The Effect Of Cane Management System On Yield And Selected Cane Characteristics Of The Red Raspberry

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One of the most important problems of raspberry cultivation is the excessive intercane competition that occurs between floricanes and primocanes, resulting in low yields and poor cane vigour. Six cane management systems, three density reduction treatments, biennial cropping, alternate side of row cropping and chemical control of primocanes were evaluated as to their influence on yield and cane vigour using the cultivars Festival, Latham and Newburgh. The study was carried over three seasons from 1984-1986. Reduction of cane density increased cane yield, however plot yield was reduced when cane density reached 5 canes/metre. Cane density reduction increased fruit weight and number, lateral branch number/cane and cane diameter. Cane density was positively related to yield/metre of row and was negatively related to yield/cane. Biennial cropping increased yield in the first year and increased both cane yield and fruit weight of Festival raspberries in 1984 and 1986. Cane height was decreased by biennial cropping. Alternate side of row cropping decreased plot yields and cane height. Chemical control of primocanes did not respond differently to the parameters measured when compared to the control, and this lack of response was thought to be due to the incomplete control that glufosinate had on early primocane growth.

Effets Des Méthodes De Régie Des Tiges Sur Certaines Caractéristiques Sélectionnées Et Sur Le Rendement De La Framboise Rouge.

Un des problèmes importants de la culture du framboisier rouge est la concurrence excessive des rejets et des cannes se traduisant en baisses de rendement et de vigueur. Au cours d'une étude échelonnée sur trois ans, de 1984 à 1986, six méthodes de régie des tiges, trois traitements pour en réduire la densité, une technique de récolte bisannuelle, l'alternance des côtés de rangs et le contrôle chimique des rejets ont été évalués quant à leurs effets sur le rendement et la vigueur des cultivars Festival, Latham et Newburgh. Le réduction de la densité des cannes par mètre de rang a contribué à en améliorer le rendement, par contre celui des parcelles a accusé une baisse lorsque la densité a été réduite à cinq cannes au mètre. La réduction de la densité des cannes a contribué à l'augmentation du poids et du nombre des fruits, du diamètre des cannes et du nombre de leur branches latérales. Il existe donc un raport positif entre la densité des cannes et le rendement par mètre de rang et un rapport négatif entre la densité et le rendement par canne. Le système de récolte bisannuelle a conduit à une augmentation du rendement au cours de la première année et une augmentation du nombre de cannes ainsi que du poids des fruits du cultivar Festival pour les années 1984 et 1986. Cette méthode aussi contribué à une réduction de la hauteur des pousses. L'alternance des côtés de rangs a diminué le rendement par parcelle et la hauteur des cannes. Aucune différence n'a été observée entre la répression chimique des rejets et le contrôle quant à leurs effets sur les paramètres mesurés et il semblerait qu'un contrôle inadéquat de la pousse hâtive des drageons par le glufosinate en soit responsable.

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1. INTRODUCTION

The commercial cultivation of raspberries in Quebec is of relatively minor importance when compared to the production levels of other fruit crops in the province. For example, in 1984 Quebec produced 11,925 tonnes of strawberries, which represented 38.7 % of the total strawberry production in Canada. By contrast, only 814 tonnes of raspberries were produced in Quebec during 1984, which represented 5.4 % of Canada's total raspberry production (Agriculture Canada, 1986). Ironically, the fresh market price of raspberries in Quebec between 1984 and 1986 has consistently remained at over two and one half times the price of strawberries (Statistics Canada, 1987).

Although Quebec has the second largest production of raspberries in Canada, more than 91% of the 14,991 tonnes produced in Canada during 1984 were grown in British Columbia. Most of British Columbia's raspberry crop is machine harvested and much of the harvested fruit is transformed to juice or preserves. The extremely perishable nature of raspberries precludes the shipment of large amounts of fresh berries from the west coast to satisfy the eastern markets. Raspberries are particularly sensitive to post harvest fungal infections, and may be safely kept for only three days under cold storage conditions at 0°C and 85-90% relative humidity (Lutz and Hardenburg, 1968; Pepin and MacPherson, 1980). Storage life can be extended up to seven or eight days using controlled atmosphere storage

(Varseveld and Richardson, 1980).

It has been estimated that there is consumer demand for approximately 2,004 tonnes of fresh raspberries in Canada (Agriculture Canada, 1986). Despite these reassuring statistics which indicate a potential need for higher production levels, the production of raspberries in Quebec continues to be small and insufficient to satisfy local demands. A significant market potential exists in Quebec for increased raspberry production. Shoemaker (1978) has stated in his book on small fruit culture that an undersupply of raspberries exists in all the eastern markets of North America.

Yields in Quebec have tended to be low; the average yield of raspberries in an eight year period between 1976 and 1984 was only 1.25 tonnes ha^{-1} (Amyot, 1985). Poor yields in Quebec have been attributed to the use of poorly adapted cultivars which are sensitive to freezing temperatures and to inappropriate cultural practices (Lareau, 1984; Amyot, 1985). Trials conducted at the Agriculture Canada Station de Recherches, St. Jean at Frelighsburg have shown that yields of up to 7.6 tonnes ha^{-1} can be attained using the currently available, better adapted cultivars on good soils, and with the adoption of proper cane management practices (Lareau and Brassard, 1980). Childers (1976) indicated that red raspberry yields in favourable Eastern U.S. planting sites may average 3.3-4.2 tonnes ha^{-1}. The discrepancy that exists between current and potential raspberry yields has prompted the Conseil Des Productions Végétales Du Québec (C.P.V.Q.) to accord a high priority rating to studies relating to the training and management of raspberries (Belzile, 1983).

One of the most serious problems in the cultivation of raspberries is the excessive competition that occurs between the fruiting and vegetative canes (Waister, Cormack and Sheets, 1977; Wright and Waister, 1982a,b). Inter-cane competition in vigorous cultivars of raspberries results in reduced yields, as resources are allocated to the production of large numbers of vegetative shoots rather than to fruit production. In addition, the excessive numbers of shoots that develop experience competition amongst themselves, leading to an even further reduction in yield as a result of poor individual primocane development (Wood, 1960; Wood and Anderson, 1962). Cane management practices employed to reduce inter-cane competition generally increasé crop productivity (Crandall, Allmendinger, Chamberlin and Biderbost, 1974; Waister, Cormack and Sheets, 1977; Crandàll, Chamberlin and Garth, 1980).

Several cane management systems have been developed in recent years to balance the number of vegetative and fruiting canes that are allowed to develop within the cropping row, with the objective of improving yields and maintaining increased productivity. Cane management systems operate by either reducing cane density within the cropping row, or by separating the vegetative canes from the fruiting canes in space or in time, thereby allowing both cane types to grow without the competitive influence of each other.

The purpose of the following study was to investigate a range of raspberry management systems, and to determine their suitability for Quebec conditions.

The objectives of this project were;

1: To test and evaluate raspberry management systems under typical field conditions in Quebec.

2: To identify and quantify cane characteristics that influence yield.

2. LITERATURE REVIEW

2.1 A Brief Description Of The Genus Rubus

Rubus spp.[Tourn.]L. Family Rosaceae; x=7; somatic nos.=21,28,35,42,49,56,63,70,77,84; deciduous or evergreen shrubs or subfruticose or herbaceous plants; stems: erect to trailing, mostly prickly and short-lived; leaves: alternate, simple, 3-foliolate or pinnately compound, stipulate; flowers: perfect, white to pink, in racemes, panicles, corymbs or solitary, terminal or rarely axillary; calyx: 5-parted, rarely 3-7 parted, with persistant lobes; petals: 5, sometimes lacking; stamens: many; pistils: many, sometimes few, on a convex torus; styles: nearly terminal; mature carpels: usually druplets, sometimes dry (Westwood, 1978).

There are more than 400 species mainly in the colder and temperate regions of the Northern Hemisphere (Westwood,1978). Hoticulturally important species of Rubus are the red raspberry, (Rubus ideaus L.), the black raspberry (Rubus occidentalis L.), the purple raspberry (Rubus neglectus, a red x black raspberry hybrid) and the heterogenus species complex known as blackberries (Rubus spp. Subgenus Eubatus) (Shoemaker, 1978).

2.2 A Horticultural Profile Of The Red Raspberry

2.2.1 Cane Characteristics

The red raspberry is a cane fruit. The canes of the raspberry plant are biennial although the root system can survive for many years. The first year cane, the primocane, develops from buds initiated on the roots, or from basal buds that occur at the base of older canes. The primocane is entirely vegetative for most cultivars of red raspberries, however there are some cultivars, known as fall bearing or primocane fruiting cultivars, in which flower buds are initiated and develop, and fruit matures on the primocane (Waldo and Darrow, 1941; Ourecky, 1975). The second year mature cane, the floricane, is where fruit production generally occurs. Floricanes do not grow extensively; instead lateral branches develop from axillary buds, and these are the sites where flowers and fruits are produced.

2.2.2 Fruit Characteristics

The raspberry fruit is an aggregate fruit, consisting of a collection of druplets. Each druplet consists of a fleshy exocarp and mesocarp, and a hardened endocarp surrounding the seed (Shoemaker, 1978). Fruit development proceeds in three stages ; a period of rapid growth beginning at full bloom; a period of reduced growth when the endocarp hardens; and finally resumption of rapid growth continuing to maturity. Most of the fruit growth is accounted for by the expansion of carpellary tissue (Shoemaker, 1978). Furthermore, berries grow more in basal than in polar diameter, and increase proportionately more in weight than in volume. The distinction between the berry of a raspberry and that of a blackberry is that with the raspberry, the torus or receptacle remains on the plant when the berry is picked, whereas in the blackberry, the torus is removed with the fruit when picked (Shoemaker, 1978).

2.2.3 Regions Of Cultivation

Red raspberries have been commercially grown almost exclusively in the northern regions of North America, and Europe, and the southern regions of New Zealand and Australia (Westwood, 1978). Production has been limited to these colder temperate zones since chilling is required to break dormancy of axillary buds and initiate development of the fruiting lateral branches (Williams and Hudson, 1956; Vasilakakis, McCown and Dana, 1980).

Raspberry production in North America occurs chiefly in the states of Washington and Oregon, and in the province of British Columbia. Smaller production occurs in the northern states and the eastern provinces. Although most of the commercial cultivars used in Europe originate from the European Red Raspberry, Rubus ideaus L., most of the older cultivars used in North America contains predominately Rubus strigosus L., the North American Red Raspberry in their pedigree to produce sturdier, winterhardy canes (Hudson, 1959; Shoemaker, 1978). Newer cultivars that have been developed in North America display more characteristics of their Rubus idaeus L. heritage.

2.2.4 Training Systems

Raspberries are grown in either hedgerows or hills. When the hedgerow system is used, raspberry suckers are encouraged to develop continuously within the cropping row, resulting in a uniformly dense hedgerow. Hedgerows are maintained at widths of between 30.5 and 61 cm. (Shoemaker, 1978). In the hill or "stool" system, plants are maintained as separate units within a cropping row. In the hill system, the production cycle is maintained by development of replacement canes, and suckers that grow between adjacent plants are removed. Plants within a row are separated by 75 to 90 cm. The hill system is popular in Scotland (Turner, 1977; Turner, 1980), whereas hedgerow training is used in England, some parts of North America, Australia and New Zealand where mechanical harvesting is commonly employed (Shoemaker, 1978).

Numerous studies have compared the productivity of raspberries grown in the two systems. Under Scottish growing conditions it was found that the hill system yielded better than the hegerow system (Wood, 1960; Wood and Anderson, 1962). Hedgerows produced more canes but these were of poorer quality and hence, individual cane yield declined significantly. A later study by Mason (1981) found that hedgerows produced a greater number of primocanes, including a greater number of weak, spindly canes which were pruned out. Canes grown in the hill system produced more numerous and larger berries per lateral branch, resulting in greater yields per cane. Yield per hectare was variable; the first three years resulted in a greater yield under the hill system but in the following two years, greater yields were produced by the hedgerow system. In Washington state, Crandall (1980) found the yield was greater from hedgerows than from the hill system. He suggested that the greater yield was a result of more evenly distributed canes, thereby allowing each cane to experience better light conditions during flowering and fruiting.

2.2.5 Life Cycle

2.2.5.1 Sucker Development

" The raspberry is an unusual plant in that it bears woody short-lived shoots on a long lived perennial root system. Each shoot passes through a well defined sequence of seasonal phases during its two year life cycle. The natural habit of the red raspberry is to form dense colonies of shoots which originate from the roots or stems of the parent plant. Some of these young shoots die from overcrowding, but those which survive can develop long-lived, sparsely branched stools and often become separated from the parent plant by the death of the parent root from which they grew " (Hudson, 1959).

Raspberry shoots can arise in three ways; as root suckers from root buds on the parent root system; as replacement shoots originating from basal buds which are located at or just below the soil level on a second year shoot; and rarely, as lateral branches from aerial axillary buds on an existing shoot (Hudson, 1959). Figure 1 illustrates shoots in various stages of growth on a two year old plant in fall.

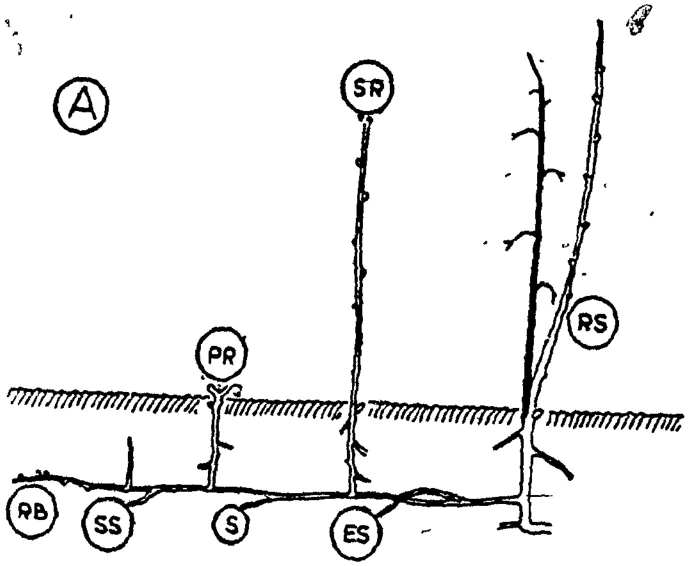
Within the establishing raspberry colony, root suckers are the principle mode of shoot proliferation (Whitney,1978). Sucker development occurs in two seasonal periods; from early March to early May, or from early August through to November (Hudson, 1954; Williams, 1959a). Suckers arising in each period undergo different stages in their morphological development. Suckers that emerge in the fall encounter shortening daylength and decreasing temperatures which induce dormancy of the terminal apex; suckers emerging in the spring encounter increasing daylength and temperature which stimulate active growth of the apex (Williams, 1959b).

Suckers emerging in the fall period elongate rapidly from

Figure 1: A two year old raspberry plant with shoots in various stages of development.

Legend

RB: root buds
SS: subterranean sucker
S: emergent sucker
PR: primary rosette
ES: elongating shoot
SR: secondary rosette
RS: replacement shoot



Source: Hudson, 1959.

proximal internodes which carry the apical meristem to the soil surface. When the meristem reaches the surface, internode elongation ceases and leaf expansion proceeds, forming a primary rosette of leaves. The development of the primary rosette is largely governed by the time of sucker emergence in relation to climatic conditions (Hudson,1959). Early emerging suckers form well developed rosettes before the onset of winter dormancy whereas later emerging suckers produce only a resting bud lying close to soil level. The leaves of the primary rosette are then shed during winter when the apical meristem is dormant. In the following spring the apical meristem resumes activity. New leaves expand and rapid vegetative growth takes place leading to the development of a shoot or cane.

Suckers initiated from root buds in early spring and emerge above soil level at this period do not form primary rosettes. Instead, these root suckers show a continous development from scale leaves underground to fully expanded leaves above ground, following a continous elongation of internodes from below to above ground in formation of the elongating shoot.

Sucker elongation begins in early spring and continues until late autumn. Cane height is usually determined by climate. In England canes may reach 1.8-2.5 metres in height, however taller canes can be produced in regions such as New Zealand where the climate is more favorable to vegetative growth (Hudson, 1959). At the same time that sucker elongation occurs, adventitious roots are produced from the underground portion of the cane.

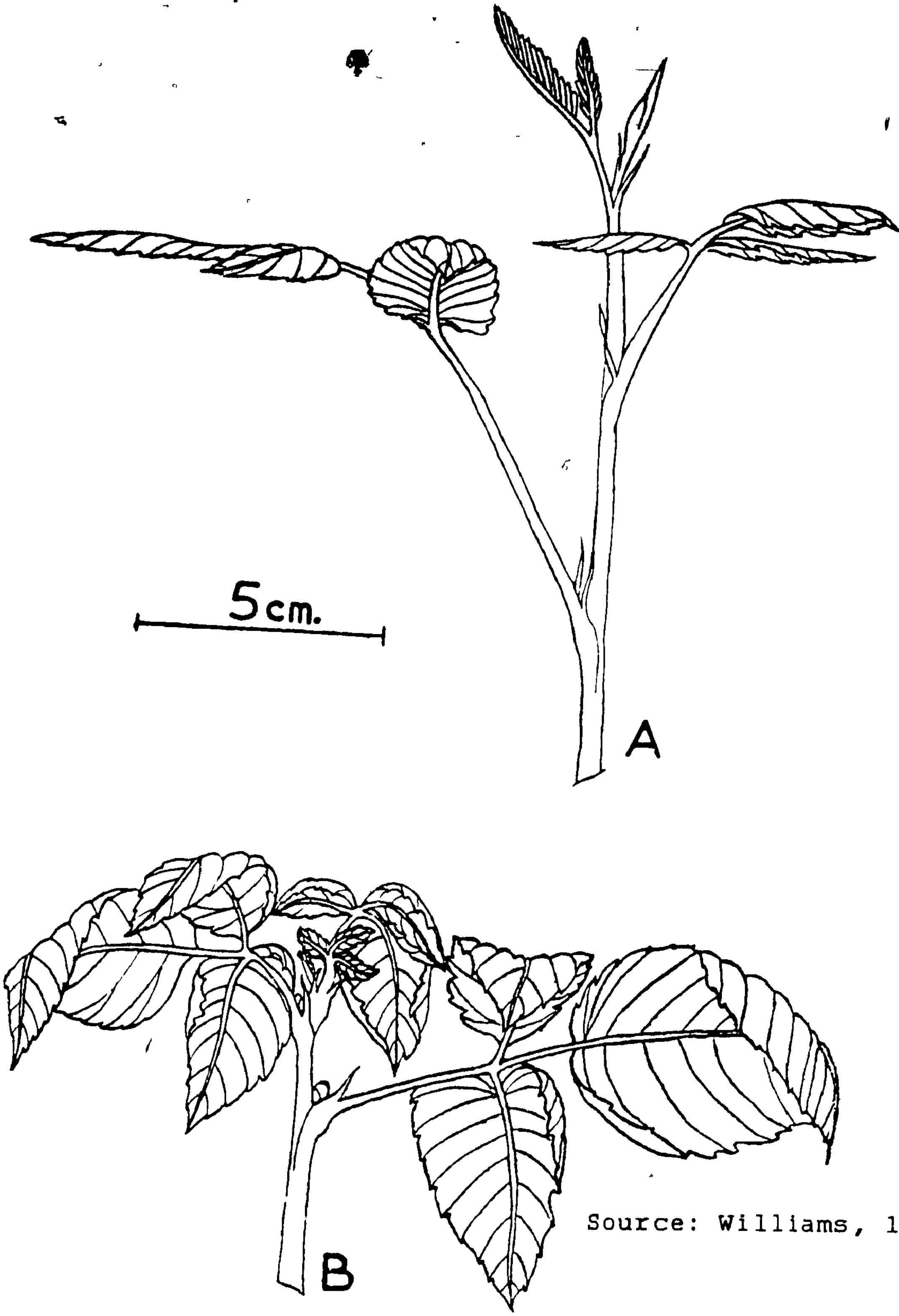
The termination of cane extension is marked by the production of a secondary rosette of leaves at the terminal apex in late autumn (Hudson, 1959)(Figure 2). As the secondary rosette forms, some of the axillary meristems initiate flower primordia within the resting lateral buds.

2.2.5.2 Flower And Fruit Development

The timing of flower initiation appears to be a function of climate, cultivar, and cane vigour: In New York state, several cultivars were found to have no apparent differentiation in the axillary buds by early October, however differentiation had occured by early January (Macdaniels, 1922). Differentiation of fruit buds occurred by November in Oregon (Waldo, 1933). In Scotland, floral development was found to be initiated by mid-September (Mathers, 1952; Robertson, 1957). Williams (1959c) found that the cultivar Malling Promise initiated flower buds by mid-September whereas the cultivar Lloyd George initiated flower buds by late August. Primordial bud development differed considerably between large and small diameter canes in early October, the smaller diameter canes showing greater early flower bud development, but by the time of bud break in March, there was little difference in bud number (Crandall and Chamberlin, 1972).

Flower initiation generally takes place earliest in the fifth to tenth bud below the terminal apex, after which further initiation proceeds basipetally down the cane (Waldo, 1933; Mage, 1975). Lateral buds that have been initiated are considered as dormant fruit buds since they must undergo a period of dormancy in order to break (Williams, 1959c). Until flower initiation occurs, canes are entirely vegetative and are commonly referred to as primocanes (Bailey, 1941).

Figure 2: Contrast between an elongating and a dormant shoot, cv. Malling Promise.
A: terminal portion of elongating shoot in May.
B: secondary rosette on shoot which has ceased elongating, drawn in late October.
Note the short petioles and the large axillary buds.



Source: Williams, 1959c.

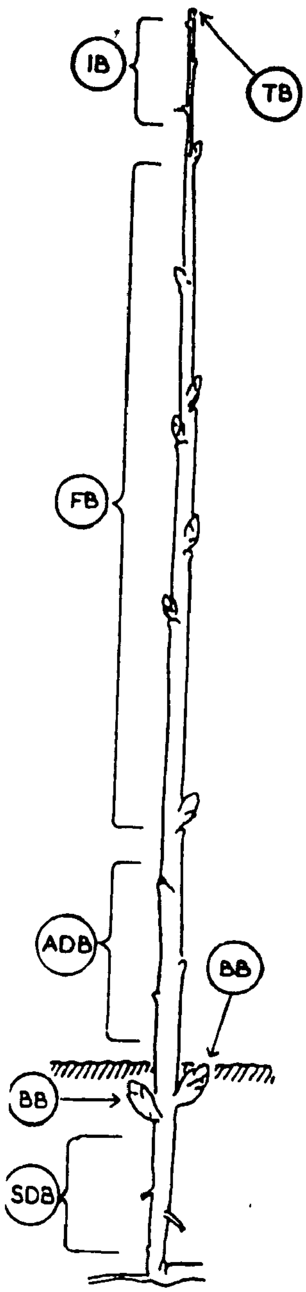
Dormant fruit buds generally require a cold treatment to break dormancy (Williams, 1959c). This cold treatment is normally satisfied by winter in cold temperate regions, however in areas of cultivation which experience mild temperatures, there may be insufficient cold to break dormancy, resulting in flower buds that are abnormal or buds that fail to flower (Sherman and Sharpe, 1971; Barrientos and Rodriguez, 1980). Once the dormancy period has been satisfied and the temperature is high enough for growth to begin, the growth of lateral branches occurs,bearing both flowers and leaves (Waldo, 1933). Inflorescences produced on the lateral branches are indeterminate and form a series of primary and secondary flower spikes. From the time at which initiation of the flower primordia takes place, the mature cane is commonly referred to as a floricane (Bailey, 1941). Figure 3 illustates the variety of buds that can occur on the floricane before the development of lateral branches.

At approximately the same time as lateral branches are developing from the dormant fruit buds on the floricane, one or more basal buds can become elongated to form a vegetative replacement shoot. By the end of the growing season, this replacement shoot will develop into a primocane, thus repeating the biennial life cycle of the raspberry cane. After fruiting, the floricane dies and is replaced by the replacement primocane, which continues to grow on the parent root system, giving rise to the formation of a stool.

Figure 3: Bud formation on a mature raspberry cane.

Legend

TB: terminal bud
IB: immature buds
FB: fruiting buds
ADB: aerial dormant buds
BB: basal buds
SDB: subterranean dormant buds



Source: Hudson, 1959.

2.3 Competition In The Red Raspberry

2.3.1 Plant Response To Competition

Competitve plant interactions are among the most important ecological phenomena affecting natural plant populations and the effects of competition on many plant characters have been extensively studied (Harper and Ogden, 1970). In stressful environments, the way in which a plant partitions its resources can have a great impact on its survival since the quality, quantity and timing of allocation of a limited amount of resources to growth, maintenance, and reproduction will affect its fitness (Snell and Burch, 1975). In many plant species, restructuring of resource allocation patterns can occur under changing environmental conditions which allows the species to better survive under these new conditions.

Plant reproductive capacity can be especially sensitive to the effects of competition. Reproductive ratios such as seeds per capsule, seeds per plant, and capsules per plant may be reduced in number as plant density is increased (Harper, 1961). Snell and Burch (1975) studied the effects of increasing intraspecific competition and decreasing nutrient levels on the Euphorbiaceae Chamaesyce hirta (L.) Millsp.. They found that as plant density was increased and as nutrient availability was decreased, the total plant energy that was allocated to reproductive tissues decreased proportionately. Furthermore, root tissues assumed a larger proportion of total plant biomass as plant density increased. Reproductive effort diminished when plant density was high, suggesting an internal shift of resource allocation patterns in response to increasing plant density.

2.3.2 Dynamics Of Inter-Cane Competition

The effect of interspecific competition on the growth and development of the red raspberry plant has been widely studied because of its relationship to fruit productivity (Brierly 1934; Crandall, Allmendinger, Chamberlin and Biderbost, 1974; Lawson and Waister, 1972; Waister, Sheets and Cormack, 1977; Wright and Waister, 1982). The influence of cane competition on the fruit production of a raspberry plantation can be considered as an influence of both inter-plant and intra-plant competition; inter-plant competition occurs when raspberry canes are grown in dense hedgerows with little inter-plant spacings; intra-plant competition occurs between floricanes and primocanes which compete with each other, via a common root system for water, nutrient and light resources (Waister, Cormack and Sheets, 1977; Wright and Waister, 1982a), effecting a net transfer of assimilates. Wright and Waister (1984) suggested that competition for light between the primocane and floricane was the most limiting factor in raspberry productivity.

In an examination of the seasonal partitioning of dry matter and non-structural carbohydrates within a natural stand of raspberries, Whitney (1978) suggested that many of the competing demands on the reserve carbohydrate system are separated compartmentally. He reasoned that the drop in the reserve carbohydrate levels of overwintered primocanes stems in early spring was attributed to lateral branch and leaf production. As the leaves expanded on the lateral branches, the photosynthate produced by these leaves initially replenished the stem reserves, but when fruit set had occured, photosynthates produced by these leaves were transferred to the developing fruit. In contrast, the assimilates required for the development of a new flush of primocanes early in the spring was dependent on the storage reserves within the root system; as primocanes emerged, assimilates stored in the root reserves were transferred to the rapidly growing primocane suckers. However once the primocane growth slowed in midseason and their leaf biomass had effectively increased, the photosynthates produced by these leaves replenished the root storage reserves. Thus, by the end of the growing season, carbohydrate reserves within the floricane were completely depleted resulting in the senescence of the floricane whereas the carbohydrate reserves within the primocane and root system continued to increase until late autumn.

Whitney believed that the segregated compartmentalization of storage reserves within the raspberry plant offered a temporal advantage since it enabled the raspberry plant to respond rapidly to favourable growing conditions during the spring. Floricanes leaf out rapidly in the spring, build up a large leaf biomass early in the season and transfer their photosynthates to the developing fruits, after which leaf senescence occurs leading eventually to the death of the floricane. However as the floricane leaves senesce, the primocane leaf area index increases. Primocanes maintain a high leaf area index well into the late autumn, providing a high level of carbohydrates for the stem and the root storage reserves. Therefore, taking this line of reasoning, the raspberry plant appears to stagger the period during the growing season when primocane or floricane development predominates, which in turn leads to reduction of competition between primocanes and floricanes in the present season and to the regeneration of stronger canes in subsequent seasons.

2.3.2.1 Yield Response To Cane Density

A fundamental relationship in raspberry cultivation is that between cane density and fruit production. Generally, increasing the number of canes contained within a row will increase the row yield. Several studies have found that increasing cane density by closer within and between row cane spacings resulted in increased yields (Wood, Anderson and Freeman, 1961; Wright and Cormack, 1980; Rodriguez, 1978; Olafsun, 1979). Retention of more cropping canes per hill in the hill system resulted in greater yields (Wood, 1960; Crandall, Allmendinger, Chamberlin and Biderbost, 1974). Though the relationship that exists between cane density and yield tends to be positive, the relationship between cane density and the yield components tends to be negative. Crandall et al (1974) observed that although increasing the number of canes per hill of Washington raspberries from 6 to 12 resulted in greater yields, lateral number and fruit number per lateral decreased. Similarily, as the number of cropping canes per hill was increased from 6 to 12 in Puyallup raspberries, fruit number per lateral and berry set was reduced. Similar results were found by Lott (1931) in Colorado, Lawson and Waister (1972) and Wood et al (1961) in Scotland, and Redalen (1981) in Norway. Since the yield components of raspberries are berry size, berry number per lateral, lateral number per cane, and the number of canes per hectare (Crandall, Chamberlin and

Biderbost, 1974), these observations infer that an increase in cane density could result in excessive inter-cane competition, resulting in a reduction of productivity per cane. Increasing the number of canes within a unit area until the cane density suffers from excessive inter-cane competition results in decreased yields. Conversely, decreasing cane density in a vigourous plantation could increase yields, even though the number of cropping plants has been reduced. This phenomenon, known as yield compensation, can occur when a reduction of cane density is offset to some degree by an increase in yield per cane.

Wood, Anderson and Freeman (1961) noticed that when cane numbers were increased by closer within and between row spacings, berry number per lateral decreased. Despite this effect, closer planting distances (1.68 m between rows and 0.61 m within rows) gave the highest yields. Waister, Wright and Cormack (1980) found a direct relationship between yield and inter-row spacing: In their experiment, reducing inter-row spacing from 180 cm to 90 cm increased yield/ha even though yield/m of row declined significantly as the alleys were narrowed. Rodriguez (1978) observed a linear relationship between planting densities of 30,000, 45,000, and 90,000 plants/ha and fruit production/ha. Olafsun (1979) found that yield was greatest when canes were not thinned, although yield per cane and berry weight were substantially reduced in the unthinned plots.

Decreasing cane density from the natural cane population can result in larger, more numerous berries per cane or greater lateral numbers since it allows the remaining canes to utilize more of the available resources in most efficiently improving fruit production. The ideal density of canes per unit area depends on cultivar vigour and region of cultivation: Under Scottish conditions, Wood (1960) found that the ideal cane density for Malling Jewel was about 8 canes per stool, and around 6 canes per stool for Lloyd George. Mason (1981) found that once 8 canes/m of row was reached in a plantation of Glen Clova, no further increase in yield was realized when cane numbers were increased. In Washington state, Orkney and Martin (1980) determined by curvilinear regression that approximately 14 canes/m of row was ideal for the cultivation of Willamette raspberries, but under Australian conditions and using the hedgerow system of cultivation, Clark (1984) found the ideal cane density for Willamette to be 15-20 canes/m of row.

The studies of Crandall, Allmendinger, Chamberlin and Biderbost (1974) further clarified the relationship between cane density and productivity. They found that reducing the number of canes per hill from 12 to 9 to 6, increased lateral numbers, fruits per lateral and fruits per cane. Despite these increases in yield components, yield/ha was reduced by cane thinning. They also noted that thinning canes allowed the development of thicker diameter canes which experienced a greater fruit set and produced more fruits per lateral than thinner canes. Cultivars with thin canes can have considerably lower yields than those with thick canes, but this is usually evident only in less favourable environments (Dale and Daubeny, 1985). In favourable environments, thicker canes may have reduced yields since they tend to produce few lateral branches (Dale, 1986). Thick canes have more carbohydrate reserves at each dormant bud, and Crandall et al (1974) reasoned that the number of flower primordia that develop and set fruit was directly related to the carbohydrate supply to the buds. A similar study by Redalen (1981) found that as cropping cane numbers are increased, berry number and fruit set per cane were significantly reduced.

2.3.2.2 Competition Between Floricanes and Primocanes

Brierly (1931) was the first investigator to speculate that competition existed between primocanes and floricanes in his study of the Latham raspberry. He reasoned that the close juxtaposition of the two phases of growth resulted in a competition for a limited amount of resources. Although his data did not support his supposition, they stimulated further research into the nature of inter-cane competition of the raspberry plant.

Lawson and Waister (1972) found that removal of suckers produced outside the hill, whether within the crop row or in the alleys, improved yield per cane and increased cane height and the number of canes. Norton (1973) and Sheets (1973) found that removal of primocanes growing when the floricane laterals were blossoming and fruiting increased yields in the year of treatment. In addition, sucker removal also stimulated the growth of stronger and more numerous primocanes within the row. Lawson and Wiseman (1979) noticed that removal of alley suckers before they reached 75 cm in height and just before the harvest period increased yield the following season, largely due to the increase of vigourous canes within the stool.

Competition between the fruiting and vegetative canes was demonstrated by growing floricanes or primocanes in the absence of one another (Waister, Cormack and Sheets, 1977; Wright and Waister, 1982 a,b). When floricanes were grown in the absence of primocanes, fruit yield increased as a result of increased yield per fruiting node. When primocanes were grown without the effects of the floricanes, greater numbers of primocanes developed, however the primocanes differed morphologically; they were shorter because of a reduced internode length. Leaf area was also reduced in this treatment. In the following year yield increased because of greater cane numbers, increased yield per cane, greater berry weight and increased berry number.

2.4 Cane Management Systems

2.4.1 Yield Improvement By Selective Pruning

One of the most important sources of crop yield improvement has been to increase the proportion of total plant dry weight partitioned into the harvested organs (Gifford and Evans, 1981). Modifying the partitioning of assimilates among sinks, tissues or organs using or storing assimilates, for available photosynthates supplied or stored by sources is the mechanism behind intraplant yield compensation. The strengths of sinks and sources can influence the pattern of assimilate partitioning, but depend on the developmental stages of the involved organs (Hale and Weaver, 1962). Modification of the assimilate partitioning pattern has been shown in the grape vine (*Vitis vinifera* L.) by selective organ removal, application of gibberellin, and by shading (Quinlan and Weaver, 1970), and in apple trees (*Malus pumila*

Mill.) by early summer shoot tip removal which increased fruit set (Quinlan and Preston, 1971). A redistribution of assimilates has been demonstrated in raspberry canes by selective removal of fruiting laterals (Waister and Barritt, 1980; Braun and Garth, 1984), which resulted in other sections of the cane compensating for the reduced number of laterals by increasing fruit per lateral or fruit size. What is not clear, however, is if a similar compensation response can be invoked by cultural methods that separate, either spatially or temporally, floricane and primocane development.

2.4.2 Biennial Cropping System

Under the biennial cropping system, primocanes and floricanes are separated from each other, thus allowing them to grow in an environment free from the influence of one another . The biennial cropping system can be set up by removing all of the first year's growth early in the spring. This can be done by mowing all canes growing within the row, resulting in the production of primocanes exclusively during the season. This phase of the biennial cropping system is refered to as an "off" year since no crop is produced. In the next year these overwintering primocanes become floricanes and produce fruit. The fruiting season of the biennial cropping system is refered to as an "on" year. Generally speaking, in the "on" year there is likely to be considerable sucker emergence, especially so when very vigorous cultivars are used, neccessitating control by cultivation or by use of a chemical pruning agent (Lawson and Wiaster, 1972; Waister, 1980). Thus, by establishment of the biennial cropping system one develops a biennial or alternate year harvest cycle (Sheets, Nelson and Nelson, 1975).

Waister, Cormack and Sheets (1977) investigated the usefulness of the biennial cropping system to reduce intercane competition between primocanes and floricanes. They noticed that when vigorous cultivars were used,biennial cropping increased yields compared to the conventional annual system of production. Norfolk Giant, a vigorous cultivar, responded much more to the biennial cropping system than the less vigorous cultivar Malling Jewel. Yield increases of 34% over the annual cropping system were realized when Norfolk Giant was cropped biennially, whereas no significant yield improvement was produced when Malling Jewel was cropped biennially.

A further series of experiments by Waister et al. (1977) elucidated the reason for the increased yield of Norfolk Giant using the biennial cropping system. In the first season of establishment of the biennial cropping system, primocanes were pruned from the floricanes which had developed the previous season in a conventional system (this is referred to as a part-biennial system by Waister et al., 1977). Yield per cane increased because of greater yields per node. The following season was an "off" season in which only primocanes developed and therefore no fruiting occured. In the next season, an "on" year where a fully biennial system was in operation with floricanes which had developed without the influence of primocanes in the current season, nor the influences of floricanes in the previous season, an increase in yield was realized compared to the annual system. However the higher yields were the result of a greater number of floricanes as well as an increase in the yield per cane. Cultivar differences were noticed; Malling Jewel produced a greater number of canes but yield per cane decreased with the net result of no improvement in yield. In Norfolk Giant, an increase in yield per cane occured because of increased node numbers retained for cropping, after tipping, even though mean berry weight was reduced. The biennial cropping system significantly reduced cane height of Norfolk Giant by reducing internode length, and this phenomenon explains why cultivars with tall, vigorous canes such as Norfolk Giant responded to biennial cropping much more than cultivars with shorter canes such as Malling Jewel.

The effect of the biennial cropping system on hedgerow grown Fairview raspberries in Oregon where tipping of canes was not practiced was also examined by Waister et al (1977). Although yields increased during the three years of the study, the difference between biennial cropping and annual cropping did not reach the 5% significance level. The conclusions that Waister et al (1977) drew concerning the usefulness of the biennial cropping system in improving yield is that it was completely dependent upon the cultivar selected, the geographic region of production and the training system that is used.

Biennial cropping of raspberries has been further tested in Switzerland (Terrettaz, 1983), Scotland (Waister and Cormack, 1981) and Australia (Clark, 1984). Terrettaz tested the biennial cropping system for two years using the English cultivar Malling Exploit. He found that biennial cropping increased yield per cane by 55% and 46% in each year. Yield/m was reduced by 23% and 27% in each year when it was considered that biennial plots remained unproductive in one out of every two years. In Scotland, biennial cropping was found to increase berry weight, but this occured only in the first year of a three year study (Waister and Cormack, 1981). Biennial cropping produced thinner primocanes with shorter internodes. In Australia, Clark (1984) found that a part-biennial cropping system increased yields by 22% over the annual system with the cultivar Williamette. The following year, a 50% increase in yield was realized by the fully biennial system when compared to the annual cropping system. The yield increase of the part-biennial system was because of an increase in yield per lateral. The yield increase realized with the fully biennial system was because of an increase in lateral number per cane as well as an increase in yield per lateral. However, as the plantation reached maturity and cane vigour declined, biennial cropping had a reduced effect on yield, reinforcing the suggestion that yield improvement under the biennial cropping system is highly dependent apon cane vigour.

Wright and Waister (1982a) have suggested that canes growing in the biennial cropping system are morphologically distinct from canes developing under an annual cropping system. Several studies have alluded to this: For example, although there appeared to be more canes in the biennial cropping system, the canes tended to be shorter and thinner in several experiments (Terretta, 1983; Waister et al, 1977). Wright and Waister compared the growth of primocanes and floricanes in an annual and a biennial cropping system and found that primocanes growing in the biennial cropping system were significantly shorter. Both node number and internode length were reduced. Primocanes growing in an annual system elongated rapidly at the beginning of the growing season compared to primocanes in the biennial system. However at the end of the season growth rates of the primocanes within each cropping system had changed; elongation of the primocanes in the annual system slowed considerably whereas the growth rate of primocanes in the biennial system did not. It was suggested that the morphological differences noticed in primocanes grown in the biennial system were primarily the result of eliminating the shading of primocanes by the floricane canopy. Canopy shading acts as a selective filter that intensifies light in the far-red region of the light spectrum (Palmer, 1977) and it is probable that far-red light acts through the phytochrome system to increase internode length (Smith, 1975; Holmes and Mcartney, 1976). By elimination of primocane shading, the biennial system stimulated growth of primocanes with shorter internode lengths and greater leaf areas. Thus, the light climate experienced by the primocanes within the biennial cropping system would likely result in better fruit production of the cane in the next year, especially if cane tipping is practiced.

Improved light climate has been suggested by Waister and Barritt (1980) to account for the compensation in yield when raspberry canes have had selected fruiting laterals removed. The hypotheses that better light conditions improve cane yield has not, however, been supported by Braun and Garth (1984). They reported that when canes were trained to grow horizontally in order to balance the exposure to light of laterals along the length of the cane, yield did not improve, although the length of laterals in the horizontally trained canes were the same for the upper and lower cane portions in contrast to the control canes which had much longer lower laterals.

2.4.3 Alternate Side Of Row Cropping

Alternate side of row cropping is a cane management system where floricanes and primocanes are separated along the row width, thereby allowing each cane the opportunity to receive adequate light and aeration required for normal growth and to reduce the incidence of cane diseases (Lareau, 1987). Alternate side of row cropping can be considered as a modified form of a biennial cropping system, where the row width is divided so that half the row contains only floricanes while the other half contains only primocanes. Thus, canes are separated spatially in the alternate side cropping system compared to the temporal separation of canes in the biennial system. In successive cropping seasons, fruit production flip-flops from one side of the row to the other.

The success of alternate side of row cropping system has been mixed. Use of a divided canopy in thornless blackberry produced greater yields and greater primocane growth than plants grown in a single canopy (Swartz et al., 1984). The success of the divided canopy in this study was probably a result of better light conditions that were made available to the primocanes. In Quebec, alternate side of row cropping has proved to be more productive, less costly and more accessible to hand picking or machine harvesting than either conventional cropping systems or biennial cropping (Lareau, 1987). In Switzerland, however, an alternate side of row cropping system did not improve productivity when compared to the traditional vertical hedgerow system (Terrettaz, 1984).

2.4.4 Control of Primocane Emergence

2.4.4.1 Mechanical Pruning

With the introduction of new and more effective herbicide formulations, chemical weed control has replaced the traditional weed control method of soil cultivation in raspberry plantations (Lawson and Wiseman, 1972). This change in cultivation practices has led to non-disturbance of soil around the stool, which allows the suckers to proliferate from an uninterrupted root network in the inter-row and between-row spaces (Lawson and Wiseman, 1979). Williams (1959a) noticed the rapid spread of suckers out of the stool region of Malling Jewel raspberry plants. Traditional soil cultivation to control weeds tended to reduce sucker development, particularily between the rows. Lawson and Waister (1972) found that allowing unrestricted sucker growth in the alleys and between the stools produced poorer quality fruiting canes within the stool, resulting in fewer canes being retained for cropping. Since cultivation of the soil is now not as frequently practiced, removal of extraneous suckers is important for the maintenance of quality fruiting canes.

The competitive relationship between suckers growing in the alleyways and fruiting canes in a non-cultivated plantation of

Malling Jewel raspberries was closely examined by Lawson and Wiseman (1979). They allowed alley suckers to grow to different heights before removing them and monitored how sucker removal at various stages affected cropping in subsequent years. As sucker removal was delayed, fewer suckers regrew upon removal of the first flush. If sucker removal was delayed until just before fruit harvest then no sucker reemergence took place. Removal of early suckers when they reached 25 cm in height resulted in taller regrowth than if early suckers were removed later. When alley suckers were removed before the tallest sucker had reached 75 cm (late June), no effect on yield or fruiting cane quality was observed in the following season. However, if sucker removal was delayed until just before harvest (mid July), then a significant decrease in yield was realized the following season, mainly because of the decrease in the number of fruiting canes produced per stool.

Investigation of timing and the frequency of sucker removal between stools, on the growth and yield of fruiting canes was also carried out by Lawson and Wiseman (1983a) on the vigorous cultivar Glen Clova. In addition they examined the difference between annual sucker removal and alternate year removal. Annual removal of suckers resulted in an average yield increase of 38% over a five year period, though yields decreased significantly by the fifth year of the study. The increase in yield came as a result of greater berry numbers per length of cane, and an increase in berry weight, the first factor being the more important of the two. Removal of suckers every other year maintained the vigour of the plantation for a longer period of time. Annual removal of suckers, even when done early in the spring resulted in poor yields and poor fruiting cane development after five years of implementation. Removal of suckers when they reached 10-20 cm in height had no effect on the total amount fruiting cane length per stool until the fifth year of the study. However, if suckers were removed later than this, the total fruiting cane length was reduced. Although removal of suckers at different stages did not affect the five year cumulative yield, later removal of suckers beyond the 10-20 cm height decreased the number of second flush canes produced and decreased cane height the following year, even though it increased the yield per cane in the year of removal.

Control of excessive suckering in vigorous cultivars is a common and widespread procedure in the state of Washington. Lawson and Wiseman (1979) speculated that control of suckers was a popular practice in Washington because of a more moderate climate, a longer growing season and inherently greater cane vigour of cultivars used in Washington which allowed growers the opportunity to eliminate early suckering without harming cane quality in successive years. Successive removal of suckers when they reached an average height of 10-20 cm was done in a four year study in Washington using the vigorous cultivar Willamette (Norton, 1974; 1980). Increases in yields were recorded in each year, with additional increments in yield in most years when two, three and even four successive sucker removal operations were carried out. Under Scottish growing conditions however, as little as one sucker removal operations when the suckers reach 10-20 cm in height can jeopordise the long term productivity of the plantation if sucker removal is done every year. Therefore an alternate year sucker removal practice is recommended for Scottish growers (Lawson and Wiseman, 1979).

2.4.4.2 Chemical Pruning

Primocane control in red raspberry, also referred to as chemical pruning, cane burning, primocane suppression or cane vigour control is the practice of spraying the basal section of the raspberry cane with a chemical dessicant, usually dinoseb (2-sec-butyl-4,6-dinitrophenol), in the spring when the new primocanes are 10-25 cm in height (Norton,1980).

The origin of this practice is somewhat obscure, but it is thought to have been originated by growers in British Columbia in the early 1960's. Bullock and Sheets (1968) recommended the use of dinoseb to control excessive basal lateral production in trailing blackberry production in Oregon. The economic advantage of using dinoseb was considerable compared to hand pruning; Bullock and Sheets (1968) estimated that treatment of lower laterals with dinoseb would cost $ 2.00 per acre compared to the 15 to 40 hours required to hand trim these lower laterals at that time. Grower interest in using dinoseb as a primocane control agent prompted research into its use. Studies done in Washington state found that paraquat (Gramoxone), Ethephon, SADH and other growth retardants were not as effective as dinoseb (Norton, 1980). Screening trials in the late 1970's in Scotland found no herbicide or dessicant proved to be as cheap, reliable and safe to the crop as the dinoseb spray (Lawson, 1980). The formula of 4 liters dinoseb, 8 liters miscible oil in 800 liters water per hectare was developed and when tested on Willamette raspberries, it was found that yield increases averaging 52% were possible with no subsequent loss of cane vigour (Sheets, 1973; Norton, 1974).

The use of primocane control has become very popular in the Pacific Northwest. In a recent survey, most plantations in Northwest Washington were treated with at least one application of dinoseb (Norton,1980). Despite its popularity, the widespread use of dinoseb has raised some concern. Hughes (1971) warned growers that the practice of primocane control is harmful and results in thin canes and reduced crops in successive years (Norton,1980). It appears that the practice does reduce vigour on previously weakened hills or on young plantings. Crandall (1973) found that although primocane control using dinoseb reduced both cane height and diameter, potential fruiting laterals were increased due to the reduction in primocane competition. Norton (1973) found that the greatest yield response to dinoseb occured with the vigorous cultivars Meeker and Canby. The weakest response occured in Matsqui, a cultivar with low vigour.

Crandall, Chamberlin and Garth (1980) examined the effect of multiple applications of dinoseb on yield and cane growth of Willamette and Sumner raspberries in a four year study. The primocanes were sprayed when they reached 18 cm in height and were resprayed when the second flush reached 18 cm. When the vigorous cultivar Willamette was treated, one or two sprays increased yields by up to 70% over unsprayed plots. Berry weight increased in some years while in other years it remained unchanged. A single spray application did not effect primocane growth, however two applications reduced cane height and diameter and reduced cane numbers in the last two years of the study. The increase in yield was a result of greater berry numbers, and the increase occured mainly on the middle and lower lateral branches. A single application did not affect Sumner, a less vigorous cultivar, however two applications greatly reduced yields the following year because of reduced cane height and a reduction in cane numbers. A chemical analysis of the canes revealed that two spray applications of dinoseb greatly reduced the carbohydrate levels of the lateral buds.

Similar results of applying dinoseb as a primocane control agent have been found in Scotland using the vigorous cultivar Glen Clova (Lawson, 1980). Long term experiments on Glen Clova show that cumulative yields on plots treated every year at 10 or 20 cm in height have been 30-40% above those on conventionally managed plots over a four and five year period. It was speculated that these yield increases were due not only to the direct effects of vigour control but also to the interaction between the delay in cane development and the incidence of pests and diseases (Williamson et al., 1979).

An emerging problem concerning the use of dinoseb as a primocane control agent is its high mammalian toxicity. Severe restrictions have been placed on its handling and application by unskilled persons (Lawson, 1980) and the use of dinoseb has been declining because of the risks involved with its use (Pritts, 1987). The potential safety risks of dinoseb, coupled with its suspension has prompted some researchers to seek an alternative cane pruning agent. One promising alternative dessicant that has been evaluated for primocane control is Glufosinate (Ammonium [3-amino-3-carboxyl-propyl] methylphosphinate). Glufosinate (coded Hoe 39866, Hoechst Canada Inc.) has been tested by Hoechst Inc. as a non-selective post emergence herbicide, with special applications as a crop dessicant, particularily for potatoes, oilseeds and lentils (Makowski and Faust, 1984). The main action of Glufosinate is generally considered to be by contact only, however small amounts may be translocated to underground plant portions in certain circumstances, giving longer term effects (Gadsby, 1986). In product testing, 0.75 kg a.i./ha glufosinate and 3.5 kg a.i./ha simazine in a tank mix worked well for weed and sucker control in orchards (Gadsby, 1986). In a comparison of glufosinate and dinoseb, glufosinate applied at 0.6 kg a.i./ha produced similar responses in fruit and cane productivity, although glufosinate was much slower acting than dinoseb (Lawson and Wiseman, 1983b).

2.5 Summary

The red raspberry possesses an unusual life cycle in that biennial canes are produced by a perennial root system. Within each growing season, the first year primocanes emerge concurrently with the fruit development of the second year floricanes. Because of the close juxtaposition of the floricanes and primocanes within the cropping canopy, intercane competition can occur for the limited amounts of resources present. When intercane competition is sufficiently great, the productivity of the plantation declines. The decline in production can be a direct result of lower productivity of the floricanes, or it can manifest itself in the following year because of the poor development of primocanes.

Cane management systems have been developed in areas of intensive raspberry production in order to increase yield and cane quality. Each cane management system can act in one of three different manners; optimization of cane density, separation of canes in space, or separation of canes in time. The success of any one system is dependent on cultivar, climate and the interactions between these two factors. Therefore different growing regions may require different cane management systems. Studies to determine which system is optimal for Quebec are necessary to maximize production of red raspberries in the province.

3. MATERIALS AND METHODS

3.1 Site Location And Description

A series of field experiments were carried out between 1984 and 1986 in the experimental raspberry plantation located in the Horticultural Research Area of Macdonald College, Quebec (45° 25' North, 73° 56' West). A soil analysis was performed in 1985 and the results are presented in Appendix 1. The field was found to contain adequate levels of Phosphorus, Potassium and Magnesium according to the field recommendations given for the cultivation of raspberries in Quebec given by the Conseil Des Productions Végétales Du Québec (C.P.V.Q. Agdex 230/20, Petits Fruit: Culture. 1985). Therefore fertilizer additions were restricted to application of Nitrogen (see 3.3 Field Maintenance).

The experimental field, established in 1981, consisted of 20 hedgerows of raspberries, each hedgerow being 25 m long and 40 cm wide. The canes within the hedgerows were supported by a two-wire trellis system suspended at 1.5 m above the ground. Alley width was maintained at 3 m to allow tractor access.

Hedgerows were oriented in a North-South direction, along a gentle slope (Plate 1). The hedgerows were grouped into two blocks of ten. Blocks were oriented East-West, perpendicular to the slope and to the direction of the rows. The plantation contained three cultivars; Festival, Latham and Newburgh. A schematic layout of the experimental field including the randomization of treatment plots within each hedgerow is presented in Appendix 2.

Plate 1: View of the experimental red raspberry field at Macdonald College in the Horticultural Research Area. Field was arranged in two blocks, Block 1 in the foreground and Block 2 in the background. Hedgerows run perpendicular to the blocks, in a North-South orientation.

Plate 2: Example of an experimental plot used in the study. Treatment plots were laid out along the hedgerow. Each plot was 2.5 metres in length and maintained at 40 centimetres in width.

3.2 Statistical Design And Field Layout

3.2.1 Experiment No. 1: The Effect Of Cane Management Systems On Yield And Cane Characteristics Of Festival, Latham And Newburgh Raspberries

The experiment used was a split-plot design, where hedgerows constituted the main plot unit, and the six management systems were randomly arranged as 2.5 m sub plots within each hedgerow (Plate 2). A total of 12 hedgerows were used, 4 hedgerows of Festival, 4 hedgerows of Latham and 4 of Newburgh. The field was divided into 2 blocks to account for a North-South gradient, and within each block, 2 hedgerows of each cultivar were selected based on their uniformity of cane growth along the hedgerow. Using 2 hedgerows per cultivar per block permitted the calculation of the variation within blocks in the statistical analysis. Hedgerows of Festival along the field perimeter served as guard rows. The first and last 2.5 m section of each hedgerow was retained as a guard.

3.2.2 Experiment No. 2: The Effect Of Cane Management Systems On Yield Components Of Festival Raspberries

The field setup used in experiment no. 1 was retained for this experiment, however only data from the cultivar Festival were collected since Festival proved to be more productive than either Latham or Newburgh, which produced inferior quality canes and fruit. The statistical design used was a randomized complete block design with four replicates.

3.3 Field Maintenance

Field maintenance of the plantation was based on the recommendations given by the C.P.V.Q. for the protection (C.P.V.Q., 1982) and the cultivation of raspberries (C.P.V.Q., 1985). Appendix 3 summarizes the application schedule and rates used for fertilization of canes, pest and weed controls. In addition to these recommended procedures, a wood chip mulch was spread in the alleys between rows in 1984 and 1985 in order to reduce weed infestation and to help conserve soil moisture.

3.4 Cane Management Treatments

Several cane management techniques were used to determine their effects on fruit yield and cane development. Three of the eight treatments specifically involved reduction of the cane density within the given hedgerow width. The other treatments were cane manipulations which altered the cane canopy but not necessarily cane density. The following are descriptions of the eight treatments used in this study:

Control: Row width was maintained at 40 cm. by mowing or by cultivation in early May. Cane growth within the row width was left untouched. Both primocanes and floricanes within the 40 cm were allowed to grow and develop freely.

Treatment 1: Annual cropping. Floricanes and primocanes reduced to 5 canes per metre of row. Primocane and floricane density were maintained by selective pruning within the row beginning at bud burst, allowing only the strongest and the most uniformly spaced canes to develop, yet restricting the cane density to 5 per metre of row. At the set-up of the experimental treatments in 1984, floricanes were pruned to the desired density in early May. Primocanes were pruned to the desired density by early June, before fruit maturation, and periodically pruned thereafter when suckers reached 15-20 cm in height to control further primocane growth occurring throughout the summer and early fall.

Treatment 2: Annual cropping. Floricanes and primocanes reduced to a density of 10 canes per metre of row. The method of cane thinning employed was the same as treatment 1 above, except that 10 floricanes and 10 primocanes were retained for each metre of hedgerow length in this treatment.

Treatment 3: Annual cropping. Floricanes and primocanes reduced to a density of 15 canes per metre of row. The method of cane thinning employed was the same as treatments 1 and 2 above, except that 15 floricanes and 15 primocanes were retained for each metre of hedgerow length in this treatment.

Treatment 4(a): Biennial cropping. "On" years 1984, 1986. During the 1984 season, all developing primocanes in this treatment plot were removed in early May, leaving only floricanes. As a result of this manipulation floricanes were not present in the 1985 season, and consequently no fruit developed during the 1985 season. However primocanes developed in the 1985 season and became floricanes in the 1986 season, hence the development of an alternate year production cycle. Additionally, the cane density of either the floricanes in the 1984 and 1986 seasons or the primocanes in the 1985 season was maintained at 10 canes per metre of row so that this treatment could be compared to the results obtained in the annual 10 canes per metre treatment (Treatment 2).

Treatment 4(b): Biennial cropping. "Off" year 1984. This treatment is actually the reverse of Treatment 4(a); this was done so that yield measurements could be obtained in 1985 when

Treatment 4(a) was in an "off" year. In 1984, all floricanes were removed and only primocanes developed. Therefore 1984 was an "off" year and no yield was obtained from these plots. However the primocanes matured as floricanes in the 1985 season, and fruit production occured. As in Treatment 4(a), both primocane and floricanes were maintained at a density of 10 canes per metre.

Treatment 5: Alternate side of row cropping. In early May of 1984, one half of the longitudinal row width (20 cm) was mowed down, which removed both primocanes and floricanes in this half of the row. On the opposite half, primocanes were pruned away, allowing only floricanes to grow in this area. Any regrowth of primocanes was pruned when they reached between 15-20 cm in height. During the course of the season, primocanes developed in the row half that was earlier mowed, resulting in one half of the row being floricanes and the other half being primocanes exclusively. In late August, after the harvest was completed, the half row containing the floricanes was mowed down completely. As a result, cropping occured in 1985 on the opposite side to which cropping took place in 1984 and primocanes also grew on the alternate side of the row.

Treatment 6: Chemical suppression of primocane growth. Primocanes emerging in this treatment were sprayed with ammonium glufosinate (HOE 39866, Hoechest Inc.), applied at the rate of 0.6 kg a.i. ha^{-1}. The application was made with a back pack sprayer (Chapin Sprayers) and spraying was directed towards the lower 10-15 cm portion of the canes to limit the damage caused by the spray to the lower lateral branches. Application was done in early May, when approximately 50% of the first emerging primocanes had reached a height of 10-15 cm. The spray was applied until the solution completely covered the leaf and stem surfaces and excess solution dripped off the foliage. Only one application was made during the season.

3.5 Data Collection

3.5.1 Experiment No. 1

The effect of cane management systems on fruiting and cane characteristics which have been found to be significant components of yield and cane quality (Crandall, Chamberlin and Biderbost, 1974) were determined: These characteristics were plot yield, yield per cane, fruit weight, number of fruits per lateral branch, cane height, cane basal diameter, node number per cane, and lateral branch number per cane. Except for plot yield, yield per cane, and fruit weight, estimates of the remaining parameters were based on a sample of 10 canes per experimental unit. In the case of the number of fruit per lateral branch, each cane sample was based on a subsample of 2 laterals taken from each of the top, middle and lower portions of the cane in order to assess the number of fruit per lateral along the full length of the cane.

Measurements were taken during the harvest period to determine plot yield and mean fruit weight. Harvesting of fruit was done every second day whenever possible. Fruit weight was determined by a sample size of twenty berries at each harvest date. Yield per cane was derived from plot yields divided by the number of floricanes in the plot. The number of fruits per lateral branch was determined just before the first harvest when the underripe berries could be easily and accurately counted. Cane height, diameter and mean node number per cane were measured in late fall when the primocanes had stopped growing and had begun hardening off. Lateral branches per cane were counted the following spring, following bud burst of the lateral nodes.

Tissue analyses were performed in the 1985 season on mature primocane leaves. Nitrogen, phosphorus, potassium, calcium, magnesium and chlorophyll concentrations were determined for each experimental plot. Appendix 4 contains the outline of the methods used to determine the mineral and chlorophyll concentrations. The mineral analyses were performed by the Soil Science laboratory at Macdonald College. Leaf samples were collected from the middle of the upper third cane section of one primocane per experimental plot. The primocanes were taken when harvesting had begun when the leaf nutrient concentrations of primocane leaves are thought to be relatively stable (Hughes et al., 1979; John and Daubeny, 1972).

3.5.2 Experiment No. 2

Yield components of the cultivar Festival were examined in 1986 for each management system. Cumulative yield and mean fruit weight were measured over the harvest period for each management system to determine if yield and fruit size were affected at different periods in the harvest. In addition, regression analyses were performed on cane density and mean plot yield, and cane density and yield per cane to determine the ideal density at which mean plot yield and yield per cane would be maximized. Data used in the regression analyses were taken from the cane density reduction treatments and the control plots.

3.6 Statistical Analysis

The parameters examined in Experiment No. 1 and Experiment No. 2 were analyzed using the analysis of variance procedure (Steel and Torrie, 1980). Examples of the analysis of variance of selected variables in 1984, 1985 and 1986 are presented in Appendix 5. Within each dependent variable tested, significant sources of variability due to cultivar, cane management system or cultivar*cane management system interaction effects were further subjected to Duncan's Multiple Range Test to locate differences among means. In the cases where the variable exhibited a significant cultivar*cane management system interaction effect, the simple effects of cane management system within each cultivar were evaluated.

Regression analysis was used to determine the relationship between cane density and mean plot yield, and the relationship between cane density and yield per cane.

4. RESULTS

4.1 Experiment No. 1: The Effect Of Cane Management Systems On Yield And Cane Characteristics Of Festival, Latham And Newburgh Raspberries.

4.1.1 Fruit Yield

Fruit yield was much greater in 1985 than in 1984 for all three cultivars tested (Table 1). Yield increases in 1985 in the cultivars Festival, Latham, and Newburgh were 217%, 171%, and 301% respectively. Festival was significantly more productive than either Newburgh or Latham in both years, and Newburgh was significantly more productive than Latham.

In 1984, yield was increased only under the biennial cropping system (Table 2). The mean plot yield was 4.450 kg in the biennial cropping system, compared to a 3.123 kg plot yield in the control plots, and the 2.990 kg yield obtained by reducing the cane density to 10 canes/m (Table 2). Reducing the cane density to 5 canes/m decreased yield when compared to the control (32 canes/m). Plot yield was significantly reduced in the alternate side of row cropping system while yield in the plots treated with ammonium glufosinate as a chemical pruning agent was not significantly different from the control.

In 1985, no cane management treatment had a greater yield compared to the control plots (Table 2). Yield results obtained in 1985 were similar to the results obtained in 1984; both reduction of cane density to 5 canes/m and the alternate side of row cropping system significantly decreased plot yield, whereas chemical pruning slightly increased yield although the difference was not significant. Total yield over the two years indicates that biennial cropping had lower yields when averaged over two

Table 1: The effect of cultivar on the 1984 and 1985 yield per plot. Experiment No. 1

Variety	mean plot yield (kg/2.5 m plot) 1984	1985	Total
Festival	4.367 A*	9.490 A	13.857 A
Newburgh	2.572 B	7.746 B	10.318 B
Latham	2.455 B	4.219 C	6.674 C

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 2: The effect of cane management systems on the 1984 and 1985 yield per plot. Experiment No. 1

Treatment	mean plot yield (kg/2.5 m plot) 1984	1985	Total
Control	3.123 B*	8.097 AB	11.220 A
Alternate Side	2.384 C	5.078 C	7.462 C
Chemical Pruning	3.413 B	8.584 A	11.997 A
# Biennial	4.450 A	7.597 AB	6.023 D
5 canes/m	2.272 C	5.907 C	8.179 C
10 canes/m	2.999 B	7.301 B	10.300 B
15 canes/m	3.278 B	7.497 B	10.775 B

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Total plot yield for biennial cropping is the mean plot yield of "on-year-1984" plot and "on-year-1985" plot. In the "off-years", plot yields are 0.

years (Table 2).

Each management system displayed a disproportionately high yield in relation to the percentage of cropping canes retained from the natural cane population in the control plots (Appendix 6). In 1984, the control plots had an average of 81 canes. Reduction of cane density to 5, 10, and 15 canes/m had, respectively, 16%, 31% and 47% of the natural (control) cane population. Yet, these same treatments produced, respectively, 73%, 96% and 105% of the yield produced by the control plots. Biennial cropping had only 31% of the canes compared to the control, yet produced 142% of the plot yield. Alternate side of row cropping and chemical pruning had 47% and 87% of the canes, respectively, yet produced 76% and 109% of the yield. In 1985, the natural cane population fell; on average there were only 59 canes per plot (Appendix 6). Cane management systems had a smaller proportionate effect on yield in 1985 than in 1984. Reducing cane density to 5, 10 and 15 canes/m, which represented 22%, 42% and 64% of the natural cane population, produced 73%, 90% and 93% of the yield by control plots. Biennial cropping, which had 42% of the natural cane population, produced 94% of the yield. Alternate side of row cropping and chemical pruning had 55% and 83% of the natural cane population, yet produced 63% and 106% of the control yield.

The simple effects of cane management treatment within each cultivar were determined for yield per cane in both 1984 and 1985 since a significant interaction was found between cultivar and cane management system in the analysis of variance. Table 3 presents the effect of cane management system on yield per cane in 1984 in the cultivars Festival, Latham and Newburgh. Table 4 presents the effect of cane management system on yield per cane in 1985 in the same cultivars.

In 1984, reduction of cane density improved cane productivity in all three cultivars (Table 3). In Festival, yield per cane consistently and significantly increased as cane density was decreased from 15 canes/m to 5 canes/m. This trend was also noticed in Latham, however yield per cane was not significantly greater than the control when density was decreased to 15 canes/m. There was no significant difference in yield per cane between 5 canes/m and 10 canes/m in Latham. In Newburgh, cane density reduction significantly increased yield per cane though there was no significant difference in yield per cane between 10 and 15 canes/m. The biennial cropping system increased yield per cane in in both Festival and Newburgh compared to the 10 canes/m density. In Latham, biennial cropping increased yield per cane, however the difference was not significantly greater. Yield per cane in either the alternate side of row cropping system or the chemical pruning treatment was not significantly greater than the control in any of the three cultivars tested although the yield per cane was consistently higher in both these treatments when compared to the control.

Generally speaking, overall yield per cane in 1985 was greater than yield per cane in 1984. As was noticed in in 1984, an inverse relationship between cane density and yield per cane was also evident in 1985 (Table 4). Furthermore, in 1985 a consistent and significant increase in yield per cane occured in

Table 3: The effect of cane management systems on the yield per cane in 1984. Experiment No. 1

Treatment	Yield Per Cane (g)		
	Festival	Latham	Newburgh
Control	56.31 d*	36.53 c	25.38 c
Alternate Side	73.07 d	61.56 c	69.61 bc
Chemical Pruning	67.92 d	46.78 c	34.21 cd
Biennial	245.97 a	122.19 a	165.86 a
5 canes/m	244.02 a	130.94 a	149.44 a
10 canes/m	171.37 b	102.39 ab	86.18 b
15 canes/m	117.63 c	68.01 bc	73.16 b

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 4: The effect of cane management systems on the yield per cane in 1985. Experiment No. 1

Treatment	Yield Per Cane (g)		
	Festival	Latham	Newburgh
Control	173.96 d*	105.91 c	130.96 d
Alternate Side	228.30 cd	98.68 c	208.28 c
Chemical Pruning	216.71 cd	134.93 bc	177.27 cd
Biennial	430.57 b	173.17 b	307.95 b
5 canes/m	657.31 a	266.81 a	439.15 a
10 canes/m	383.46 b	185.39 b	307.29 b
15 canes/m	265.78 c	106.69 c	219.43 c

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

both Festival and Newburgh as cane density was reduced. In Latham, yield per cane was not significantly different between the control and the 15 canes/m treatment. In 1985, the biennial cropping system did not significantly differ in yield per cane compared to the 10 cane/m density. The alternate side of row cropping system significantly increased yield per cane in Newburgh but was not significantly different from the control in Festival or Latham. Yield per cane in the chemical pruning treatment did not differ significantly from the control in any of the three cultivars tested.

4.1.2 Mean Fruit Weight

In 1984 mean fruit weight of berries from the cultivar Latham was significantly less than the weight of berries of Festival or Newburgh (Table 5). Reducing cane density to 5 and 10 canes/m significantly increased fruit weight compared to the control (Table 6). There was no significant difference in fruit weight between the berries from the 15 canes/m treatment and the berries from the control plots. The biennial cropping system produced the largest fruits compared to any treatment in 1984 and fruit weight was significantly greater than from the 10 canes/m treatment (Table 6). There were no significant differences in fruit weight between berries from the alternate side of row cropping, chemical pruning or the control plots.

In 1985 the analysis of variance of mean fruit weight demonstrated a significant cultivar*treatment interaction, therefore the simple effects of cane management system on mean fruit weight for the three cultivars are presented in Table 7.

Table 5: The effect of cultivar on the mean fruit weight in 1984. Experiment No. 1

Cultivar	Mean Fruit Weight (g)
Festival	2.54 A*
Newburgh	2.40 A
Latham	1.64 B

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 6: The effect of cane management systems on the mean fruit weight in 1984. Experiment No. 1

Treatment	Mean Fruit Weight (g)
Control	2.08 CD*
Alternate Side	2.10 CD
Chemical Pruning	2.03 D
Biennial	2.44 A
5 canes/m	2.27 B
10 canes/m	2.28 B
15 canes/m	2.15 C

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Reducing cane density to 5 or 10 canes/m significantly increased the mean fruit weight when compared to berries from the control plots in all of the three cultivars. There was no significant difference in fruit weight of berries from the 5 or 10 canes/m treatment in all three cultivars tested. Fruit weight in the 15 canes/m treatment was not significantly different from fruit weight in the control plots of Festival and Latham, however the 15 canes/m treatment significantly increased fruit weight in the cultivar Newburgh. Fruit weight was significantly increased by the biennial cropping system compared to the 10 canes/m treatment only in the cultivar Newburgh . Fruit weight was not affected by the biennial cropping system in either Festival or Latham. Fruit weight was increased by the alternate side of row cropping system in the cultivar in Newburgh but this management system had no effect on this character in either Festival or Latham. Fruit weight was decreased by the chemical pruning treatment in the cultivar Festival, however it was not affected by this treatment in Latham or Newburgh.

4.1.3 Mean Fruit Number Per Lateral Branch

In 1985 the analysis of variance of the number of fruit per lateral branch produced a significant cultivar*treatment interaction, therefore the simple effects of cane management system on fruit number per lateral branch for the three cultivars tested are presented in Table 8. Reducing the cane density to 5 canes/m increased fruit number per lateral compared to the fruit number per lateral in the control plots in the cultivars Festival and Newburgh. Fruit number per lateral in the 5 canes/m

Table 7: The effect of cane management systems on the mean fruit weight in 1985. Experiment No. 1

Treatment	Mean Fruit Weight (g)		
	Festival	Latham	Newburgh
Control	2.61 b*	2.00 cd	2.67 c
Alternate Side	2.71 ab	2.02 bcd	2.89 b
Chemical Pruning	2.44 c	2.00 cd	2.57 c
Biennial	2.83 a	2.12 abcd	3.39 a
5 canes/m	2.84 a	2.17 a	2.97 b
10 canes/m	2.75 a	2.16 ab	2.97 b
15 canes/m	2.59 b	1.96 d	2.92 b

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 8: The effect of cane management systems the mean fruit number per lateral branch in 1985. Experiment No. 1

Treatment	Mean Fruit Number Per Lateral		
	Festival	Latham	Newburgh
Control	18.73 b*	10.16 bc	15.87 c
Alternate Side	15.86 c	9.36 c	15.80 c
Chemical Pruning	15.87 c	11.54 a	16.68 bc
Biennial	20.18 a	10.38 abc	17.68 ab
5 canes/m	20.36 a	11.01 ab	18.08 a
10 canes/m	20.03 a	11.14 ab	16.58 bc
15 canes/m	18.72 b	9.55 c	15.55 c

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

treatment was not different from fruit number per lateral in the control plots in the cultivar Latham. Fruit number per lateral in the 10 canes/m treatment was greater than the control in the cultivar Festival, but not in Latham or Newburgh. The number of fruits per lateral was not affected when cane density was reduced to 15 canes/m. The biennial cropping system did not influence the number of fruit per lateral in any of the cultivars tested. Fruit number was significantly decreased in the alternate side of row cropping system in the cultivar Festival, however fruit numbers in Latham or Newburgh were not affected by this treatment. Chemical pruning decreased the number of fruits per lateral in the cultivar Festival, however fruit number per lateral was increased by this treatment in the cultivar Latham. Chemical pruning had no effect on fruit number per lateral in Newburgh.

4.1.4 Mean Lateral Branch Number Per Cane

In 1984, both Festival and Latham produced more lateral branches per floricane than the cultivar Newburgh (Table 9). In 1985, the cultivar Festival had significantly more lateral branches per cane than either Latham or Newburgh, and Newburgh produced fewer lateral branches than Latham.

In 1984, reduction of cane density significantly increased branching compared to the control when cane density was maintained at 5 and 10 canes/m (Table 10). Branching in the 15 canes/m treatment was not significantly different than the lateral branch production in the control plots. In 1985, only extreme cane density reduction to 5 canes/m significantly increased lateral number per cane compared to lateral production

Table 9: The effect of cultivar on the mean lateral branch number per cane in 1984 and 1985. Experiment No. 1

Cultivar	Lateral Branch No. Per Cane	
	1984	1985
Festival	25.11 A*	27.52 A
Newburgh	18.18 B	20.30 C
Latham	23.30 A	22.37 B

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 10: The effect of cane management systems on the mean lateral branch number per cane in 1984 and 1985. Experiment No. 1

Treatment	Lateral Branch No. Per Cane	
	1984	1985
Control	20.41 CD*	22.50 B
Alternate Side	18.28 D	22.18 B
Chemical Pruning	22.33 BC	23.87 AB
Biennial	23.13 AB	23.06 AB
5 canes/m	25.44 A	25.04 A
10 canes/m	23.67 AB	23.64 AB
15 canes/m	22.11 BC	23.08 AB

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

of canes in the control. In both 1984 and 1985, the number of laterals per cane in the biennial cropping system was the same as the number of lateral branches per cane in the 10 canes/m treatment. Neither the alternate side of row cropping nor the chemical pruning treatment significantly affected lateral branch production in 1984 or 1985 compared to lateral branch production of the control canes.

4.1.3 Mean Primocane Height

In 1984 the analysis of variance of mean primocane height indicated a significant cultivar*cane management treatment interaction, therefore the simple effects of cane management system within each cultivar are presented in Table 11. Reduction of cane density produced little change in primocane height of the three cultivars tested. In Latham, reducing the cane density to 10 canes/m increased primocane height, however a further reduction in density to 5 canes/m produced no significant difference in primocane height relative to the control canes. Only in the cultivar Latham was mean primocane height smaller in the biennial cropping system compared to canes in the 10 canes/m treatment. Festival primocanes were slightly shorter than primocanes in the 10 canes/m treatment, however this difference was not significant. The alternate side of row cropping system produced shorter primocanes than canes in the control plots in all three cultivars. The chemical pruning treatment produced significantly shorter primocanes of the cultivar Festival when compared to the primocanes in the control plots.

Table 11: The effect of cane management systems on the mean primocane height in 1984. Experiment No. 1

Treatment	Mean Cane Height (cm)		
	Festival	Latham	Newburgh
Control	137.15 a*	152.65 b	159.25 ab
Alternate Side	117.60 b	127.55 c	130.75 c
Chemical Pruning	120.30 b	153.65 b	146.20 b
Biennial	119.95 b	141.00 b	160.50 a
5 canes/m	138.35 a	149.35 b	157.50 ab
10 canes/m	130.00 ab	168.70 a	157.45 ab
15 canes/m	143.10 a	149.60 b	165.60 a

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

In 1985 Festival produced the shortest primocanes of the three cultivars tested (Table 12). Reduction of the cane density did not significantly affect primocane height (Table 13). However, the biennial cropping system produced significantly shorter canes than either the control or the 10 canes/m density. Additionally, the alternate side of row cropping system also reduced primocane height in 1985. The chemical pruning treatment had no effect on the height of primocanes.

4.1.4 Primocane Basal Diameter

In 1984, the basal diameter of primocanes of Festival and Newburgh was greater than the basal diameter of primocanes of Latham (Table 14). Table 15 indicates the effect of management system on the basal primocane diameter in 1984. Reducing cane density significantly increased cane thickness; the 5 canes/m treatment produced canes with the largest basal diameter and although canes produced in the 10 and 15 canes/m treatments also were significantly thicker, they were not as stout as canes in the 5 canes/m treatment. Primocanes produced under the biennial cropping system were thinner than primocanes in the 10 canes/m treatment. Primocane basal diameter in the alternate side of row cropping or the chemical pruning treatment was not significantly different from the primocane basal diameter of the control canes.

In 1985 the analysis of variance of mean primocane basal diameter showed a significant cultivar*cane management treatment interaction, therefore the simple effects of cane management treatment within each cultivar are presented in Table 16. Reduction of cane density to 5 canes/m significantly increased

Table 12: The effect of cultivar on the mean primocane height in 1985. Experiment No. 1

Cultivar	Mean Cane Height (cm)
Festival	132.19 B*
Newburgh	148.66 A
Latham	141.50 A

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 13: The effect of cane management systems on the mean primocane height in 1985. Experiment No. 1

Treatment	Mean Cane Height (cm)
Control	145.32 AB*
Alternate Side	134.16 C
Chemical Pruning	137.37 BC
Biennial	118.03 D
5 canes/m	150.17 A
10 canes/m	144.07 AB
15 canes/m	145.34 AB

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 14: The effect of cultivar on the mean basal diameter of primocanes in 1984. Experiment No. 1

Cultivar	Mean Cane Diameter (mm)
Festival	10.85 A*
Newburgh	11.05 A
Latham	9.80 B

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 15: The effect of cane management systems on the mean basal diameter of primocanes in 1984. Experiment No. [illegible]

Treatment	Mean Cane Diameter (mm)
Control	9.75 D*
Alternate Side	9.28 D
Chemical Pruning	9.50 D
Biennial	10.49 C
5 canes/m	12.61 A
10 canes/m	11.39 B
15 canes/m	10.93 BC

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

the basal diameter of primocanes all three cultivars. In Newburgh, reducing cane density to 10 and 15 canes/m also increased the primocane basal diameter compared to the diameter of control canes. However, in Festival or Latham, the 10 and 15 canes/m treatments did not significantly affect the basal diameter. The biennial cropping system had no effect on primocane diameter in Festival or Newburgh, however in Latham, the biennial cropping system reduced the primocane basal diameter. Alternate side of row cropping system and the chemical pruning treatment did not affect basal primocane diameter in any cultivar.

4.1.5 Mean Number Of Nodes Per Cane

Table 17 shows the mean number of nodes per cane in 1984 and 1985. In 1984, the primocanes of Latham produced a significantly greater number of nodes than either Festival or Newburgh. In 1985, the primocanes of Latham still had significantly more nodes per cane than Festival, however the node number was not significantly greater than Newburgh.

Reducing the cane density to 5 and 10 canes/m significantly increased the number of nodes on the mature primocanes (Table 18), whereas reducing the cane density to 15 canes/m did not have any effect. The biennial cropping system did not influence node numbers per cane relative to the 10 canes/m treatment. Similarily, neither the alternate side of row cropping nor the chemical pruning treatment influenced the number of nodes per cane in 1984 or 1985, relative to the control canes.

Table 16: The effect of cane management systems on the mean basal diameter of primocanes in 1985. Experiment No. 1

Treatment	Mean Cane Diameter (mm)		
	Festival	Latham	Newburgh
Control	9.35 c*	8.35 bcd	8.00 b
Alternate Side	9.55 bc	8.05 cd	8.40 b
Chemical Pruning	9.00 c	8.18 bcd	8.30 b
Biennial	10.68 a	7.50 d	10.10 a
5 canes/m	10.43 ab	10.05 a	10.35 a
10 canes/m	10.08 abc	9.18 ab	10.00 a
15 canes/m	9.88 abc	8.68 bcd	9.50 a

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 17: The effect of cultivar on the mean node number per cane in 1984 and 1985. Experiment No. 1

Cultivar	Node Number Per Cane	
	1984	1985
Festival	29.15 B*	31.95 B
Newburgh	29.94 B	33.43 AB
Latham	36.46 A	35.00 A

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 18: The effect of cane management systems on the mean node number per cane in 1984 and 1985. Experiment No. 1

Treatment	Node Number Per Cane	
	1984	1985
Control	28.90 CD*	31.86 B
Alternate Side	26.58 D	32.24 B
Chemical Pruning	29.20 CD	31.22 B
Biennial	34.33 AB	34.23 AB
5 canes/m	36.68 A	36.10 A
10 canes/m	35.27 A	35.22 A
15 canes/m	31.97 BC	33.37 AB

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

4.1.6 Leaf Tissue Analysis

Of the nutrients analyzed, only calcium and magnesium showed significant differences between cultivars (Table 19). Both Festival and Newburgh had higher leaf concentrations of calcium than Latham. Festival had higher magnesium concentrations in its leaves than either Latham or Newburgh.

The leaf tissue concentration of nitrogen, phosphorus, potassium, calcium and magnesium for primocanes in each management treatment are presented in Table 20. Significant effects due to cane management treatments were found in the leaf concentrations of nitrogen, phosphorus and magnesium. Although the cane management treatments affected nitrogen concentration, no cane management treatment was significantly different from the control with respect to the level of nitrogen in the leaves. Leaf phosphorus was significantly lower in alternate side of row cropping compared to the control canes. Magnesium concentration in the chemical pruning treatment was significantly greater than in the control. Neither biennial cropping nor reducing cane density had any effect on nutrient content of primocane leaves.

The leaf tissue concentration of total chlorophyll for primocanes of each cultivar is presented in Table 21. Primocane leaves from Festival had significantly higher concentrations of chlorophyll than primocane leaves from either Latham or Newburgh. Although cultivar differences in the concentrations of leaf chlorophyll were noticed, there were no differences between the cane management treatments tested (Table 22).

Table 19: The effect of cultivar on the nutrient concentration of primocane leaves in 1985. Experiment No. 1

Cultivar	Nutrient Concentration (mg/g leaf tissue)				
	N	P	K	Ca	Mg
Festival	34.51	3.00	18.53	15.90 A*	8.29 A
Newburgh	33.94	2.84	19.61	15.67 A	7.10 B
Latham	31.27	3.05	18.54	11.96 B	6.09 B

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 20: The effect of cane management systems on the nutrient concentration of primocane leaves in 1985. Experiment No. 1

Treatment	Nutrient Concentration (mg/g leaf tissue)				
	N	P	K	Ca	Mg
Control	33.94 AB*	3.06 A	19.78	13.97	7.21 B
Alternate Side	32.21 B	2.82 B	19.05	14.47	6.80 B
Chem. Pruning	35.34 A	3.08 A	18.33	14.48	7.86 A
Biennial	32.98 B	2.94 AB	18.33	14.53	6.78 B
5 canes/m	32.86 B	3.03 A	19.55	14.37	7.03 B
10 canes/m	32.72 B	2.96 AB	17.97	14.69	7.10 B
15 canes/m	32.63 B	2.89 AB	19.25	15.07	7.35 B

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 21: The effect of cultivar on the leaf chlorophyll concentration in 1985. Experiment No. 1

Cultivar	Total Chlorophyll a+b (mg/g wet leaf tissue)
Festival	1.76 A*
Latham	1.51 B
Newburgh	1.57 B

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

Table 22: The effect of cane management systems on the leaf chlorophyll concentration in 1985. Experiment No. 1

Treatment	Total Chlorophyll a+b (mg/g wet leaf tissue)
Control	1.63
Alternate Side	1.58
Chem. Pruning	1.66
Biennial	1.68
5 canes/m	1.63
10 canes/m	1.55
15 canes/m	1.58

4.2 Experiment No. 2: The Effect Of Cane Management Systems On Yield Components Of Festival Raspberries

Table 23 shows the plot yield, yield per cane and the cane yield components under each cane management system in 1986 using the cultivar Festival. All parameters except lateral branch number per cane were affected by cane management system.

Reduction of cane density to 5 canes/m decreased plot yield. There was no difference in plot yield between 10 canes/m, 15 canes/m and control plots. Conversely, yield per cane increased as cane density was reduced; yield per cane at 5 canes/m was higher than at 10 canes/m. Yield per cane at 15 canes/m was not greater than at 10 canes/m or the control plots. Fruit number per lateral and mean fruit weight was increased relative to the control when cane density was reduced to 5 canes/m.

Plot yield was increased by the biennial cropping system compared to the 10 canes/m annual treatment. Moreover, biennial cropping also increased yield per cane, fruit number per lateral and mean fruit weight.

Plot yield was reduced by the alternate side of row cropping system compared to the control, however yield per cane and mean fruit weight were significantly greater. Fruit number per lateral was not affected by alternate side of row cropping.

The chemical pruning treatment showed no effect on yield components when compared to the control.

4.2.1 Cumulative Yield Of Festival Over The Harvest Period

Figure 4 shows cumulative yield for each cane management system in 1986. Differences in the cumulative yields were observed 9 days after the beginning of harvest, although at this

Table 23: The effect of cane management system on yield components of the cultivar Festival in 1986. Experiment No. 2

Treatment	Plot Yield (g)	Yield Per Cane (g)	Lateral No.	Fruit No./Lateral	Mean Berry Weight (g)
Control	8510.3 AB*	188.05 D	18.08	10.70 C	2.71 D
Alternate Side	5690.5 C	284.24 BC	19.58	12.81 ABC	2.96 BC
Chemical Pruning	8888.3 AB	210.03 D	17.30	11.48 BC	2.85 CD
Biennial	9708.8 A	409.22 A	21.58	14.68 A	3.23 A
5 canes/m	5697.3 C	438.25 A	20.85	13.55 AB	3.14 AB
10 canes/m	7328.8 BC	307.85 B	19.28	11.73 BC	2.88 CD
15 canes/m	8262.5 AB	253.18 BCD	18.88	11.61 BC	2.88 CD
Significance	0.01	0.01	n.s.	0.05	0.01

* Mean separation within columns by Duncan's Multiple Range Test at the 5% level.

period no treatment was better than the control. However, on the 13th day of the harvest period, both the alternate side of row cropping system and the 5 canes/m density had significantly lower cumulative yields compared to the control. The cumulative yields of the 5 canes/m density treatment and the alternate side of row cropping system became progressively more divergent from the cumulative yield of the other treatments as the harvest continued. At the 9th day of the harvest, the cumulative yields of the 5 and 10 canes/m densities were significantly less than the 15 canes/m density. However, at the 15th day of harvest the cumulative yield of the 10 canes/m density rose; only the differences between the 15 canes/m density and the 5 canes/m density were significant.

4.2.2 Fruit Weight Over The Harvest Period

Figures 5 represents the weight of a ten berry sample taken at each harvest date for the cane management treatments in 1986. Fruit weight at each harvest was estimated by the average of two subsamples of ten berries. Generally speaking, fruit increased in weight at the beginning of harvest, reaching a peak somewhere in the middle of the harvest period, thereafter declining in weight towards the end of harvest. Maximum fruit weight occurred at a cane density of 5 canes/m, where, after 7 days of harvest each berry weighed almost 4.0 g. Minimum fruit weight occurred in the control at the end of harvest when each berry weighed approximately 2.2 g.

Reduction of cane density tended to increase fruit weight over most of the harvest period, although most differences were

Figure 4: The effect of cane management system on the cumulative fruit yield of Festival at each harvest date in 1986. Experiment No. 2
Vertical bars represent the lsd range at the .05 level for each harvest date where there was a significant treatment effect.

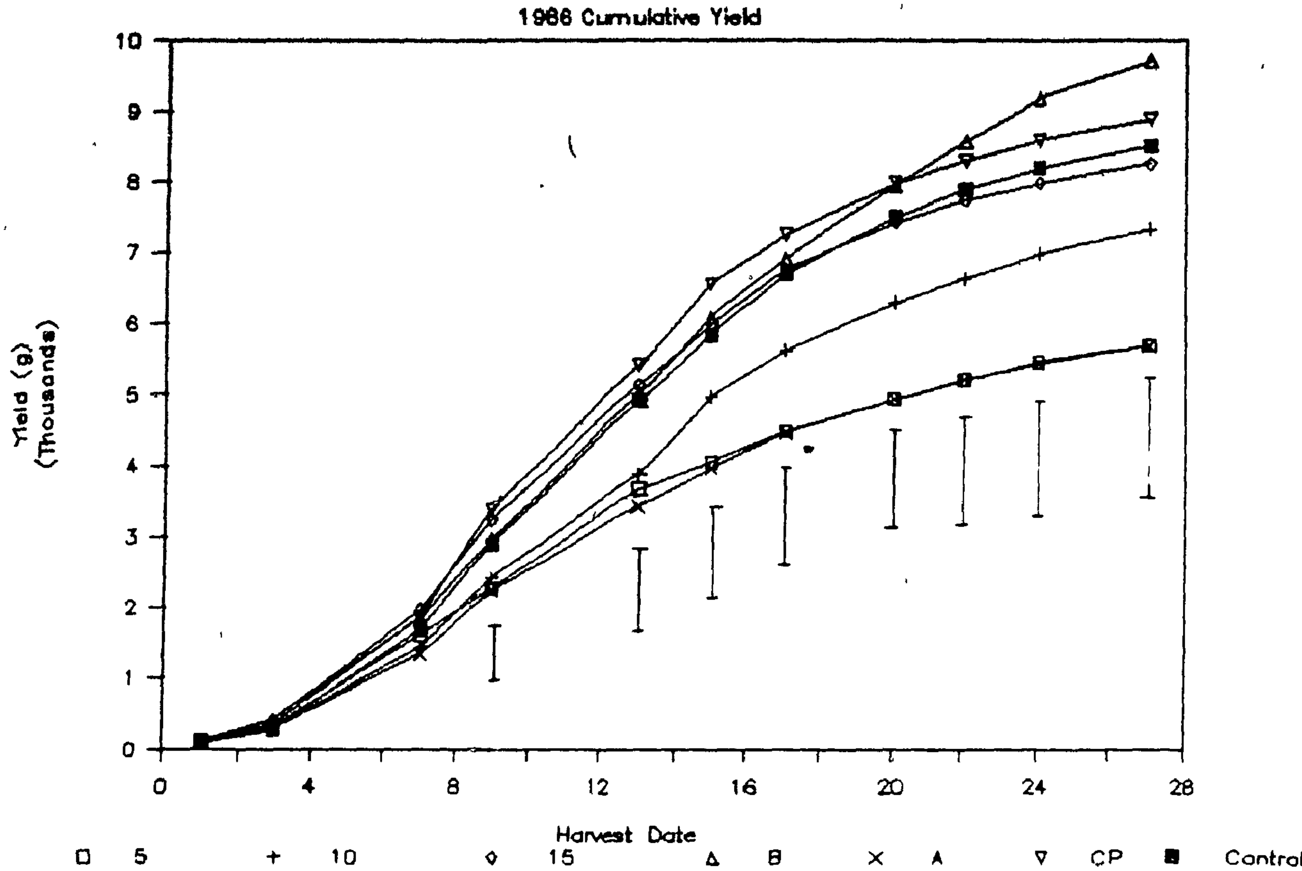
Legend

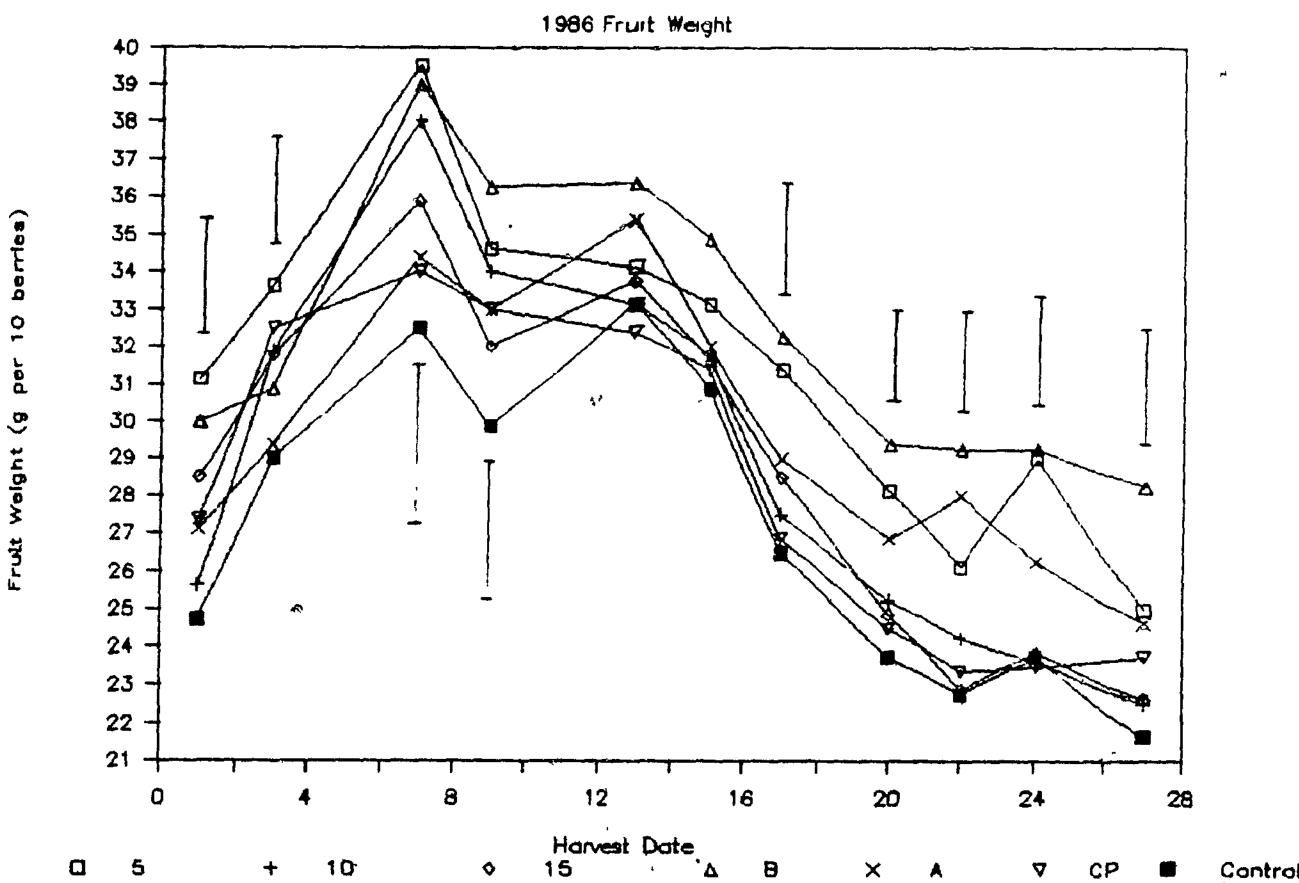
5: 5 canes/m
10: 10 canes/m
15: 15 canes/m
B: Biennial cropping
A: Alternate side of row cropping
CP: Chemical pruning
Control: Control treatment

Figure 5: The effect of cane management system on the fruit weight of Festival at each harvest date in 1986. Experiment No. 2
Vertical bars represent the lsd range at the .05 level for each harvest date where there were significant treatment variations.

Legend

5: 5 canes/m
10: 10 canes/m
15: 15 canes/m
B: Biennial cropping
A: Alternate side of row cropping
CP: Chemical pruning
Control: Control treatment


1986 Cumulative Yield
Yield (g)
(Thousands)
0
1
2
3
4
5
6
7
8
9
10
0
4
8
12
16
20
24
28
Harvest Date
5
10
15
B
A
CP
Control


1986 Fruit Weight
Fruit Weight (g per 10 berries)
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
0
4
8
12
16
20
24
28
Harvest Date
5
10
15
B
A
CP
Control

not significant. However, the 5 canes/m density produced larger fruit than either the 10 or 15 canes/m density at day 20, 22, 24 of the harvest period. Similarily, biennial cropping increased fruit weight late in the harvest period at days 17, 20, 22 and 27.

Alternate side of row cropping increased fruit weight at the end of harvest, and was significantly greater than the fruit weight of the control at day 22. Control of early primocanes using glufosinate produced increased fruit weight early in the harvest period when compared to the control, after which fruit weight declined in essentially the same pattern as the control.

4.2.3 The Effect Of Cane Density On Plot Yield And Yield Per Cane

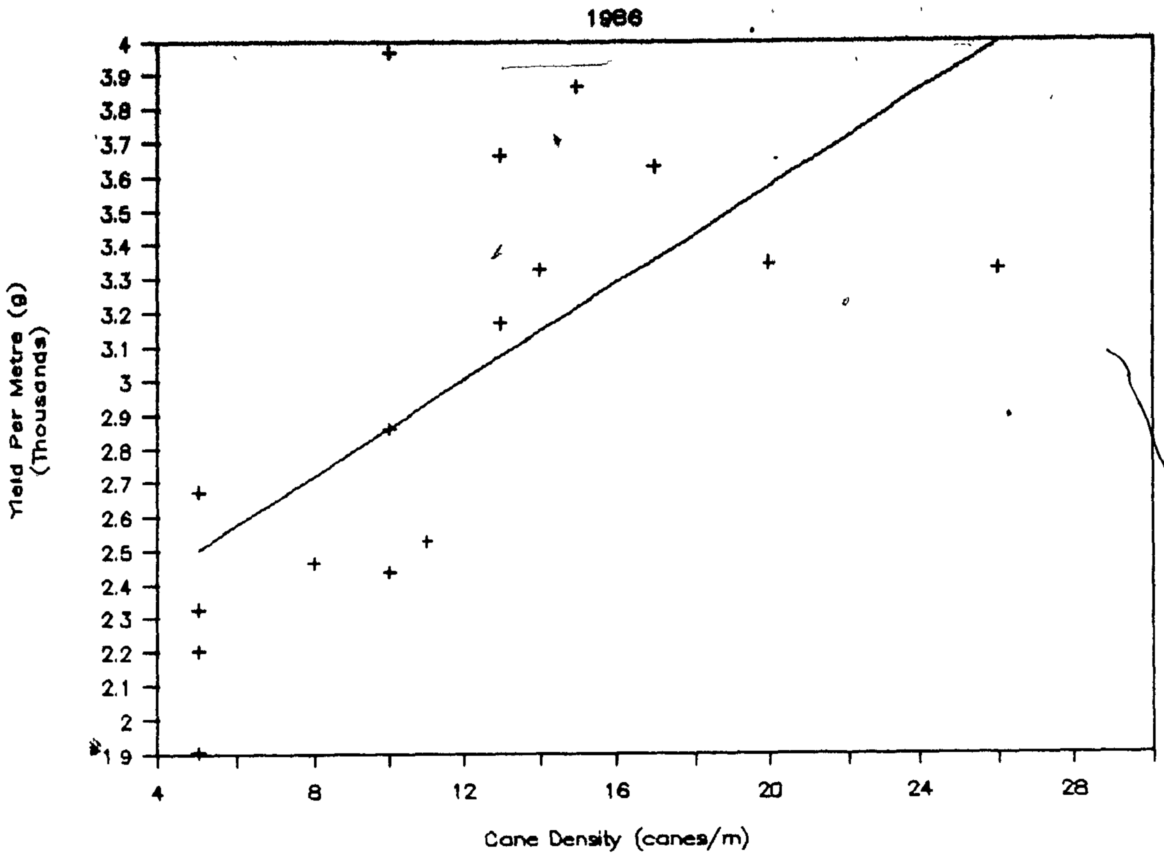
Analysis of the yield data in 1986 produced regression lines which represent the relationship between cane density and plot yield (Figure 6), and the relationship between cane density and yield per cane (Figure 7). A positive linear relationship existed between cane density and plot yield. However, a negative linear relationship was found between cane density and yield per cane. Thus an increase in cane density resulted in a linear increase in plot yield and a linear decrease in yield per cane.

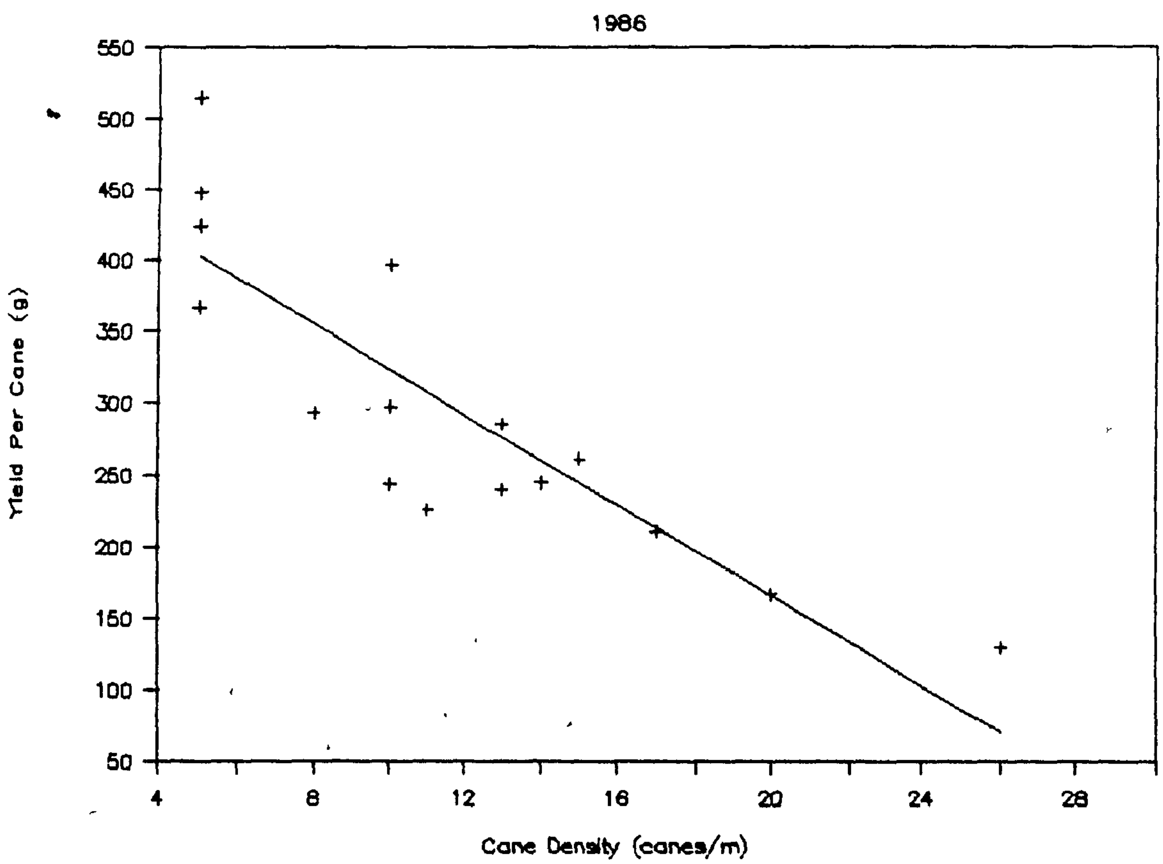
Figure 6: The relationship between cane density and yield per metre of hedgerow of Festival in 1986. Experiment No. 2

Yield Per Metre = 2149.89 + 70.94X R^2 = 0.412

Figure 7: The relationship between cane density and yield per cane of Festival in 1986. Experiment No. 2

Yield Per Cane = 481.79 - 15.81X R^2 = 0.740


1986
Yield Per Metre (g)
(Thousands)
Cane Density (canes/m)
4
3.9
3.8
3.7
3.6
3.5
3.4
3.3
3.2
3.1
3
2.9
2.8
2.7
2.6
2.5
2.4
2.3
2.2
2.1
2
1.9
4
8
12
16
20
24
28


1986
Yield Per Cane (g)
Cane Density (canes/m)
550
500
450
400
350
300
250
200
150
100
50
4
8
12
16
20
24
28

5. DISCUSSION

5.1 Cane Density Reduction

It has frequently been observed that yield per unit area decreased as cane numbers are reduced, even though yield per cane greatly increased as cane numbers declined (Lott, 1931; Wood et al, 1961; Lawson and Waister, 1972; Crandall et al, 1974; Redalen, 1981). However, under conditions of extremely high cane density leading to excessive competition amongst the canes, reduction of floricane number has also increased yield per unit area (Orkney and Martin, 1980). In our study, reducing cane density from the natural cane population present in the control plots produced no improvement in plot yields either in 1984 or 1985. Furthermore, reducing density to 5 canes/m significantly decreased plot yields in both years. The cumulative plot yields of Festival in 1986 indicate that reducing cane density to 10 canes/m delayed fruit production until later in the harvest period, whereas at 5 canes/m, fruit production was significantly reduced. Though reducing the cane density to 15 and 10 canes/m did not affect yield, reducing cane density to 5 canes/m significantly decreased yield.

Yield per unit area is a function of both individual cane yield and the number of canes per plot. Maintaining the cane density at 10 canes/m reduced the natural cane population by 69% and 58% in 1984 and 1985, respectively, even though plot yields decreased by only 4% and 10 % respectively (Appendix 6). At a density of 5 canes/m, plot yields were significantly decreased, but then the cane population was reduced by 84% and 78% in 1984 and 1985 respectively. The reduction in cane density, while greatly reducing the number of productive canes per unit area, was compensated for by an increase in individual cane yield. This is especially true when the natural cane density was high; management systems had more pronounced effect on the proportionate yield in 1984, when the natural cane density was 81 canes per plot or 32 canes/m, than they had in 1985 when there were 59 canes per plot or 24 canes/m (Appendix 6). Yield compensation has been shown to occur within individual raspberry canes when yielding ability of the cane is disturbed by selective removal of lateral buds (Waister and Barritt, 1980; Braun and Garth, 1984).

Perhaps a more useful measure of the effect of cane density on fruit production is yield per cane. As cane density is reduced, yield per cane greatly increased. This inverse relationship between cane density and cane productivity was most pronounced in Festival, the most productive cultivar, and was least pronounced in Latham, the least productive cultivar. This observation is not surprising since the response of cultivars to various cropping methods often depends on their inherent vigour (Norton, 1973; Waister et al, 1977; Lawson and Wiseman, 1979; Dale and Daubeny, 1985).

The regression analysis of the 1986 yield data of Festival indicates a positive linear relationship between cane density and plot yield, and a negative linear relationship between cane density and individual cane yield. A positive relationship between cane numbers and yield per unit area has been recorded by a number of investigators (Lawson and Waister, 1972; Norton, 1976; Stene, 1933). However, Orkney and Martin (1980) found a negative linear correlation between yield and the number of canes per plot in their study, which they attributed to an excessively high cane population. The relationship between cane density and plot yield in our study suggests that under Quebec growing conditions and using these cultivars, the natural cane population was not at a point where excessive inter-cane competition occured and therefore reduction of cane density did not improve yield per unit area. Nevertheless, reducing cane density resulted in a compensatory increase in yield per cane. Extreme cane thinning to 5 canes/m, although increasing yield per cane, did not completely compensate for the lower cane numbers. Although cane density of approximately 10 canes/m did not dramatically improve yield, it is possible that the incidence of cane disease might be reduced, damage due to physical abrasion of lateral branches against one another might be lessened, pruning and harvesting might be easier.

Decreasing cane density increased average berry weight and fruit number per lateral branch. The most notable increase in both the berry weight and the fruit number per lateral occured when density was reduced to less than 10 canes/m. Both Festival and Newburgh were very responsive to reducing cane density and showed increased berry weight and numbers, whereas Latham did not respond as strongly, especially with respect to berry number. Studies of cane density in other growing regions have found that as cane density is reduced, fruit weight (Olafson, 1979) and fruit number per lateral tend to increase (Crandall et al, 1974; Redalen, 1981).

Reducing cane density had virtually no effect on primocane height, however reduction of cane density increased cane diameter, especially when cane density was 5 canes/m. Cane thickness has been found to correlate well to cane productivity in Scotland (Dale and Daubeny, 1985). Thicker canes have also been found to have more reserve carbohydrates, and the development of flower primordia and fruit set depends on these reserves (Crandall et al, 1974). However, thicker canes may have a negative effect on lateral branch number because of increased internode length (Dale, 1986). Our results do not support this, since decreasing the cane density to 10 canes/m or below tended to increase the number of nodes per cane and the number of laterals per cane while primocane height was not affected. Crandall et al (1974) also reported increased lateral branches when the number of canes per hill was reduced from 12 to 6.

5.1.2 Biennial Cropping

Only in 1984 and 1986 did biennial cropping significantly improve plot yield. In 1984, when the experiment was initiated, the "on year" biennial treatment plots, should actually, by definition, be considered as a part-biennial system (after Waister et al, 1977): In this year, the floricanes in the biennial "on year" plots were cropped without the competing influence of primocanes throughout the season, however in the previous season these canes had developed within a mixed canopy of primocanes and floricanes. Waister et al (1977) found that under a part biennial system, yield increases were entirely due to an increase in yield per cane, whereas in a fully biennial system, yield increases were mostly due to an increased number of canes per plot, in addition to an increase in individual cane productivity. In this study, the number of canes per metre of row in the biennial treatment plots were fixed at 10 canes/m, therefore yield increases could only be accounted for by an increase in yield per cane. Hence, a significant increase in plot yield was realized in 1984 and 1986, but not in 1985. To corroborate these observations, individual cane yield was significantly greater in the cultivars Festival And Newburgh in the 1984 season, however in 1985 biennial cropping did not significantly increase individual cane yield in any of the three cultivars tested. In 1986 individual cane yield of Festival was greater under biennial cropping, resulting in a greater plot yield. It should be noted that perhaps the flip-flop of yield measurements over the three year period is an artifact of the experimental design itself: Data from the biennial cropping were collected from the same plot in both 1984 and 1986 whereas data for biennial cropping in 1985 were collected from different plots.

Studies of biennial cropping have maintained that the most important component of increased yield per cane was an increase in the number of cropping nodes per cane (Waister et al, 1977; Wright and Waister, 1982b; Clark, 1984): In the part biennial system, increases in the yield per cane were principly due to both an increase in fruit number per lateral and an increase in fruit size (Lawson and Wiseman, 1975; Waister et al, 1977; Wright and Waister, 1982b). Biennial cropping increased fruit weight in

1984 and 1986, however fruit weight was not significantly increased in 1985. Fruit number per lateral was not affected by biennial cropping in 1985, however biennial cropping increased fruit number per lateral ~~in 1986~~. The 1984 results confirm that fruit weight was increased, however fruit number per lateral was not recorded in the 1984 season. Wright and Waister (1982a) observed that a fully biennial cropping treatment increased fruit number per node but not fruit size. In 1985, fruit number per lateral was not significantly improved by biennial cropping, and only the cultivar Newburgh showed an increase in fruit weight. The absence of an increase in fruit number can explain the reason why no significant yield increase was realized in 1985: In the 1986 season, both an increase in fruit number per lateral and an increase in fruit weight contributed to increases in plot yield.

In 1984, primocane height was not greatly influenced by the part biennial treatment except in the cultivar Latham, but in 1985 primocane height of all cultivars was considerably reduced, consistent with reports that primocane height is reduced by biennial cropping because of smaller internode length (Waister et al, 1977; Wright and Waister, 1982a) Primocane basal diameter was significantly smaller in 1984 and in the cultivar Latham in 1985. Waister et al (1977) and Waister and Cormack (1981) reported that the effects of biennial cropping on cane characteristics was highly dependent on vigour. In our study, the cultivar Latham proved to be the least vigourous cultivar. Despite the effect of biennial cropping on primocane growth, both the node number and the number of lateral branches produced were unaffected by biennial cropping. In areas where cane tipping is practiced, shorter internode lengths of primocanes growing under the biennial cropping system are adventageous since more nodes are retained after the tipping operation (Waister et al, 1977; Wright and Waister, 1982a). However, tipping is not normally done in our region therefore shorter primocanes do not have the potential to improve yield.

Biennial cropping did not affect mineral nutrient levels nor the chlorophyll content of primocane leaf tissues. These findings confirm the view by Waister et al (1980) that the competition experienced between floricanes and primocanes does not appear to be the result of competition for mineral nutrients. However the results of the leaf chlorophyll analysis do not support the theory that competition between floricanes and primocanes is primarily dependent on the light climate (Wright and Waister, 1982a; Waister et al, 1984).

5.1.3 Alternate Side Of Row Cropping

Although other studies of alternate side of row cropping in Quebec found this system to produce as much as the conventional system with the added convenience of separating the primocanes and floricanes (Lareau, 1984; Lareau, 1987), our studies indicate that alternate side of row cropping considerably reduced plot yield in 1984, 1985 and 1986. This could be expected since only one half of the row width contained floricanes. Even though only one half of the hedgerow was productive, the alternate side of row cropping produced 76.4%, 62.7% and 66.9% of the plot yields compared to the control in 1984, 1985 and 1986 respectively. Pritts (1987) found that alternate row mowing of Titan and

Royalty reduced overall yields by 30% compared to the conventional system of pruning. Although yield per cane in 1984 was marginally greater than the yield per cane of the control canes, the difference in yield did not achieve stastistical significance. In 1985, the alternate side of row cropping system increased yield per cane in the cultivar Newburgh. In 1986, yield per cane of Festival was increased by the alternate side of row cropping.

In both 1985 (Newburgh), and 1986 (Festival), fruit weight was increased by using the alternate side of row cropping system, which may have accounted for the increased yield per cane. This observation is contrary to Pritt's (1987) that berry size was reduced under alternate row mowing. This apparent contradiction may be explained by the differences between alternate side cropping and alternate row mowing; with alternate side of row cropping, both primocanes and floricanes are separated within the same row and therefore they are separated spatially but not exclusively from each other within the same hedgerow. In alternate row mowing, every second row is mowed when canes are dormant, resulting in rows of either primocanes or floricanes. Additionally, the mowing of hedgerows stimulates increased sucker production in the following season. Therefore, alternate row mowing produced higher cane numbers and greater plot yields, although berry size and quality were reduced (Pritts, 1987). An examination of fruit weight of Festival over the 1986 harvest period found that berry weight increased mostly towards the end of the harvest. Fruit number per lateral was reduced in 1985 with the cultivar Festival using the alternate side of row cropping system.

Alternate side of row cropping significantly reduced primocane height in all cultivars in 1984 and 1985, however primocane diameter was not affected by the alternate side of row cropping system. It is interesting to note that both the biennial cropping system and the alternate side of row cropping system, where primocanes are separated temporally in the first case and spatially in the second case, produced primocanes of reduced height. Wright and Waister (1982a) explained the reduction in primocane height in a biennial system as due to the elimination of selective shading effects of the canopy on the developing primocanes. Shading of the primocanes by the plant canopy acts as a selective filter which concentrates the light in the far-red region of the spectrum (Palmer, 1977), and which probably acts through the phytochrome system to increase internode length (Smith, 1975; Holmes and McCartney, 1976). Since lateral bud number and lateral branch number were not significantly affected by alternate side of row cropping, it may be assumed that internode length was reduced in primocanes within the alternate side of row cropping treatment.

Leaf tissue analysis showed that the primocane leaf tissue from the alternate side cropping contained lower phosphorus levels than leaf tissue from the control. Primocanes from the alternate side of row cropping system, because they are separated from the cropping canes and are not shaded by them, seemed to mature earlier resulting in shorter canes. Smith (1962) has found that N, P, and K concentrations decrease with age of tissue while

Ca and Mg tend to increase. Despite this difference, the levels of phophorus contained in the tissues of primocanes from the alternate side of row cropping were within the acceptable range of P concentration as reported by the C.V.P.Q. Agdex 230/20 Petits Fruits: Culture (1985).

5.1.4 Chemical Pruning

Control of early primocane emergence using ammonium glufosinate as a dessicating agent did not improve plot yield nor did it improve individual yield per cane. The most probable reason why glufosinate produced little response was that the spray concentration was too low. As a result, the early emerging primocanes were not completely dessicated, and these weakened primocanes continued to develop. According to Lawson (1980), incomplete dessication results in the survival of injured and disease-prone canes and discourages the emergence of a second healthy flush of canes. Gadsby (1984) noted that higher rates of glufosinate could produce faster top kill and lessen the amount of chemical translocated to the root system. Lawson and Wiseman (1983) found that a spray rate of 0.6 kg a.i./ha of glufosinate applied to emerging primocanes was suitable for control, comparable to that of dinoseb-in-oil, however its action was slower. Therefore, it is possible that higher application rates of glufosinate in our study would have provided a greater response to yield and fruiting characteristics. Gadsby (1986) found the most promising rate of application for the dessication of rapeseed, fababeans and lentils to be 0.75 kg a.i./ha.

Although fruit weight was not generally affected by the application of glufosinate, in 1985 fruit weight was reduced in the cultivar Festival. The effect of glufosinate on fruit number per lateral was inconsistent; it reduced the number of fruits per lateral in Festival in 1985 but it increased fruit numbers in Latham. Furthermore, fruit numbers per lateral of Festival in 1986 were not affected and in fact showed a tendency to increase.

Glufosinate significantly reduced primocane height in Festival in 1984 although the basal diameter was not affected. This is understandable since the second flush of primocanes that emerge are shorter because they have a shorter growing season. Chemical primocane suppression using dinoseb has also been reported to reduce primocane height (Crandall et al, 1980; Lawson, 1980; Norton, 1980; Lawson and Wiseman, 1983), though reduction in height occured when two applications of dinoseb were sprayed on less vigorous cultivars. Lawson and Wiseman (1983) noted that spraying one application of either dinoseb or glufosinate on Glen Clova in Scotland reduced final primocane heights but not the number of primocanes. Both the production of lateral buds per cane and the number of lateral branches per cane were unaffected by spraying of glufosinate, therefore although primocane height had a tendency to be reduced especially in Festival, it seems likely the reduced height was related to shorter internode length and not due to a reduced amount of nodes or lateral branches.

Canes treated with glufosinate had a significantly higher concentration of Mg in the leaf tissue. Though the higher levels of Mg were statistically significant, it is doubtful that this higher level of Mg is of physiological significance. Levels of Mg in the tissue were still within the acceptable range for raspberry leaf tissue analysis given by Quebec (C.P.V.Q., Agdex 230/20, Petits Fruits: Culture, 1985). The higher concentrations of Mg could be attributed to the less advanced state of the second flush of primocanes emerging later in the growing season. High mineral levels are frequently found in actively growing tissues and mineral concentration is reduced as tissues enlarge and age (Smith, 1962). Wright and Wiaster (1980) found that levels of Mg dropped in primocane leaves as the season progressed, indicating a decline in the levels of Mg as the primocanes matured.

6. Conclusion

The objective of this study was to test various management systems under Quebec growing conditions for their effect on yield compared to the standard practices. The conclusion that one can draw from this study is that cane management systems when properly implemented, can deliver greater yields or improve the long term yield ability, provided that a sufficient number of fruiting canes are retained for cropping. Our study indicated that a cane density of between 10-15 canes/m of row would be suitable for Quebec growing conditions especially when using a vigorous cultivar. Although this cane density did not greatly increase overall yield per se, it greatly increased the productivity per cane, and would be easier to manage than the higher densities commonly used. Certainly the choice of cultivar also influences the success of the operation; vigorous cultivars such as Festival and Newburgh respond more consistently to cane management and have higher potential yields.

In considering the alternative management systems, it would be difficult, if not misleading, to wholely recommend one cane management system over the others. Biennial cropping can greatly improve yield in the "on year", however yield is actually reduced when examined over a two year period. Additionally, the long term effect of biennial cropping on cane quality needs to be further assessed. The main advantage to biennial cropping is the relative ease of cane management and harvest. Greater berry size may also contribute to its success. However, the shortening of primocanes is not advantageous in Quebec since cane tipping is unnecessary in this region. In fact, most cultivars used in the northeast, such as Festival, naturally produce relatively short canes which rarely exceed 1.5 m. In our study, the biennial cropping system was fixed at 10 canes/m so that a direct comparison could be made to the annual system at a density of 10 canes/m. However one advantage of biennial cropping mentioned in other studies was the increase in primocane numbers, which could not be assessed in our study. The alternate side of row cropping system reduced overall yield since only one half of the row was productive in any one year, however yield decreased by only 24-38% compared to the control. It may be a feasible practice since the cropping canes are separated from the primocanes, therefore facilitating harvest and cane management. Glufosinate as a primocane control agent was not a useful treatment and could not be recommended based on the results of this study. A more thorough study of this chemical, using a range of application rates is necessary to completely assess its usefulness.

In conclusion, reduction in cane number per linear metre, by row narrowing, cane thinning or separating primocanes from floricanes (spatially or temporally) is a useful management practice which would improve fruit size, cane yield and cane health without reducing yields. Indeed it is likely that by manipulating row spacing, yield per hectare may be significantly increased.

7. Suggestions For Further Work

Since cane density reduction was found to be successful in increasing yield per cane and cane quality without reducing overall yield, a practical method of achieving the desired cane density might be by row thinning. A grower would then be able to thin canes to a specific density by simply narrowing the row width. This method of cane thinning in its extreme form would be the linear hedgerow system.

One characteristic of the biennial cropping system that needs to be studied further is its effect on primocane production. In our study, the biennial cropping system was fixed at a density of 10 canes/m and therefore cane production in a biennial system and its effect on yield could not be fully evaluated. Ammonium Glufosinate as a chemical pruning agent needs to be examined at a series of application rates higher than the rate used in this study. Although the results of this study show little effect when canes were treated with glufosinate, there was a tendency for plots treated with glufosinate to increase in yield. Additionally, the translocation properties of this chemical needs to be further assessed.

A final recommendation for further study is a definitive examination of the effects of light, temperature and water levels on the physiological and morphological development of both primocane and floricane.

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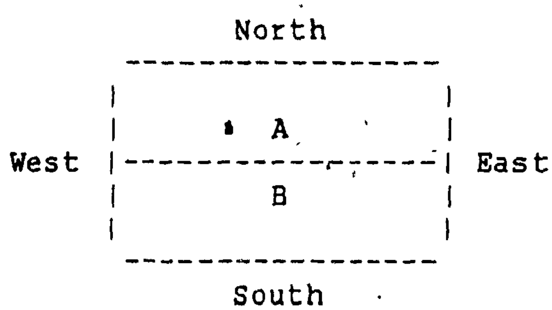
APPENDIX

Appendix 1: Soil Analysis of Raspberry Plantation

Soil type: deep clay loam

Block	water pH	buffer pH	organic matter %	Kg./ha. P	Kg./ha. K	Kg./ha. Mg
A	6.2	6.6	2.9	693	381	479
B	6.0	6.5	2.4	573	323	476



PROCEDURE

1) field was divided into 2 blocks as shown at left.
2) 15 soil sub-samples were taken in each block.
3) soil analysis was performed by Le Ministere De L'Agriculture, Des Pecheries Et De L'Alimentation Du Quebec

Appendix 2: Schematic Layout Of Experimental Field

```
___________BLOCK 2____________          ___________BLOCK 1____________
                                   ^
F===========================       |    F===========================
                                   |
                                   |
F=|T3|T1|T5|T8|T4|T7|T2|T6|=       |    F=|T8|T2|T6|T3|T1|T7|T4|T5|=
                                   |
                                   |
N===========================       |    L===========================
                                   |
                                   |
N=|T2|T5|T7|T6|T1|T4|T3|T8|=       |    L=|T4|T6|T7|T1|T3|T2|T8|T5|=
                                   |
                                   |
N=|T6|T4|T1|T3|T7|T5|T8|T2|=       |    L=|T8|T5|T3|T2|T6|T7|T1|T4|=
                                   |
                                   |33m
L=|T8|T1|T2|T7|T6|T4|T5|T3|=       |    N=|T7|T1|T8|T4|T2|T6|T5|T3|=
                                   |
                                   |
L=|T7|T2|T6|T4|T1|T3|T5|T8|=       |    N=|T5|T2|T3|T7|T6|T1|T4|T8|=
                                   |
                                   |
F===========================       |    F=|T2|T1|T5|T8|T4|T6|T3|T7|=
                                   |
                                   |
F=|T1|T4|T8|T5|T7|T6|T3|T2|=       |    F===========================
                                   |
                                   |
F===========================       |    F===========================
                                   v
<------------------------------------------------------------------->
 North                            53m                          South
```

LEGEND

```
=======  Hedgerow
F   Festival     L   Latham     N   Newburgh
T1   Control
T2   5 canes/m
T3   10 canes/m
T4   15 canes/m
T5   Biennial Cropping; On 1984, 1986
T6   Biennial Cropping; On 1985
T7   Alternate Side Of Row Cropping
T8   Primocane Control Using Glufosinate
```

Appendix 3: Fertilizer, Pesticide and Herbicide Application Schedule, 1984-1986.

Fertilizer

10-10-10 applied at the rate of 550 kg ha^{-1} in early May

Pesticide

Pesticide	Time of Application	* Amount Applied
Elgetol (DNOC)	Green Tip	1.51 l
Ferbam 76-W	} Prebloom, 2 sprays	756 g
Benlate 50-W	} 10 days apart	149 g
Guthion 50-W	}	189 g
Captan 80-W	At bloom; repeated every 8 days until early June	304 g
Ferbam 76-W	Post Harvest	607 g
Kelthane AP 35-W	Post Harvest	304 g

* Amount applied is based on a 0.135 ha field area

Herbicide

Simazine 80-W and Gramoxone (Paraquat) 200-SN applied to alleys in early May at the rate of 2.80 Kg and 2.80 l/ha respectively.

Appendix 4: Analytical methods used to determine the mineral and chlorophyll content of primocane leaves in Experiment No. 1

Analysis Of N, P, K, Ca and Mg

1: Leaf samples were collected and dried in a vacum oven for 48 hrs at 65 degrees C. Dried tissue was ground in a Wiley Micro Mill with a 40 mesh screen and a 1.0 g sample was collected for each treatment plot.

2: 250 mg of the dried ground tissue was placed in 250 ml flask and 4 ml of concentrated Sulphuric Acid was added to digest tissue. The flask was heated at 225 degrees C until all tissue was charred, after which flask was removed from the hot plate and allowed to cool slightly.

3: 4 drops of 30% Hydrogen Peroxide was added to the flask, while the flask was swirled and gently heated for 2-5 minutes. This step was repeated 13 times.

4: Flask was cooled and brought up to volume (250 ml), covered and shaken end to end, 20 times. Solution in the flask was transferred to collection vials and was allowed to stand for 3-4 hrs to permit silica to settle out.

5: The concentrations of N and P were determined colorimetrically using a Technicon Autoanalyzer I. A Perkin Elmer 2380 Atomic Absorption Spectrophotometer was used to determine the concentrations of K, Ca and Mg.

Reference: Thomas et al. 1967. Agronomy Journal, vol 59. pp. 240-243.

Analysis Of Chlorophyll Content

1: Total chlorophyll concentrations were obtained by a colorimetric procedure based on the absorption of light by aqueous acetone extracts (80%) of chlorophyll used by Chong (1972) to determine the chlorophyll content of _Malus_ callus tissue.

2: Primocane leaves from each treatment plot were cut into small pieces and a 5 g sample was thoroughly homogenized for 2 minutes in 100 ml of 80% acetone using a blender. Until the treatment samples were homogenized, they were stored separately in bags under refrigeration to prevent moisture loss and chlorophyll degradation.

Appendix 4 Continued...

3: The homogenate was filtered through #50 filter paper into a suction flask. The blender container and the filter paper were rinsed with 200 ml of 80% acetone and filtered. Filtrates were combined and brought up to the 300 ml volume by addition of acetone.

4: Absorption values of the filtrate were determined at 645 um and 663 um using a Philips Pye Unicam Spectrophotometer.

5: The total chlorophyll, C, contained in the extract was based on the equation C = 20.2 (A645um) + 8.02 (A663um)
where; C = total chlorophyll content in mg/l
A645 um = amount of absorption of chlorophyll a
A663 um = amount of absorption of chlorophyll b

6: The value $\bar{C}$ was then multiplied by the dilution factor, 0.06 l/g to give the final total chlorophyll concentration in mg/g of leaf tissue.

Reference: Chong, C. 1972. Growth and Sorbitol metabolism of *Malus* tissues in vitro. Phd. Dissertation. McGill University.

Appendix 5: Anaysis of variance of yield and cane variables presented in Experiment No. 1 and Experiment No. 2, 1984-1986.

Plot Yield

1984 C.V. = 17.207

Sources Of Variation	df	SS	F value	Prob > F
Block	1	2196403.44	2.09	0.1986
Variety	2	64328035.71	30.57	0.0007**
Block*Variety	2	146572.67	0.07	0.9335
Error a	6	6312903.07		
Treatment	6	37838463.00	21.72	0.0001**
Treatment*Variety	12	5839381.79	1.68	0.1142
Treatment*Block	6	5067926.14	2.91	0.0204*
Treatment*Variety*Block	12	6066585.50	1.74	0.0984
Error b	36	10454250.43		

1985 C.V. = 16.54

Sources Of Variation	df	SS	F value	Prob > F
Block	1	6175549.71	8.20	0.0286*
Variety	2	403841493.24	268.22	0.0001**
Block*Variety	2	1943418.29	1.29	0.3418
Error a	6	4616892.29		
Treatment	6	109627294.48	13.06	0.0001**
Treatment*Variety	12	27629474.60	1.65	0.1223
Treatment*Block	6	15115339.95	1.80	0.1267
Treatment*Variety*Block	12	19726865.55	1.18	0.3366
Error b	36	50365295.71		

* significant at the 0.05 level
** significant at the 0.01 level

Appendix 5 continued....

Yield Per Cane

1984 C.V. = 24.367

Sources Of Variation	df	SS	F value	Prob > F
Block	1	1442.20	1.43	0.2774
Variety	2	58346.07	28.86	0.0008**
Block*Variety	2	291.35	0.14	0.8687
Error a	6	6065.63		
Treatment	6	233501.25	62.62	0.0001**
Treatment*Variety	12	29500.58	3.96	0.0007**
Treatment*Block	6	6151.80	1.65	0.1620
Treatment*Variety*Block	12	6807.57	0.91	0.5441
Error b	36	22373.67		

1985 C.V. = 15.715

Sources Of Variation	df	SS	F value	Prob > F
Block	1	9582.73	3.59	0.1071
Variety	2	473656.28	88.65	0.0001**
Block*Variety	2	4219.95	0.79	0.4960
Error a	6	16029.50		
Treatment	6	870706.03	95.17	0.0001**
Treatment*Variety	12	160562.54	8.78	0.0001**
Treatment*Block	6	15877.23	1.74	0.1409
Treatment*Variety*Block	12	10998.32	0.60	0.8267
Error b	36	54892.62		

* significant at the 0.05 level
** significant at the 0.01 level

Appendix 5 continued...

Mean Berry Weight

1984 C.V. = 6.097

Sources Of Variation	df	SS	F value	Prob > F
Block	1	0.616	4.28	0.0841
Variety	2	6.669	46.29	0.0002**
Block*Variety	2	0.060	0.21	0.8184
Error a	6	0.864		
Treatment	6	1.496	13.95	0.0001**
Treatment*Variety	12	0.416	1.94	0.0621
Treatment*Block	6	0.222	2.07	0.0809
Treatment*Variety*Block	12	0.076	0.35	0.9713
Error b	36	0.643		

1985 C.V. = 6.626

Sources Of Variation	df	SS	F value	Prob > F
Block	1	0.052	0.44	0.5296
Variety	2	10.798	46.41	0.0002**
Block*Variety	2	0.038	0.16	0.8526
Error a	6	0.698		
Treatment	6	1.635	9.53	0.0001**
Treatment*Variety	12	0.710	2.07	0.0458*
Treatment*Block	6	0.168	0.98	0.4538
Treatment*Variety*Block	12	0.150	0.44	0.9364
Error b	36	1.029		

* significant at the 0.05 level
** significant at the 0.01 level

Appendix 5 continued...

Mean Fruit Number Per Lateral Branch

1985 C.V. = 9.788

Sources Of Variation	df	SS	F value	Prob > F
Block	1	8.27	3.74	0.0611
Variety	2	998.54	64.86	0.0001**
Block*Variety	2	7.82	0.51	0.6256
Error a	6	46.18		
Treatment	6	71.37	5.38	0.0005**
Treatment*Variety	12	57.93	2.18	0.0353*
Treatment*Block	6	23.88	1.80	0.1270
Treatment*Variety*Block	12	21.83	0.82	0.6256
Error b	36	79.66		

* significant at the 0.05 level
** significant at the 0.01 level

Appendix 5 continued...

Mean Primocane Height

1984 C.V. = 5.899

Sources Of Variation	df	SS	F value	Prob > F
Block	1	470.49	4.83	0.0704
Variety	2	9312.34	47.77	0.0002**
Block*Variety	2	63.08	0.32	0.7354
Error a	6	584.82		
Treatment	6	6850.80	15.80	0.0001**
Treatment*Variety	12	2816.96	3.25	0.0030**
Treatment*Block	6	479.60	1.11	0.3778
Treatment*Variety*Block	12	1544.45	1.78	0.0897
Error b	36	2601.01		

1985 C.V. = 7.375

Sources Of Variation	df	SS	F value	Prob > F
Block	1	139.55	1.14	0.3351
Variety	2	2189.89	8.92	0.0224*
Block*Variety	2	11.70	0.10	0.7700
Error a	6	613.77		
Treatment	6	6372.57	10.08	0.0001**
Treatment*Variety	12	1992.02	1.58	0.1526
Treatment*Block	6	257.22	0.41	0.8636
Treatment*Variety*Block	12	179.54	0.28	0.9400
Error b	36	3161.86		

* significant at the 0.05 level
** significant at the 0.01 level

Appendix 5 continued...

Mean Primocane Diameter

1984 C.V. = 5.870

Sources Of Variation	df	SS	F value	Prob > F
Block	1	1.19	4.33	0.0826
Variety	2	25.09	45.66	0.0001**
Block*Variety	2	5.27	9.59	0.0135*
Error a	6	1.65		
Treatment	6	101.22	43.88	0.0001**
Treatment*Variety	12	6.68	1.45	0.1903
Treatment*Block	6	3.43	1.49	0.2105
Treatment*Variety*Block	12	5.45	1.18	0.3331
Error b	36	13.84		

1985 C.V. = 7.249

Sources Of Variation	df	SS	F value	Prob > F
Block	1	0.32	1.67	0.2532
Variety	2	23.16	61.28	0.0003**
Block*Variety	2	0.12	0.64	0.4604
Error a	6	0.95		
Treatment	6	23.29	8.70	0.0001**
Treatment*Variety	12	12.27	2.29	0.0324*
Treatment*Block	6	1.09	0.41	0.8695
Treatment*Variety*Block	12	1.30	0.49	0.8138
Error b	36	13.38		

* significant at the 0.05 level
** significant at the 0.01 level

Appendix 5 continued...

Mean Node Number Per Cane

<u>1984</u> C.V. = 11.859

Sources Of Variation	df	SS	F value	Prob > F
Block	1	0.27	0.03	0.8668
Variety	2	901.05	50.35	0.0002**
Block*Variety	2	91.91	5.14	0.0501
Error a	6	53.69		
Treatment	6	1016.14	11.87	0.0001**
Treatment*Variety	12	182.87	1.07	0.4135
Treatment*Block	6	73.41	0.86	0.5348
Treatment*Variety*Block	12	121.89	0.71	0.7297
Error b	36	513.47		

Mean Lateral Branch Number Per Cane

<u>1985</u> C.V. = 14.395

Sources Of Variation	df	SS	F value	Prob > F
Block	1	90.94	2.34	0.1766
Variety	2	723.33	9.33	0.0144*
Block*Variety	2	2.73	0.04	0.9657
Error a	6	232.70		
Treatment	6	386.07	6.30	0.0001**
Treatment*Variety	12	203.30	1.66	0.1184
Treatment*Block	6	96.97	1.58	0.1803
Treatment*Variety*Block	12	153.00	1.25	0.2899
Error b	36	367.46		

* significant at the 0.05 level
** significant at the 0.01 level

Appendix 5 continued...

Mean Plot Yield

1986 C.V. = 13.451

Sources Of Variation	df	SS	F value	Prob > F
Block	3	9582224.19	3.18	0.0775
Treatment	3	19484480.19	6.47	0.0126*
Error	9	9036695.06		

Yield Per Cane

1986 C.V. = 17.442

Sources Of Variation	df	SS	F value	Prob > F
Block	3	9042.91	1.12	0.3896
Treatment	3	135437.33	16.84	0.0005**
Error	9	24123.70		

* significant at the 0.05 level
** significant at the 0.01 level

Appendix 6: Cane population and the percentage of canes retained compared to the control population, and yield per plot and the percentage of yield obtained in comparison to the control plots for cane management systems in 1984 and 1985.

Treatment	1984			
	Cane No.	% of Control	Yield	% of Control
Control	81	100%	3123.5	100%
Alternate Side	38	47%	2384.8	76%
Chemical Pruning	71	87%	3413.8	109%
Biennial	25	31%	4450.2	143%
5 canes/m	13	16%	2272.4	73%
10 canes/m	25	31%	2999.5	96%
15 canes/m	38	47%	3278.2	105%

Treatment	1985			
	Cane No.	% of Control	Yield	% of Control
Control	59	100%	8097.4	100%
Alternate Side	28	55%	5078.4	63%
Chemical Pruning	49	83%	8584.9	106%
Biennial	25	42%	7597.4	94%
5 canes/m	13	22%	5907.5	73%
10 canes/m	25	42%	7301.2	90%
15 canes/m	38	64%	7497.5	93%