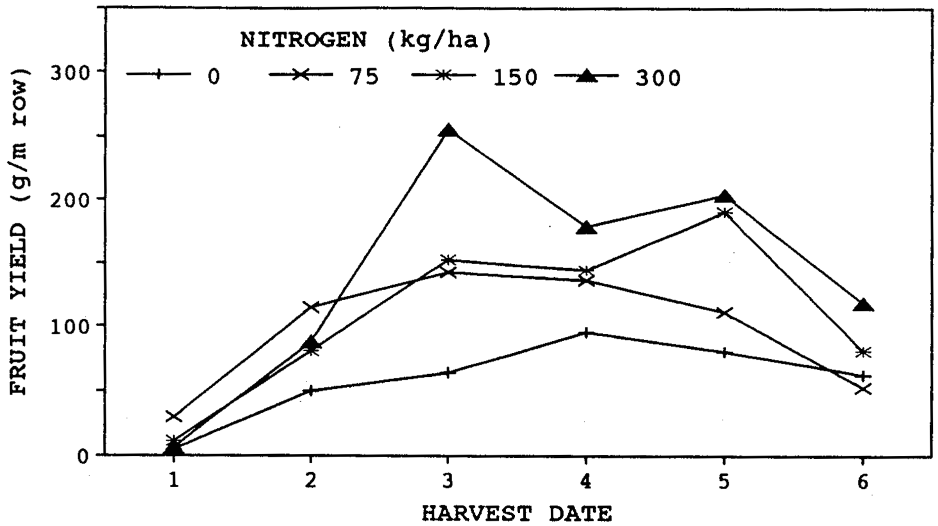


Figure 18. Effect of nitrogen level on fruit yield by harvest date in the primocane bearing red raspberry '8008' at St. Adolphe, 1990

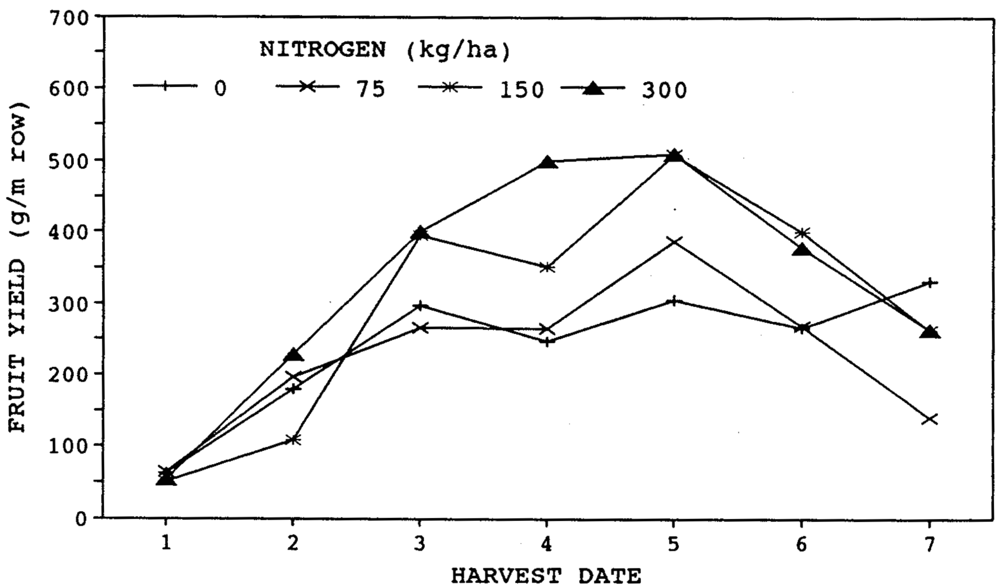


Figure 19. Effect of nitrogen level on fruit yield by harvest date in the primocane bearing red raspberry '8008' at Morden, 1990

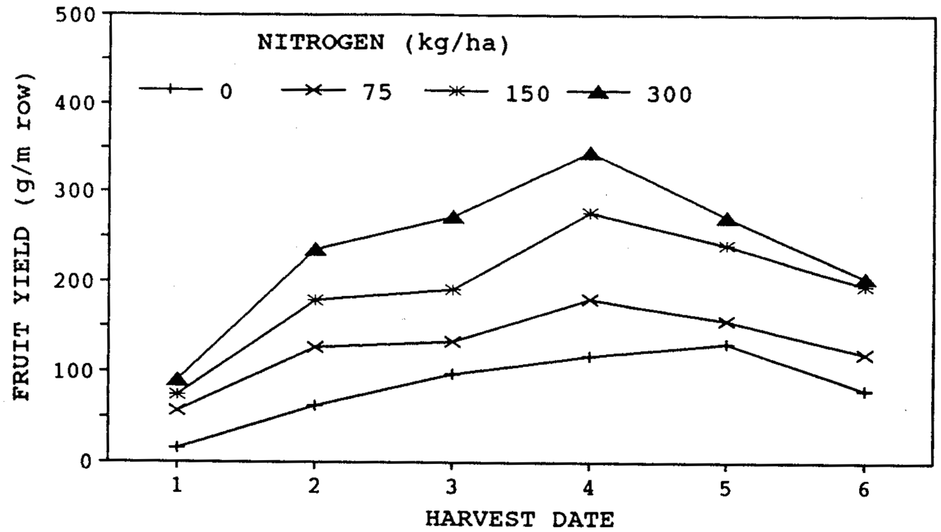


Figure 20. Effect of nitrogen level on fruit yield by harvest date in the primocane bearing red raspberry '8008' at Souris, 1990

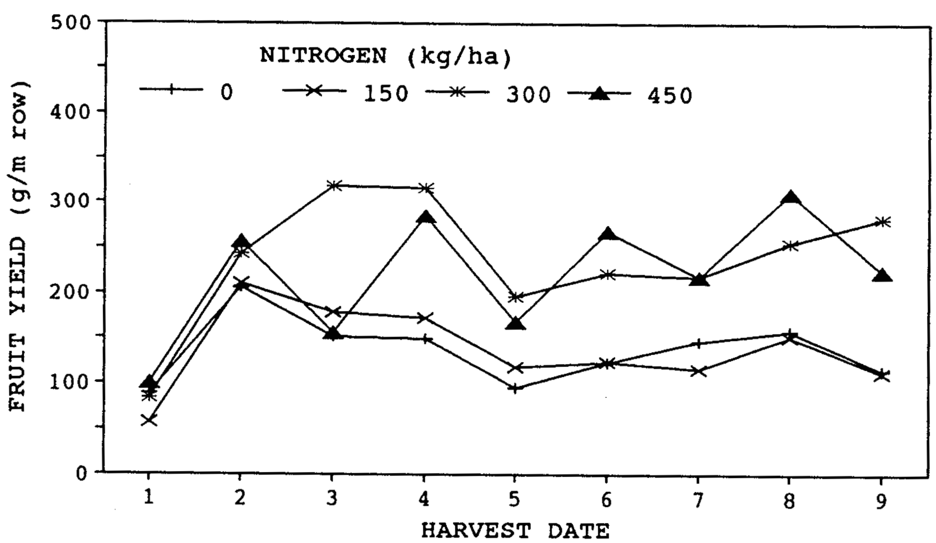


Figure 21. Effect of nitrogen level on fruit yield by harvest date in the primocane bearing red raspberry '8008' at Morden, 1991

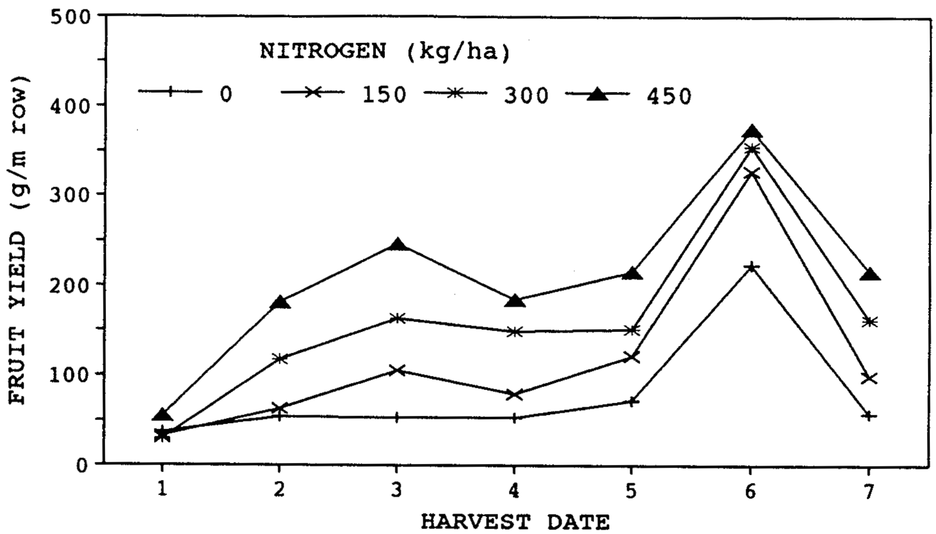


Figure 22. Effect of nitrogen level on fruit yield by harvest date in the primocane bearing red raspberry '8008' at Souris, 1991

4.1.0.2. Fruit Size

In both the field and the container experiments, nitrogen increased fruit size (Tables 16, 18, 19 and 20 and 22). Fruit size data for Morden 1990 are not available. Fruit size was increased by as much as 132 % between the control and the highest nitrogen rate at Souris in 1991 (Table 20). In containers, the overall changes in fruit size between treatments were not as large as those observed under field conditions. For example, there was a 57 % size increase in fruit size between the control and the highest nitrogen rate in containers compared to 132 % size increase at Souris for a similar nitrogen range.

There was a difference in response to nitrogen at each site in 1991. Fruit size was much lower at Souris under low nitrogen conditions, again reflecting low nitrate-nitrogen at this site. At the higher levels of nitrogen, fruit size was similar at both sites.

It is clear from the data that the application of nitrogen promoted the development of larger fruits which in turn increased the overall fruit yield. Increase in fruit size due to the application of nitrogen has been reported (Chaplin and Martin, 1980; Collison and Slate, 1943; De Gomez et al., 1986; Kowalenko, 1982), but it is not clear from the reports whether the increase in fruit size also resulted in higher fruit yields. Furthermore, the increases in size in response to nitrogen previously reported were not as large as those observed in the present investigation. For example, Kowalenko (1982) reported that the weight per 10 fruits only increased by about 4 g from 0 to 268 kg nitrogen per ha, and Chaplin and Martin (1980) obtained only a 3 g increase from 0 to 134 kg nitrogen per ha. The differences between Chaplin and Martin (1980), Kowalenko (1982) and the result for '8008' may be due to genotype and age differences among the experimental material. Chaplin and Martin (1980) and Kowalenko (1982) both worked with the June bearing red raspberry cultivar 'Willamette' and while Kowalenko (1982) gives the age of the plantation as 2 years, Chaplin and Martin did not state the age of the plantation. In other fruit crops such as apples, the application of nitrogen consistently results in larger fruits (Benson et al., 1957; Harris and Boynton, 1952; Fisher et al., 1948). The lack of increase in fruit size in 1991 at the 450 kg nitrogen per ha for Morden was not unusual, since Kowalenko (1982) found that in 2 out 3 years, the highest nitrogen rate gave fruits that were significantly smaller than fruits at the medium rate. Similarly, in peaches, Harris and Boynton (1952) found that fruits were larger in the first than in the second and third seasons. It is generally considered that very high nitrogen levels may be inhibitory to plant growth (Chandler, 1920; Sham and Huffacker, 1984).

4.1.0.3. Fruit Dry Weight

Fruit dry weight was affected similarly for both the field and green house grown red raspberry fruits. Dry weight increased with added nitrogen and tended to level off or decrease slightly at the high nitrogen level in both experiments (Tables 19, 20 and 22). The treatments differed significantly when the data for field sites were pooled by 2-way analysis, but the differences were not significant at Morden. There was also no difference between the field sites. In red raspberries, the response of fruit dry weight to added nitrogen has not been demonstrated previously. In other fruit crops, the application of nitrogen has been shown to increase soluble solids which essentially account for dry weight (Claypool, 1975; Mason, 1968). Conversely, Stembridge et al. (1962) reported that excessive levels of nitrogen could diminish the amount of soluble solids which is a component of fruit quality. The tendency for fruit at the 450 kg nitrogen to have numerically lower values of dry weight seems to agree with the result of Stembridge et al. (1962). Similarly, Mason (1968) found that the highest amount of soluble solids was obtained at the medium rather than at the high nitrogen level.

At each field site, the largest fruit had the greatest percent dry weight (Tables 19 and 20). This would indicate that increases in fruit size were associated with an increase in dry matter. On the other hand, the relatively small fruit produced by the container grown material (Table 22) had a much higher proportion of dry weight indicating the probability that water accumulation per fruit was considerably less. Limited root and growth medium volume in containers may have led to the limited accumulation of water by the green house produced fruits.

4.1.0.4. Number of Flowers per Lateral and per Cane

In the container experiment, it was possible to quantitatively analyse flower production and fruit set. Added nitrogen increased the number of flowers per lateral and per cane (Table 21). The increase in the number of flowers per lateral and per cane with N varied proportionately with both the number of fruits per lateral and per cane and with the overall fruit yield per container indicating a direct relationship between the variables. In raspberries, Daubeny et al. (1986) and Nehrbas and Pritts (1988a) showed that the number of flowers per lateral and per cane and actual harvested fruit yield were highly correlated.

Few studies have quantified the effect of added nitrogen on the number of flowers per lateral and per cane in red raspberries. Lockshin and Elfving (1981) found nitrogen to cause more flowers to develop per unit of vegetative growth in the primocane bearing red raspberry cultivar 'Heritage' grown in containers. However, fruit yield was not determined. In apricots and peaches, Albrigo et al. (1965) and Harris and Boynton (1952) showed that the application of nitrogen increased the number of flowers produced on a tree. The agronomic implication of the result of the present study and that of Lockshin and Elfving (1981) is that nitrogen has a vigorous stimulatory effect on flower production which has the potential to be translated into harvestable fruit yield (Daubeny et al. 1986; Nehrbas and Pritts 1988a).

4.1.0.5. Fruit Set

The results of the container experiment showed that percent fruit set was greatest at the higher than at the low nitrogen levels (Table 22). However, further increases in added nitrogen past 1.74 g had no effect and there is an indication that fruit set may actually decrease at higher rates (Table 22).

The application of nitrogen is generally reported to increase fruit set. In peach and apple trees, the use of nitrogen has been shown repeatedly to increase fruit set (Harris and Boynton, 1952; Stembridge et al.,1962; Yogaratnam and Greenham, 1982). On the other hand, very high levels of nitrogen have been associated with reduced fruit set because high-nitrogen fruit are more prone to June and pre-harvest drop than those low in nitrogen (Bramlage et al. 1979), a similar situation may have occurred in the container experiment. At Morden, in 1991, the greater numbers of fruits per lateral and per cane at the 300 kg nitrogen compared to the 450 kg level may provide further evidence. Moreover, Yogaratnam and Greenham (1982) argue that addition of nitrogen will improve fruit set only if the added nitrogen serves to correct an evident nitrogen deficiency. Nitrogen was not considered particularly limiting at the Morden site.

4.1.0.6. Days to Flowering and Ripening

The number of days to flowering and ripening were affected similarly by added nitrogen. Increasing the rate of nitrogen application had the effect of advancing both the onset of flowering and ripening (Table 23). Advancing the date of flowering by application of nitrogen has been reported for primocane bearers in containers (Lockshin and Elfving, 1981) and in the field for June bearing red raspberries (Kowalenko, 1982). De Gomez et al. (1986) did not find any effect of increasing nitrogen rates on flowering date in the primocane bearing red raspberry cultivar 'Amity'. An advancement in ripening date in '8008' was unexpected, since the usual concept has been that increased nitrogen supply would delay ripening date (Claypool, 1975; Kowalenko, 1982; Schneider and McClung, 1957; Stembridge et al., 1962). For example, although the date of flowering was advanced in the June bearing red raspberry cultivar 'Willamette', the date of ripening was delayed and the delay was attributed to the large fruits which took longer to develop and mature at the high nitrogen rates (Kowalenko, 1982). Similarly, Stembridge et al. (1962) found that in peaches, nitrogen application delayed the maturity of fruits. In contrast, De Gomez et al. (1986) found that nitrogen did not have an effect on the date of ripening. Field observations in '8008' indicate that the application of nitrogen advanced fruit yields, pointing to the fact that added nitrogen may have the potential of not only advancing the flowering date but also fruit yields in primocane bearing red raspberries, overcoming one of the major problems of yield loss in the primocane bearing type of red raspberries- late ripening at fall freeze up.

4.1.1. Cane Characteristics

4.1.1.0. Cane Height

Canes grew taller with added nitrogen in both the containers and field grown plants (Tables 24 to 29). The increases in cane height were accompanied by an increase in the number of fruits per cane and the overall fruit yield (e.g., compare Table 28 and 20 with Figure 17).

The increase in cane height was not linear in every situation. At Morden in 1991, cane height growth stabilised at the 300 kg N per ha rate (Table 27). There is evidence in the container study that very high levels of nitrogen may be inhibitory to cane height growth (Table 29). Conversely, cane height continued to increase at Souris to the highest added nitrogen level (Tables 26 and 28).

A direct relationship between cane height growth and fruit yield was reported by Crandall et al. (1974a), Darrow and Waldow (1934) and Wood et al. (1961) who found that taller canes were more productive than shorter ones because the taller canes had more fruits per lateral. Cherry (1931) found that the application of nitrogen increased cane height in black raspberries. Chandler (1920) found that although nitrogen increased cane height, it did not increase fruit yields as much in the June bearing red raspberry cultivar 'Cuthbert'. Similar results in other fruit crops have been reported. In apples and peaches, added nitrogen was shown to increase terminal growth (Benson et al., 1957; Fisher et al., 1948; Harris and Boynton, 1952). Related work in other fruit crops has failed to show differences in height growth between moderate and high or between high rates of nitrogen (Benson et al., 1957; Boynton et al., 1950; Cain, 1953). The results of the present study may be explained by the observation that Morden was inherently high in soil nitrate-nitrogen whereas Souris was not (Appendix 1, Tables A.1 and A.2). It is probable therefore that the highest rates had exceeded the optimum at Morden. Results of the container experiment support this conclusion as the 3.48 g rate was greater than the 450 kg nitrogen in the field.

4.1.1.1. Number of Nodes per Cane and Internode Length

Both the number of nodes per cane and internode length increased with nitrogen level for the field (data for 1991 only) and container experiments indicating the importance of both variables in determining cane height (Tables 24 to 29). However, the increases in internode length with N were not significant at Souris in 1991. The relative contribution of internode length and node numbers to cane height was variable. At Souris, a greater number of nodes per cane was responsible for the increase at high nitrogen levels (Table 28) while at Morden both variables contributed to cane height (Table 27). In the container material, the reduction in total height at the highest nitrogen level was mostly attributable to a decrease in internode length because the number of nodes did not change (Table 29). It has been shown in previous studies that added nitrogen promotes the development of a greater number of nodes per cane and an increase in internode length (Lockshin and Elfving, 1981; Smolarz et al., 1982). However, the relative importance of each component in relation to added nitrogen as they affect cane height is not well understood. It appears that internode length may be more sensitive to excess nitrogen than the number of nodes because elongation ceased or decreased before node numbers decreased.

It was demonstrated in the present investigation that the number of fruits per cane and overall fruit yield varied directly with the number of nodes per cane (Tables 16 to 21, Tables 24 to 29). The number of nodes per cane has been found to be positively correlated with fruit yield (Gundershein and Pritts, 1991; Hoover et al., 1988; Jennings and Dale, 1982; Jennings and McCregor, 1989). In addition, Dale and Topham (1980) showed that canes with many nodes had vigorous lower laterals which would be more fruitful (see section 4.1.1.4).

4.1.1.2. Cane Diameter

Cane diameter was consistently increased by added nitrogen at all field sites in both years and for the container experiment (Tables 24 to 29). Cane diameter varied with internode length, number of nodes per cane and cane height, indicating that as added nitrogen increased cane diameter, the other three components also increased (Tables 24 and 29). There were differences among sites with Morden having the thickest canes overall in both years. In 1991, there was an interaction between site and diameter. At high nitrogen levels, cane diameter was relatively similar at both sites. At low nitrogen levels, cane diameter was considerably greater at the Morden site. Because of the low inherent nitrate-nitrogen level at Souris, the cane diameter response to added nitrogen was greater. The pattern of response between the field and container experiments was similar, but the canes in the green house were slightly thinner than those in the field. The canes were also taller in containers than in the field which might partially explain why they were thinner (see section 4.1.1.2).

Although it has been reported that added nitrogen increased cane diameter in raspberries (Chandler, 1920; Childs and Hoffman, 1933; Martin et al., 1980), the increases in cane diameter have rarely been quantified and were not as large as those observed in the present study. Chandler (1920) reported that added nitrogen caused canes of the June bearing raspberry cultivar 'Cuthbert' to grow thicker but the increase in thickness was not quantified. On the other hand, Childs and Hoffman (1933) and Martin et al. (1980) quantified increases in cane diameter due to nitrogen application but they did not find any significant differences. Moreover, the studies were mainly in June bearing types of red raspberries and black raspberries and none of the studies reported was carried out under green house conditions. The result in the present investigation may be attributed to: (a) differences in raspberry type- that cane diameter in primocane bearing red raspberries is probably more responsive to added nitrogen than June bearing types (b) the range of levels tested previously has usually been very small; for example, Martin et al. (1980) tested 0 and 68 kg nitrogen per hectare while in the present study, nitrogen levels tested ranged from 0 to 450 kg per hectare. In fact in the present investigation, no differences were observed between the 0 and the next level of nitrogen except in containers.

Increase in stem diameter due to added nitrogen in other fruit crops has been reported. Benson et al. (1957), Harris and Boynton (1952) and Schneider and McClung (1957) found in peaches and apples that increased nitrogen supply resulted in increased trunk diameter. If the increase in cane diameter observed in '8008' with added nitrogen can be obtained in other primocane bearing red raspberries, this finding may be of economic importance to growers.

4.1.1.3. Length of the Laterals

There was more lateral length growth at the high than at the low nitrogen level in both green house and field grown plants (Tables 24 to 29). In both experiments there were 2 classes of lateral length. The length of laterals was several times longer at the 2 highest nitrogen levels compared to the 2 lowest. Moreover, the sites differed in both years with Morden generally having more lateral length growth at any level of nitrogen.

Laterals grew progressively longer from the tip to the bottom of the cane (Figures 27 and 28). The relationship was much stronger (with respect to r^2 values) at high than at low nitrogen because at low nitrogen, there were more laterals that remained vegetative towards the bottom of the cane and these were shorter. The taller canes tended to have longer laterals. The length of laterals corresponded with overall fruit yield per meter of row although the relationship was not as apparent as that observed between the number of fruits per cane and fruit yield.

Lateral length growth with respect to added nitrogen in red raspberries has been poorly documented. There is evidence from related work in other fruit crops that added nitrogen increases lateral shoot extension. Benson et al. (1957) and Harris and Boynton (1952) found in apples that application of nitrogen increased lateral growth. In '8008', the use of nitrogen can lead to longer lateral growth and probably more fruit per lateral. Long laterals have been associated with high fruit numbers per lateral in other raspberries (Dale, 1990). It has been suggested that long laterals intercept light better than short ones (Waister et al., 1980).

The relationship between the application of nitrogen, lateral length and their position on the cane is not clear. Dale (1979) demonstrated that under natural conditions, the pattern of lateral length growth on the cane varied according to genotype. Lateral length usually increased towards the bottom of the cane but in some genotypes, the rate of increase was not constant, giving a curvilinear relationship. Dale (1979) also pointed out that the linear or curvilinear relationships could be altered by environmental conditions, cultural practices or age of the plants within genotypes. In the present study, the application of nitrogen increased the length of the laterals towards the bottom of the cane essentially improving their potential for bearing more fruits (Figures 27 and 28). Unfortunately long laterals have been associated with lateness of harvest in the season (Dale and Topham, 1980).

4.1.1.4. Number of Laterals per Cane, Percent Reproductive Nodes And Percent Fruiting Cane

The total number of lateral shoots per cane increased with nitrogen level for both the field and container grown plants (Tables 22, and 30 to 34). In previous reports, only a general reference has been made to the effect of nitrogen fertilization on branching in red raspberries. Woods (1935) found that increased soil nutrients tended to induce a greater number of laterals in the June bearing red raspberry cultivar 'Cuthbert'. Only Lawson and Waister (1972b) and Lockshin and Elfving (1981) reported specific observations relating added nitrogen to the number of laterals produced. Lawson and Waister (1972b) found that nitrogen had no effect on the number of laterals per cane in the June bearing red raspberry cultivar 'Malling Jewel'. The result by Lawson and Waister (1972b) may be attributed to the very low levels of nitrogen tested.

In addition to the increase in overall shoot production with increasing nitrogen, there was a general increase in the number of reproductive laterals in both field and container grown plants (Tables 22, and 30 to 34). Similarly, the proportion of the cane occcupied by reproductive laterals increased with nitrogen. However, the increase was typically greater than for the proportion of reproductive laterals. Such variation may have been caused by the occurrence of laterals that remained vegetative between the tip of the cane and the lowest fruiting lateral which extended the zone of reproduction. Both the number of reproductive shoots and the proportion of the cane which fruited was higher at the Morden site under low nitrogen treatments than the other sites. At the higher levels of nitrogen, the sites were similar.

Lockshin and Elfving (1981) found the application of nitrogen promoted the formation of a greater number of flowering nodes per cane in green house grown plants of the primocane bearing red raspberry cultivar 'Heritage'. However, the effect of added nitrogen on the percentage of fruiting nodes has not been demonstrated previously under field conditions either for June or primocane bearing red raspberries. In peaches, Harris and Boynton (1952) found the number of lateral shoots to increase with nitrogen fertilization. With regard to the percent fruiting nodes, most work has simply indicated its importance as a yield component in both June and primocane bearing red raspberries (Hoover et al., 1988; Nehrbas and Pritts, 1988a; Lawson and Waister, 1983).

The number of laterals that became reproductive varied with the number of fruits per cane and overall fruit yield (Tables 22, 30 to 34, 16 to 21), indicating a strong relationship between the number of reproductive laterals and fruit yield. This has been previously reported (Crandall, 1980; Dale, 1988; Hoover et al.,1986; Wood et al., 1961).

In the field experiments, as the number of reproductive laterals increased, there was a corresponding decrease in the number of vegetative shoots produced (Tables 30 to 34). This shift in the proportion of reproductive to vegetative laterals indicates the importance of nitrogen in stimulating reproduction. Conversely, Chandler (1920), Smolarz et al. (1982) and Wallace (1938) found that added nitrogen generally stimulates vegetative growth at the expense of reproductive growth, particularly at very high nitrogen levels. Although the high levels of added nitrogen at Morden in 1991 resulted in an increase in the number of reproductive laterals, there was not a corresponding increase in overall yield. Part of this response was related to a reduction in the number of fruits per lateral which is also a measure of reproductive growth. Nevertheless, nitrogen could be effectively used to stimulate the production of a greater number of fruiting laterals in primocane bearing red raspberries as long as it was added in moderation based on the inherent nitrate-nitrogen levels.

Similar to the increase in reproductive laterals, the application of nitrogen to the raspberries in containers also increased the number of laterals that remained vegetative (Table 22). This variation in response from field grown '8008' may have been related to the green house conditions.

4.1.1.5. Biomass Production

Measurements of both fresh weight and dry weight (green house nitrogen study only) of spent canes showed that the application of nitrogen resulted in increased fresh and dry weight (Table 23). Although the pattern of change was similar for both fresh and dry weight, the ranges in measurements varied. Fresh weight varied from 33 g at 0 g nitrogen to 116 g at 3.48 g nitrogen, while dry weight ranged from 18.9 g to 70.7 g at corresponding rates of nitrogen (ranges 83 and 51.8 for fresh and dry weight respectively) indicating that cane fresh weight may be more sensitive than dry weight to nitrogen levels. The increases in biomass reflected changes in cane height, cane diameter, number of flowers per lateral and per cane, fruit size, number of fruits per lateral and per cane and overall fruit yield reported in previous sections (see Tables 21 and 23 respectively).

There is clear evidence from the present investigation that nitrogen increased total growth in the green house grown plants. Lockshin and Elfving (1981) and Smolarz et al. (1982)

reported similarly that the application of nitrogen promoted greater total and dry weight growth (in roots, canes, leaves and flowers) in the primocane bearing red raspberry cultivar 'Heritage' and June bearing cultivars 'Latham', 'Malling Promise' and 'Souvenir de Paul Camenzid' respectively. In peaches, Harris and Boynton (1952) found that nitrogen fertilization increased the fresh weight of prunings. Interpreting the greater total growth in terms of cane height, dry weight, total nodes and internode length as a vigour response (Lockshin and Elfving, 1981), then it can be concluded that, the application of nitrogen stimulated the vigour of the raspberry plants and in turn increased overall fruit yield. In related studies, Crandall et al. (1974a), Darrow and Waldo (1934) and Wood et al. (1961) reported that the more vigorous canes yielded more than the less vigorous ones, probably because of the greater number of fruits per cane and the higher percentage of fruit set (Crandall et al. 1974a).

Table 23. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (Greenhouse 1991)

g N per cont.	days to flower	days to ripen	fresh cane weight (g)	dry cane weight (g)
0.000	77.3a	106.5a	33.0a	18.9a
0.435	72.6b	101.0b	40.7a	23.6a
0.870	68.8cd	95.2cd	69.5b	40.9b
1.748	66.6d	93.0d	96.5c	59.1c
3.480	70.0bc	96.8c	116.0d	70.7d
C.V. (%)	8.8	7.5	43.3	40.5

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 24. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (St. Adolphe 1990)

kg N per ha	cane height (cm)	nodes per cane	cane diam. (mm)	lateral length (cm)
0	88.4a	29.7a	5.8a	5.9a
75	93.3a	29.9a	6.3a	5.4a
150	104.8b	33.4b	8.3b	9.8b
300	105.8b	33.9b	8.6b	10.9b
C.V (%)	4.6	2.2	10.8	19.3

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 25. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (Morden 1990)

kg N per ha	cane height (cm)	nodes per cane	cane diam. (mm)	lateral length (cm)
0	114.5a	33.4a	8.6a	14.7a
75	112.0a	30.9b	8.9a	17.1a
150	118.1ab	33.9a	10.1b	18.6ab
300	127.2b	36.8c	10.7b	22.3b
C.V.(%)	4.9	4.4	7.6	16.4

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 26. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (Souris 1990)

kg N per ha	cane height (cm)	nodes per cane	cane diam. (mm)	lateral length (cm)
0	81.9a	29.2a	5.6a	4.1a
75	87.7a	28.2a	6.1a	6.3a
150	105.8b	32.9b	8.6b	11.1b
300	109.9b	33.8c	9.1b	13.6b
C.V. (%)	7.7	4.0	8.8	25.0

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 27. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (Morden 1991)

kg N per ha	cane height (cm)	nodes per cane	internode length (cm)	cane diam. (mm)	lateral length (cm)
0	99.1a	30.8a	3.2a	6.3a	6.9a
150	99.9a	31.0a	3.2a	6.7a	9.1a
300	132.5b	36.6b	3.7b	11.1b	24.8b
450	132.6b	37.5b	3.6b	11.5b	29.8b
C.V. (%)	2.4	2.8	2.9	6.3	21.9

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 28. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (Souris 1991)

kg N per ha	cane height (cm)	nodes per cane	internode length (cm)	cane diam. (mm)	lateral length (cm)
0	74.4a	30.5a	2.4a	4.4a	4.1a
150	85.0a	31.5a	2.6a	5.2a	6.8a
300	119.0b	38.0b	3.1a	10.5b	23.4b
450	131.9c	41.3c	3.2a	12.2c	24.2b
C.V. (%)	7.7	3.5	7.1	7.4	12.8

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 31. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (Morden 1990)

kg N per ha	no.of lats. per cane (tot.)	(repr.)	(veg.)	percentage of repr. nodes	percentage of cane fruiting
0	17.2a	14.5a	2.8a	63.1a	43.8a
75	16.9a	14.6a	2.3a	69.4a	47.3a
150	17.8a	16.8a	0.9b	70.2a	49.6a
300	18.4a	17.9b	0.4b	77.8b	50.5a
C.V. (%)	9.3	9.6	42.5	10.9	9.8

values followed by the same letter are not significantly different at $P<0.05$ (LSD).

Table 32. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (Souris 1990)

kg N per ha	no.of lats. per cane (tot.)	(repr.)	(veg.)	percentage of repr. nodes	percentage of cane fruiting
0	13.3a	9.9a	3.1a	35.7a	34.2a
75	14.1a	11.2a	2.9a	51.4b	39.7a
150	16.9b	15.7b	1.3b	72.4c	46.6b
300	17.8b	17.3b	0.5c	80.6c	52.9c
C.V. (%)	6.2	7.5	21.4	8.7	13.2

values followed by the same letter are not significantly different at $P<0.05$ (LSD).

Table 33. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (Morden 1991)

kg N per ha	no.of lats. per cane (tot.)	(repr.)	(veg.)	percentage of repr. nodes	percentage of cane fruiting
0	13.0a	10.8a	2.2a	34.9a	26.1a
150	14.1a	12.0a	2.1a	38.7a	42.4b
300	20.8b	20.0b	0.8b	54.8b	75.1b
450	23.9b	23.1c	0.8b	61.6b	82.2c
C.V. (%)	8.9	8.3	38.6	7.2	14.7

values followed by the same letter are not significantly different at P<0.05 (LSD).

Table 34. Effect of varying nitrogen levels on cane characteristics of primocane fruiting red raspberry '8008' (Souris 1991)

kg N per ha	no.of lats. per cane (tot.)	(repr.)	(veg.)	percentage of repr. nodes	percentage of cane fruiting
0	12.3a	9.6a	2.6a	31.6a	33.6a
150	13.3a	11.0a	2.3a	34.9a	36.2a
300	18.8b	17.1b	1.7ab	47.8b	81.4a
450	21.8b	19.9b	0.6b	48.2b	86.6a
C.V. (%)	11.7	13.5	46.5	13.2	6.0

values followed by the same letter are not significantly different at P<0.05 (LSD).

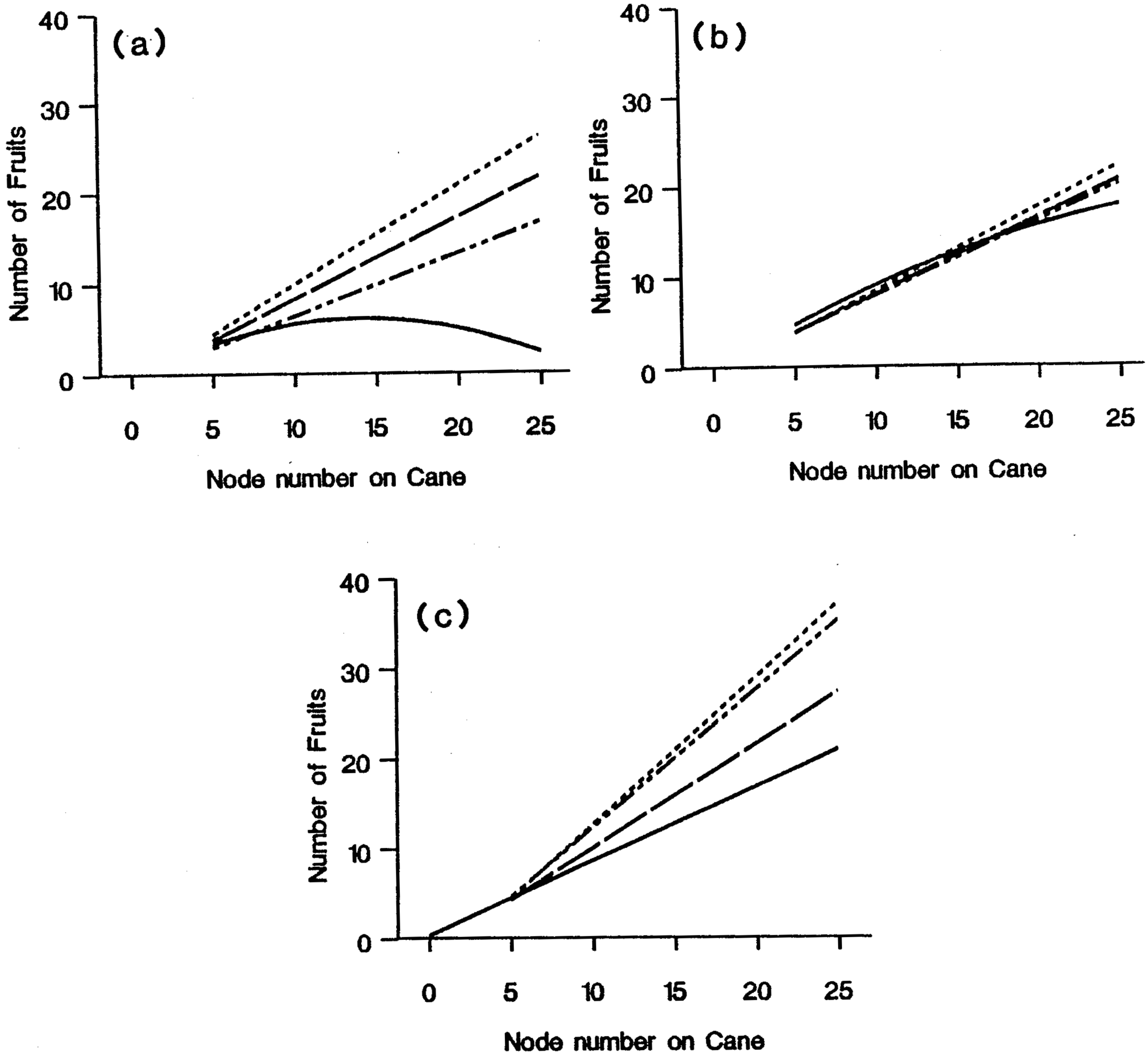


Figure 23. Regression lines for the number of fruits against the node position on the cane for primocane red raspberry '8008' in 1990 **(a) St. Adolphe:** 0 kg N (_____, Y = -0.2815+0.9078, r^2 = 0.42), 75 kg N (____ ____ ____, Y = -0.6664+0.8937, r^2 = 0.38), 150 kg N (__ _ _ __, Y = -0.4254+0.6858, r^2 = 0.58), 300 kg N (_ _ _ , Y = -0.9901+1.0908, r^2 = 0.81) **(b) Morden:** 0 kg N (____, Y = -0.3019+1.0854-0.0143, r^2 = 0.61), 75 kg N (____ ____ ____, Y = -0.2324+0.8381, r^2 = 0.60), 150 kg N (__ _ _ __, Y = -0.1577+0.8149, r^2 = 0.59), 300 kg N (_ _ _ , Y = -0.7045+0.9193, r^2 = 0.63) **(c) Souris:** 0 kg N (____, Y = -0.3814+0.8269, r^2 = 0.59), 75 kg N (____ ____ ____, Y = -1.4475+1.5560, r^2 = 0.53), 150kg N (__ _ _ __, Y = -3.0088+1.5379, r^2 = 0.59), 300 kg N (_ _ _ , Y = -3.6943+1.6404, r^2 = 0.69)

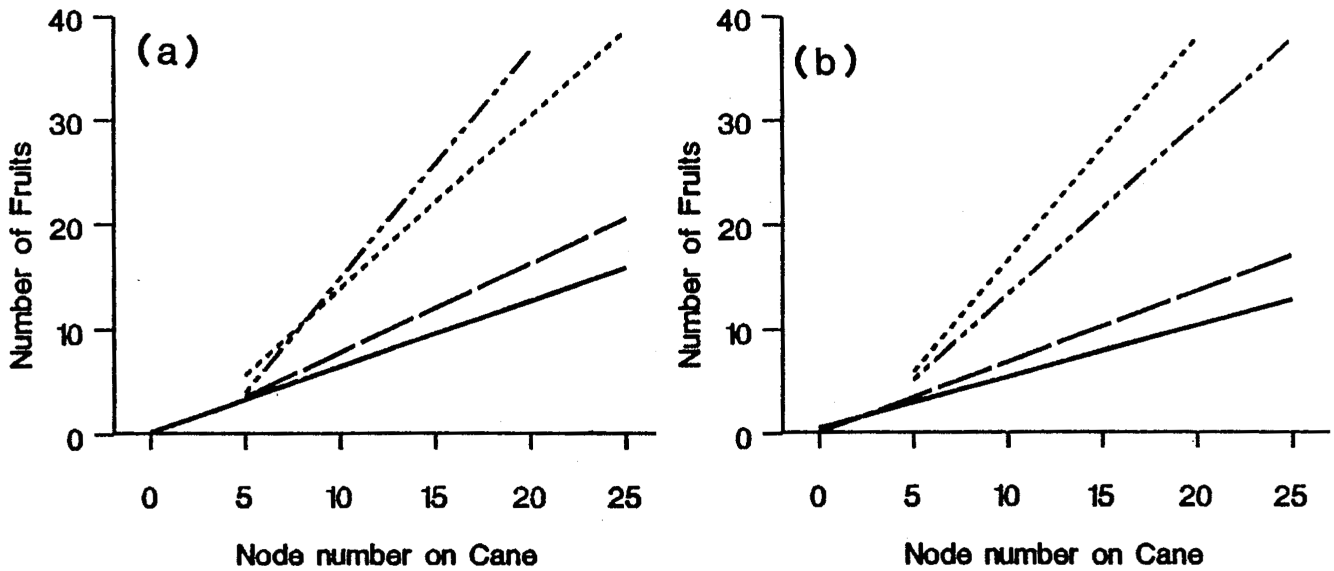


Figure 24. Regression lines for the number of fruits against the node position on the cane for primocane red raspberry '8008' in 1991 **(a) Morden:** 0 kg N (________, Y = 0.1708+0.6323, r^2 = 0.46), 150 kg N (___ ___ ___, Y = -0.6914+0.8530, r^2 = 0.54), 300 kg N (___ _ _ ___, Y = -6.9695+2.1890, r^2 = 0.69), 450 kg N (_ _ _ , Y = -2.5883+1.6519, r^2 = 0.67) **(b) Souris:** 0 kg N (____, Y = -0.4737+0.4951, r^2 = 0.65), 150 kg N (___ ___ ___, Y = -0.0950+0.6794, r^2 = 0.63), 300kg N (___ _ _ ___, Y = -3.0351+1.6355, r^2 = 0.73), 450 kg N (_ _ _ , Y = -4.7763+2.1353, r^2 = 0.78)

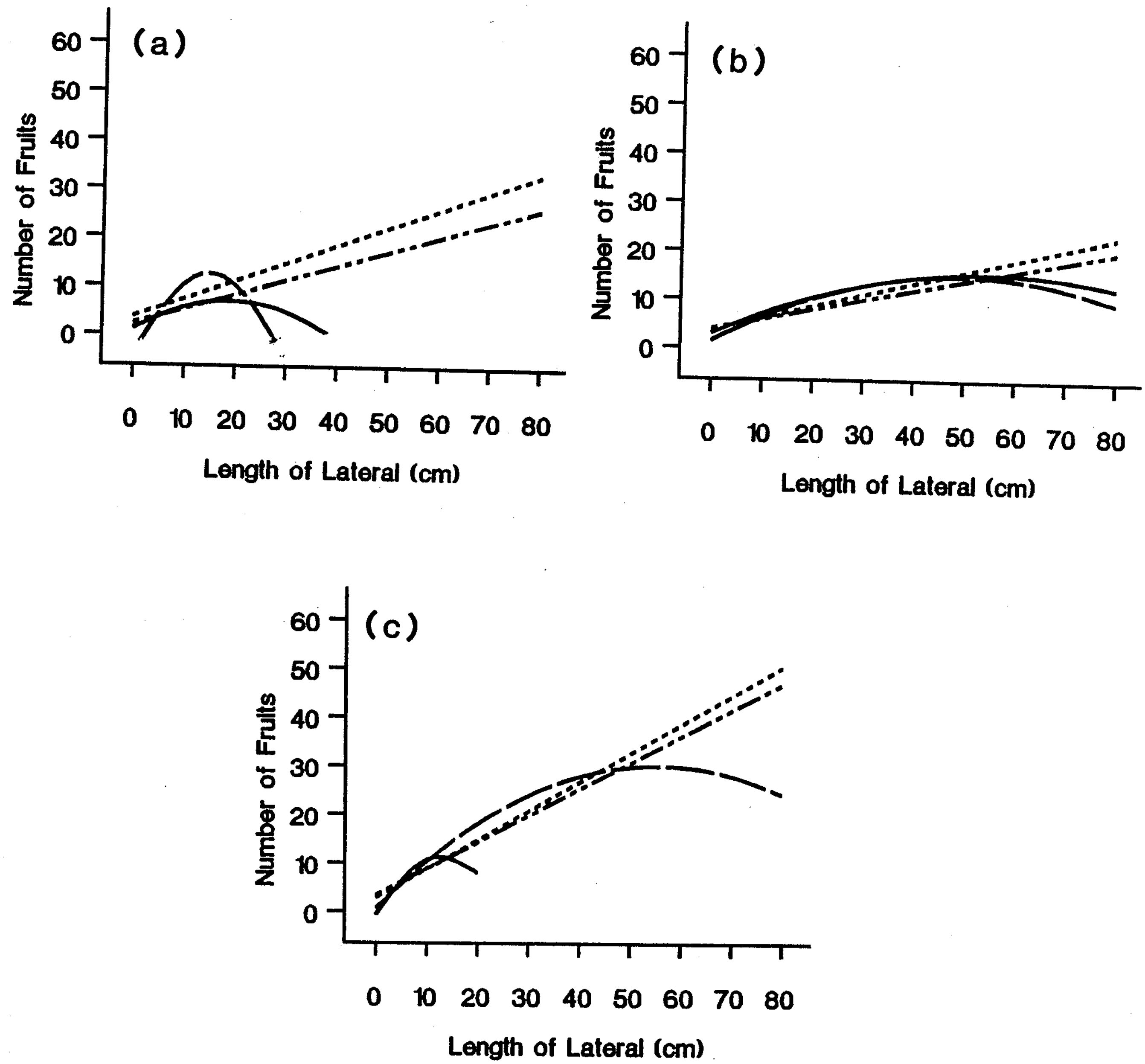


Figure 25. Regression lines for the number of fruits against lateral length for primocane red raspberry '8008' in 1990 **(a) St. Adolphe:** 0 kg N (____, Y = 1.0923+0.6235-0.0167, r^2 = 0.39), 75 kg N (___ ___ ___, Y = -4.1259+2.1878, r^2 = 0.51), 150 kg N (__ _ _ __, Y = 2.2526+0.2990, r^2 = 0.49), 300 kg N (_ _ _ , Y = 3.6356+0.3702, r^2 = 0.68) **(b) Morden:** 0 kg N (____, Y = 2.9225+0.4601-0.0042, r^2 = 0.54), 75 kg N (___ ___ ___, Y = 1.3970+0.5523-0.0056, r^2 = 0.55), 150 kg N (__ _ _ __, Y = 3.8702+0.2037, r^2 = 0.52), 300 kg N (_ _ _ , Y = 3.7481+0.2433, r^2 = 0.66) **(c) Souris:** 0 kg N (____, Y = -0.6994+1.8630-0.0714, r^2 = 0.65), 75 kg N (___ ___ ___, Y = 0.6914+1.0636-0.0096, r^2 = 0.71), 150kg N (__ _ _ __, Y = 3.4063+0.5463, r^2 = 0.67), 300 kg N (_ _ _ , Y = 2.8258+0.5968, r^2 = 0.87)

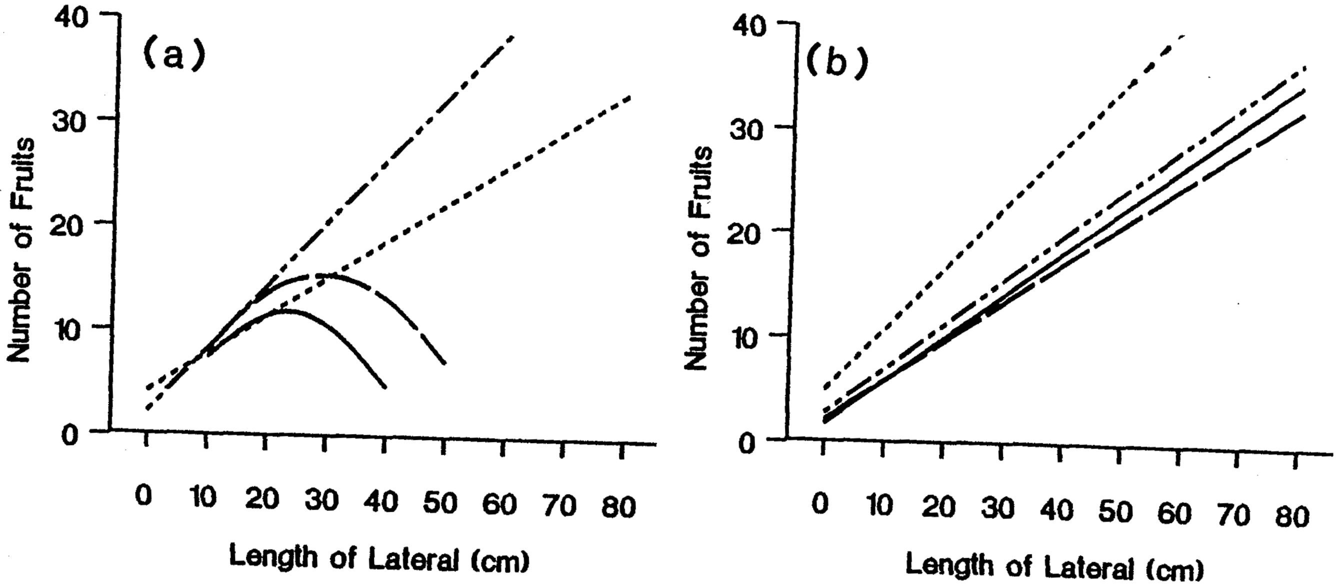


Figure 26. Regression lines for the number of fruits against lateral length for primocane red raspberry '8008' in 1991 **(a) Morden:** 0 kg N (_____, Y = -1.0689+1.1318-0.0244, r^2 = 0.51), 150 kg N (____ ____ ____, Y = -1.0135+1.1149, r^2 = 0.57), 300 kg N (___ _ _ ___, Y = 2.1998+0.6106, r^2 = 0.79), 450 kg N (_ _ _ , Y = 4.1899+0.3641, r^2 = 0.74) **(b) Souris:** 0 kg N (_____, Y = 1.7817+0.4153, r^2 = 0.35), 150 kg N (_____ _____ _____, Y = 2.1137+0.3798, r^2 = 0.41), 300kg N (___ _ _ ___, Y = 2.7674+0.4304, r^2 = 0.73), 450 kg N (_ _ _ , Y = 4.9986+0.5913, r^2 = 0.84)

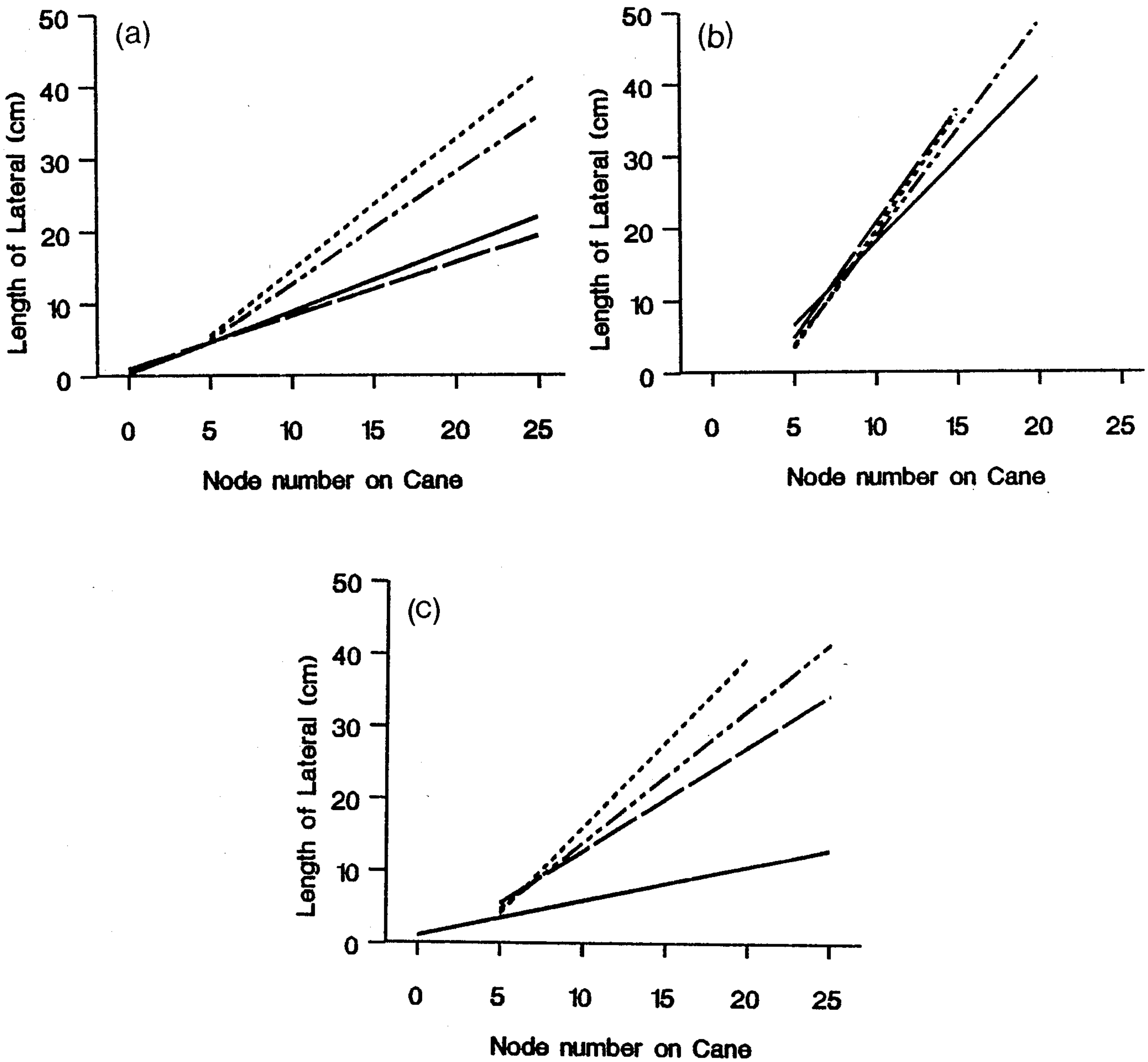


Figure 27. Regression lines for lateral length against the node position on the cane for primocane red raspberry '8008' in 1990 **(a) St. Adolphe:** 0 kg N (______, Y = 0.3192+0.8677, r^2 = 0.32), 75 kg N (____ ____ ____, Y = 1.0043+0.7388, r^2 = 0.44), 150 kg N (__ _ _ __, Y = -2.7017+1.5421, r^2 = 0.54), 300 kg N (_ _ _ , Y = -3.4624+1.8077, r^2 = 0.48) **(b) Morden:** 0 kg N (____, Y = -4.8471+2.2948, r^2 = 0.39), 75 kg N (____ ____ ____, Y = -11.0058+3.1717, r^2 = 0.63), 150 kg N (__ _ _ __, Y = -11.0538+2.9812, r^2 = 0.66), 300 kg N (_ _ _ , Y = -12.7520+3.2361, r^2 = 0.69) **(c) Souris:** 0 kg N (____, Y = -1.1136+0.4781, r^2 = 0.36), 75 kg N (____ ____ ____, Y = -1.7311+1.4521, r^2 = 0.36), 150kg N (__ _ _ __, Y = -4.5827+1.8521, r^2 = 0.45), 300 kg N (_ _ _ , Y = -7.7189+2.3781, r^2 = 0.61)

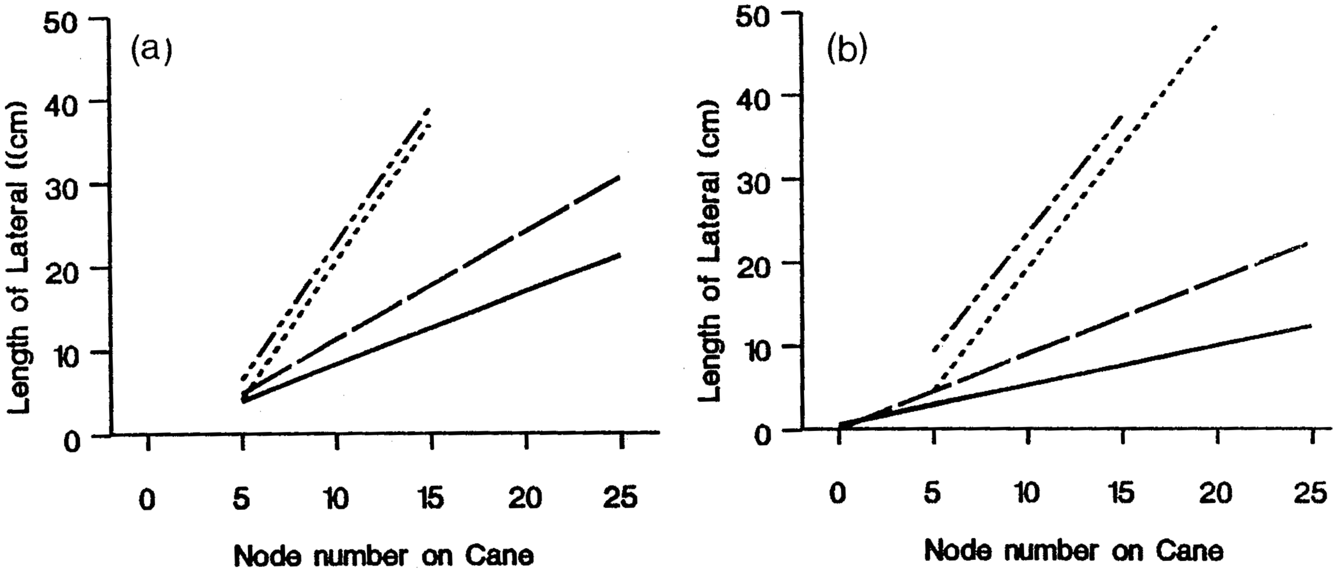


Figure 28. Regression lines for lateral length against the node position on the cane for primocane red raspberry '8008' in 1991 **(a) Morden:** 0 kg N (_______, Y = -0.3094+0.8669, r^2 = 0.34), 150 kg N (___ ___ ___, Y = -1.5849+1.2895, r^2 = 0.45), 300 kg N (__ _ _ __, Y = -9.6631+3.2394, r^2 = 0.63), 450 kg N (_ _ _ , Y = -12.2160+3.2789, r^2 = 0.65) **(b) Souris:** 0 kg N (____, Y = 0.6095+0.4732, r^2 = 0.37), 150 kg N (___ ___ ___, Y = 0.1003+0.8939, r^2 = 0.46), 300kg N (__ _ _ __, Y = -4.7124+2.8135, r^2 = 0.56), 450 kg N (_ _ _ , Y = -9.9226+2.9217, r^2 = 0.64)

5. SUMMARY AND CONCLUSIONS

Reducing cane density had a considerable impact on the expression of the various yield components in the primocane bearing red raspberry selection '8114'. At low cane density, the canes were shorter but larger in diameter, and the canes initiated and developed a greater number of nodes and lateral shoots. The laterals were longer and increased in length linearly from the tip to the bottom of the cane at low cane density while at high cane density, the relationship was more curvilinear. Similarly at low cane density, there was an increase in the total number of laterals, the number of fruitful laterals and the proportion of cane that fruited. Moreover, canes had more fruits per lateral and the fruits were larger in size than the fruits at high cane density. Large size fruits are particularly desirable for the pick-your-own market system. Large increases in overall fruit yield pere m row were limited to the low cane density. The increase in yield at high cane density was generally small, often stabilising or tending to decrease after an optimum cane number per meter row was reached. The effect of high cane density on yield was not significant due to the greater productivity of individual canes at low cane density. The density at which maximum fruit yields were obtained varied with site and with year at some sites.

The application of nitrogen produced effects on cane characteristics similar to those of low cane density except for cane height. High nitrogen increased cane height, the number of nodes per cane and cane diameter. Similarly, nitrogen increased the total number of laterals, and the number which became reproductive. At high nitrogen, the laterals were generally longer with a linear increase from the tip to the bottom of the cane.

The number of flowers per lateral and per cane, the number of fruits per lateral and per cane, fruit size and overall fruit yield were significantly increased with added nitrogen. At Morden, an optimum level of nitrogen was reached in 1991, while at Souris an optimum level was not reached in either year. Overall responses to added nitrogen were greater on the fine-sand and soilless medium than on the clay-loam soils. Response to added nitrogen was also better in 1991 when nitrogen was applied in mid-May than in 1990 when it was applied in mid-June.

In conclusion, high fruit yields in primocane red raspberries can be realised through improved yield component performance which can be achieved by the manipulation of cultural practices. Cane density manipulation and nitrogen fertilization produced significant responses in fruit and fruit yield components. For best results, cultural practices (e.g., thinning, application of nitrogen) need to be applied early to promote early growth and rapid development of a sufficient fruiting surface. Moreover, because primocane bearing red raspberries ripen in the fall, rapid development will ensure that growers realise the full yield potential of the crop before the fall freeze. Cultural practices should also be matched to site location, for example, at Morden less nitrogen and a lower cane number per meter row than at Souris resulted in optimum fruit yields.

More research is required to determine the relationship between nitrogen and cane density. There is need to examine the interaction of added nitrogen and various cane densities. For example would added nitrogen alter the performance of red raspberry at the low or high cane density? The relationship between cane density and dry matter accumulation should also be investigated. This would indicate how the raspberry plant partitions photosynthates (resource efficiency) at the various cane densities. Related to the above, research in the agronomic and physiological responses to lateral branch angle would indicate what is responsible for variation in lateral branch angles: whether environmental or endogenous factors are involved.

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7. APPENDICES

APPENDIX 1

Soil test results of experimental sites

Table A1.1. Soil test results for St.Adolphe, Morden and Souris, June 1990

Site	Depth (cm)	Available Nutrients (kg/ha) NO_3-N[1]	P[1]	K[2]	SO_4-S[3]	pH	texture
St. Adolphe							
	0-15	9.0	55.8	855	8.3	7.0	Clay
	15-30	9.4	16.2				
	30-45	4.4	44+				
	45-60	6.6	44+				
Morden							
	0-15	12.6	108+	972	4.7	7.3	Clay-loam
	15-30	10.8			4.3		
	30-45	11.0			8.3		
	45-60	7.9			14.0		
Souris							
	0-15	11.0	34.0	438	5.0	7.2	Fine Sand
	15-30	8.5			5.0		
	30-45	8.3			5.2		
	45-60	6.2			3.1		

[1]Sodium Bicarbonate Extractable
[2]Ammonium Acetate Exchangeable
[3]Water Soluble

Table A1.2. Soil test results for Morden and Souris, May 1991

Site	Depth (cm)	Available Nutrients (kg/ha) NO_3-N[1]	P[1]	K[2]	SO_4-S[3]	pH	texture
Morden							
	0-15	13.8	116.7	1169.2	3.2	7.6	Clay-loam
	15-30	11.8	76.66	985.2	4.2		
	30-45	15.0	34.8	767.1	19.2		
	45-60	11.5	18.3	599.7	17.9		
	60-75	7.5	13.0	502.3	35.0		
Souris							
	0-15	6.3	35.0	428.8	1.4	7.5	Fine Sand
	15-30	4.3	25.6	392.0	1.3		
	30-45	3.5	22.4	322.0	1.3		

table A1.2. contd.....

45-60	2.0	17.6	274.0	1.3
60-75	1.9	14.0	245.6	1.4

[1]Sodium bicarbonate Extractable
[2]Ammonium Acetate Exchangeable
[3]Water soluble

APPENDIX 2

Fertilizer management of plots before study

Table A2. Fertilizer rates for St. Adolphe, Morden and Souris (1987 -1989)

Site	Fertilizer element	Rate (kg/ha/year)
Morden	Nitrogen	183
	Phosphorous	183
	Zinc	0.454/growing season
Souris	Nitrogen	340
	Phosphorous	200
	Zinc	0.454/growing season
St. Adolphe	Nitrogen	260
	Phosphorous	260
	Zinc	0.454/growing season

APPENDIX 3

Analysis of variance - fruit yield, yield components and cane architecture characteristics

Table A3.1. Sums of square values for fruit yield in '8114'

Source	df	St. Adolphe 1990	
		Fruit yield (g/m row)	Fruit yield (g/cane)
RepNo	3	209598.53	1587.94
Density	3	13247.35	6032.24*
Error a	9	120609.27	803.08
		No.of fruits per lateral	No. of fruits per
cane RepNo	3	5.78	3577.12
Density	3	47.17*	31695.33*
Error a	9	3.38	2768.73
		Fruit size	
RepNo	3	8.05	
Density	3	230.83*	
Error a	9	12.77	

Table A3.2. Sums of square values for fruit yield in '8114'

Source	df	Morden 1990	1991
		Fruit yield (g/m row)	
RepNo	3	415937.63	611565.53
Density	3	414680.07	1159812.94
Error a	9	745256.26	1344915.67
		Fruit yield (g/cane)	
RepNo	3	5352.68	2763.55
Density	3	67183.55*	132672.84*
Error a	9	11175.06	7558.07
		No. of fruits per lateral	
RepNo	3	4.49	11.82
Density	3	59.42*	450.66*
Error a	9	6.72	27.74
		No.of fruits per cane	
RepNo	3	2807.28	11802.30
Density	3	47494.67*	657603.91*
Error a	9	9945.68	26100.12
		Fruit size	
RepNo	3	9.95	529.56
Density	3	743.94*	1051.87
Error a	9	25.39	1452.06
		Fruit dry weight	
RepNo	3	n.a.	0.04
Density	3	n.a.	0.06
Error a	9	n.a.	0.07

n.a. = not available

Table A3.3. Sums of square values for fruit yield in '8114'

Source	df	Souris 1990	1991
		Fruit yield (g/m row)	
RepNo	3	600133.53	138281.94
Density	3	1159812.94	99695.05*
Error a	9	830129.32	119210.00
		Fruit yield (g/cane)	
RepNo	3	6765.11	763.75
Density	3	25058.22*	19934.00*
Error a	9	14941.69	20697.76
		No. of fruits per lateral	
RepNo	3	3.40	6.33
Density	3	47.96*	493.39*
Error a	9	10.08	25.54
		No.of fruits per cane	
RepNo	3	5768.48	2573.62
Density	3	32920.14*	434383.75*
Error a	9	14494.96	11312.95
		Fruit size	
RepNo	3	3.84	18.49
Density	3	624.55*	548.84*
Error a	9	18.57	27.17
		Fruit dry weight	
RepNo	3	n.a.	0.06
Density	3	n.a.	0.02
Error a	9	n.a.	0.13

n.a. = not available

Table A3.4. Sums of square values for cane architecture characteristics in '8114'

Source	df	St. Adolphe 1990	
		No. nodes per cane	Cane height
RepNo	3	38.93	1235.78
Density	3	10.71	185.99*
Error a	9	29.66	510.68
		Cane diameter	Lateral branch angle
RepNo	3	7.79	183.24
Density	3	23.39*	1716.76*
Error a	9	3.62	275.18
		No. of laterals per cane	No. reproductive laterals per cane
RepNo	3	14.37	22.19
Density	3	65.63*	232.80
Error a	9	3.10	35.20
		No. vegetative nodes	Percentage of reproductive nodes
RepNo	3	4.67	77.29
Density	3	53.86*	1669.26*
Error a	9	30.37	286.65
		Percentage of cane fruiting	Lateral length
RepNo	3	140.06	30.55
Density	3	6747.44*	268.05*
Error a	9	1064.36	40.43

Table A3.5. Sums of square values for cane architecture characteristics in '8114'

Source	df	Morden 1990	1991
	No. nodes per cane		
RepNo	3	16.35	27.62
Density	3	7.32	143.37*
Error a	9	36.15	27.50
	Cane height		
RepNo	3	23.70	208.81
Density	3	948.32*	1204.31*
Error a	9	328.24	724.81
	Cane diameter		
RepNo	3	0.19	2.44
Density	3	39.86*	93.58*
Error a	9	7.92	2.85
	Lateral branch angle		
RepNo	3	75.56	108.02
Density	3	1866.30*	2919.47*
Error a	9	162.15	215.11
	No. laterals per cane		
RepNo	3	1.91	13.63
Density	3	29.26	167.64*
Error a	9	43.58	41.52
	No.reproductive laterals per cane		
RepNo	3	9.85	11.64
Density	3	173.29*	261.67*
Error a	9	39.90	32.62
	No. vegetative laterals		
RepNo	3	6.62	0.92
Density	3	58.67*	10.92*
Error a	9	26.12	6.64
	Percent of reproductive nodes		
RepNo	3	73.05	163.06
Density	3	979.77*	605.87*
Error a	9	183.92	196.83
	Percentage of cane fruiting		
RepNo	3	223.96	1040.79
Density	3	2197.37*	2279.42*
Error a	9	713.64	1542.60

table A3.5. contd....

	Lateral length		
RepNo	3	2.93	6.75
Density	3	833.34*	1386.40*
Error	9	129.62	41.15
	Internode length		
RepNo	3	n.a.	0.08
Density	3	n.a.	2.29*
Error a	9	n.a.	0.24

n.a. = not available

Table A3.6. Sums of square values for cane architecture characteristics in '8114'

Source	df	Souris 1990	1991
	No. nodes per cane		
RepNo	3	8.21	18.37
Density	3	5.12	104.62*
Error a	9	21.64	28.50
	Cane height		
RepNo	3	311.07	224.79
Density	3	654.20*	380.29
Error a	9	590.50	587.51
	Cane diameter		
RepNo	3	0.38	4.35
Density	3	27.12*	121.28*
Error a	9	3.68	3.88
	Lateral branch angle		
RepNo	3	12.48	5.25
Density	3	1648.04*	2750.13*
Error a	9	93.04	34.47
	No. laterals per cane		
RepNo	3	36.62	10.79
Density	3	27.96	373.79*
Error a	9	27.43	55.64
	No.reproductive laterals per cane		
RepNo	3	55.95	7.67
Density	3	257.72*	486.17*
Error a	9	25.84	68.64
	No. vegetative laterals		
RepNo	3	7.40	1.25
Density	3	143.43*	8.12*
Error a	9	11.85	4.12
	Percent of reproductive nodes		
RepNo	3	538.44	53.08
Density	3	1858.27*	1859.64*
Error a	9	160.92	490.47
	Percentage of cane fruiting		
RepNo	3	34.70	208.54
Density	3	1196.53*	8307.59*
Error a	9	275.00	464.62

table A3.6. contd.....

		Lateral length	
RepNo	3	12.56	19.34
Density	3	410.11*	1040.09*
Error	9	63.86	42.47
		Internode length	
RepNo	3	n.a.	0.03
Density	3	n.a.	0.75
Error a	9	n.a.	0.24

n.a. = not available

Table A3.7. Sums of square values for fruit yield in '8008'

Source	df	St. Adolphe 1990	
		Fruit yield (g/m row)	No. fruits per lateral
RepNo	3	202544.35	15.87
Nitrogen	3	464362.07*	56.23*
Error a	9	215317.40	13.34
		No. fruits per cane	Fruit size
RepNo	3	4156.95	7.53
Nitrogen	3	19208.22*	424.79*
Error a	9	29.99	21.66
		Fruit dry weight	
RepNo	3	0.06	
Nitrogen	3	0.07	
Error a	9	0.17	

Table A3.8. Sums of square values for fruit yield in '8008'

Source	df	Morden 1990	1991
		Fruit yield (g/m row)	
RepNo	3	476709.56	103413.72
Nitrogen	3	1091071.34	3062517.72*
Error a	9	1508071.86	806317.35
		No. of fruits per lateral	
RepNo	3	4.25	22.06
Nitrogen	3	13.20*	745.12*
Error a	9	10.03	97.57
		No.of fruits per cane	
RepNo	3	1857.88	13696.63
Nitrogen	3	5489.41*	434383.75*
Error a	9	6404.64	49078.95
		Fruit size	
RepNo	3	n.a.	20.68
Nitrogen	3	n.a.	472.17*
Error a	9	n.a.	42.43

table A3.8 contd.....

		Fruit dry weight	
RepNo	3		0.06
Nitrogen	3		0.07
Error a	9		0.17

n.a. = not available

Table A3.9. Sums of square values for fruit yield in '8008'

Source	df	Souris 1990	1991
		Fruit yield (g/m row)	
RepNo	3	741010.59	619613.18
Nitrogen	3	2007283.63*	1989369.83*
Error a	9	56004.34	193100.81
		No. of fruits per lateral	
RepNo	3	34.47	5.33
Nitrogen	3	88.62*	645.90*
Error a	9	6.16	25.86
		No.of fruits per cane	
RepNo	3	14279.05	3603.56
Nitrogen	3	40642.95*	340097.59*
Error a	9	2314.72	30587.41
		Fruit size	
RepNo	3	16.81	2.36
Nitrogen	3	435.05*	613.65*
Error a	9	10.84	7.56
		Fruit dry weight	
RepNo	3	n.a.	0.03
Nitrogen	3	n.a.	0.13*
Error a	9	n.a.	0.02

n.a. = not available

Table A3.10. Sums of square values for cane architecture characteristics in '8008'

Source	df	St. Adolphe 1990	
		No. nodes per cane	Cane height
RepNo	3	15.39	619.78
Nitrogen	3	61.12	887.53*
Error a	9	4.46	183.75
		Cane diameter	No. laterals per cane
RepNo	3	1.77	17.02
Nitrogen	3	23.99*	23.06
Error a	9	5.59	30.54
		No. reproductive laterals per cane	No. vegetative laterals per cane
RepNo	3	21.22	4.84
Nitrogen	3	106.51*	29.90
Error a	9	10.22	10.42
		Percent reproductive laterals per cane	Percent of fruiting cane
RepNo	3	615.70	303.81
Nitrogen	3	1003.74	2503.00*
Error a	9	482.31	1371.43
		Length of laterals	
RepNo	3	4.75	
Nitrogen	3	89.68*	
Error a	9	21.38	

Table A3.11. Sums of square values for cane architecture characteristics in '8008'

Source	df	Morden 1990	1991
		No. nodes per cane	
RepNo	3	25.03	0.92
Nitrogen	3	70.89*	154.79*
Error a	9	20.39	8.51
		Cane height	
RepNo	3	449.96	37.81
Nitrogen	3	530.37*	4390.31*
Error a	9	300.89	69.81
		Cane diameter	
RepNo	3	1.69	2.41
Nitrogen	3	12.69*	93.55*
Error a	9	4.79	2.89
		No. laterals per cane	
RepNo	3	2.33	6.06
Nitrogen	3	5.40	328.31*
Error a	9	24.02	23.06
		No.reproductive laterals per cane	
RepNo	3	9.74	4.79
Nitrogen	3	35.05*	437.79*
Error a	9	21.44	17.14
		No. vegetative laterals	
RepNo	3	3.09	0.54
Nitrogen	3	14.32*	8.29*
Error a	9	4.16	2.89
		Percent of reproductive nodes	
RepNo	3	195.96	24.08
Nitrogen	3	106.58	1957.78*
Error a	9	246.54	106.02
		Percentage of cane fruiting	
RepNo	3	15.66	167.90
Nitrogen	3	436.29	8509.00*
Error a	9	430.64	618.23
		Lateral length	
RepNo	3	20.40	45.26
Nitrogen	3	120.72*	1552.21*
Error	9	80.05	134.69

table A3.11 contd.....

		Internode length	
RepNo	3	n.a.	0.01
Nitrogen	3	n.a.	0.60*
Error a	9	n.a.	0.08

n.a. = not available

Table A3.12. Sums of square values for cane architecture characteristics in '8008'

Source	df	Souris 1990	1991
		No. nodes per cane	
RepNo	3	3.26	5.31
Nitrogen	3	88.81*	320.68*
Error a	9	14.45	13.93
		Cane height	
RepNo	3	370.76	613.49
Nitrogen	3	2216.65*	8929.34*
Error a	9	501.93	569.00
		Cane diameter	
RepNo	3	0.56	0.87
Nitrogen	3	36.90*	179.05*
Error a	9	3.81	3.24
		No. laterals per cane	
RepNo	3	16.03	2.37
Nitrogen	3	56.63*	245.00*
Error a	9	8.49	33.62
		No.reproductive laterals per cane	
RepNo	3	14.97	0.92
Nitrogen	3	147.91*	311.79*
Error a	9	9.40	35.64
		No. vegetative laterals	
RepNo	3	0.51	2.17
Nitrogen	3	19.09*	9.04*
Error a	9	1.56	6.64
		Percent of reproductive nodes	
RepNo	3	152.94	11.01
Nitrogen	3	793.78*	898.26*
Error a	9	129.62	260.02

table A3.12 contd.....

		Percentage of cane fruiting	
RepNo	3	34.45	248.85
Nitrogen	3	4970.94	9715.23*
Error a	9	569.47	115.95
		Lateral length	
RepNo	3	33.44	35.75
Nitrogen	3	222.89*	1367.34*
Error	9	43.22	31.70
		Internode length	
RepNo	3	n.a.	0.42
Nitrogen	3	n.a.	1.57*
Error a	9	n.a.	0.36

n.a. = not available

Table A3.13. Sums of square values for fruit yield in '8008' (Greenhouse, 1991)

Source	df		
		Fruit yield (g/plot)	No. fruits per lateral
Nitrogen	4	95186.54*	200.73*
Error a	19	51576.17	236.15
		No. fruits per cane	Fruit size
Nitrogen	4	242930.23*	116.99*
Error a	19	144537.60	6.33
		No. flowers per lateral	No. flowers per cane
Nitrogen	4	257.56*	303344.00*
Error a	19	317.09	216995.95
		Days to flowers	Days to ripen
Nitrogen	4	294.00	504.73
Error a	19	751.95	1026.60
		Percent fruit set	
Nitrogen	4	897.92*	
Error a	19	660.48	

Table A3.14. Sums of square values for cane architecture characteristics in '8008' (Greenhouse, 1991)

Source	df		
		No. nodes per cane	Cane height
Nitrogen	4	136.75*	4721.70*
Error a	19	136.20	4182.80
		Cane diameter	Internode length
Nitrogen	4	25.18*	1.02*
Error a	19	8.81	1.35
		No. laterals per cane	No. reproductive laterals
Nitrogen	4	538.60*	259.60*
Error a	19	229.40	158.35
		No. vegatative laterals	Percent reproductive nodes
Nitrogen	4	62.55*	737.59*
Error a	19	91.95	630.98
		Fresh cane weight	Dry cane weight
Nitrogen	4	23694.83*	9349.72*
Error a	19	18902.15	5946.32
		Lateral length	Fruit dry weight
Nitrogen	4	996.56*	0.32
Error a	19	1410.11	0.88

APPENDIX 4

Analysis of variance - combined Site analysis model

Table A4.1. Combined analysis model used for anova (1990, 1991)

Source	degrees of freedom	df
Site	(s-1)	2
RepNo	(r-1)	3
Trt	(t-1)	3
Site * Trt	(s-1)(t-1)	6
Error a	(r-1)(t-1)	9

APPENDIX 5

Detailed experimental site characterisation

Table A5.1. Detailed soil characterisation of the St. Adolphe, Morden and Souris experimental sites in Manitoba

Site	Soil description	Parent material	Reference
St. Adolphe	Osborne clay, Rego Black-Chenozem, poorly drained, moderately calcarious	developed on fine lacustrine sediments	Ehrlich et al. (1953)
Morden	Orthic Black, Eigenhorf series, moderately well drained, moderately calcarious	developed on moderately fine alluvial and lacustrine deposits	Michalyna (1968)
Souris	Orthic Black-Chenozem, Lylton sandy-loam, well drained moderately calcarious	developed on lacustrine deposits	Podolsky (1985)

Table A5.2. Summary of agroclimatic statistics at the St. Adolphe, Morden, and Souris experimental sites, Manitoba in 1990-1991

Site	Climatic measurement	Year	
		1990	1991
St. Adolphe	Total precipitation	436.6	483.0
	Degree days above 5°C (No.)	n/a	1570.0
	Avg. high temp. (°C)	9.3	9.8
	Avg. low temp. (°C)	-5.0	-2.3
	Frost-free days (No.)	155.0	163.0
Morden	Total precipitation	508.6	683.0
	Degree days above 5°C (No.)	n/a	2068.4
	Avg. high temp. (°C)	9.8	8.6
	Avg. low temp. (°C)	-1.0	1.5
	Frost-free days (No.)	180.0	186.0
Souris	Total precipitation	592.7	694.4
	Degree days above 5°C (No.)	n/a	1859.3
	Avg. high temp. (°C)	9.2	9.8
	Avg. low temp. (°C)	-4.1	-0.9
	Frost-free days (No.)	161.0	163.0