STUDIES WITH THE ASPARAGUS 'MOTHER FERN' CULTURE IN A TEMPERATE CLIMATE

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ABSTRACT

In temperate regions, asparagus is normally harvested in spring. An extended harvest season could prolong the supply of fresh asparagus and perhaps lead to an economic gain through high off-season prices. High production costs and low yield of some alternative strategies compared to the normal spring harvest seem to discourage their commercial use. However, field investigations on the mother fern system in a temperate climate have not been done.

From 1995 through to 1996, field and controlled climate growth cabinets studies were conducted to evaluate the asparagus mother fern system in New Zealand. Separate field experiments, for UC 157 and Rutgers Beacon were carried out. Harvesting treatments were, normal spring harvest (September-early December) and two mother fern treatments, run from October-March and December-March. The carry-over effects of the experiment was determined in the spring of 1996, when the crop was harvested for one month (September-October) using the normal spring harvest system only.

In the field study, peak spear production occurred in early December and mid-January, for normal spring harvest and mother fern treatments, respectively. Production of spears declined steadily from January to the end of March. The mother fern treatments resulted in a harvest season, which was 15 weeks longer than the normal harvest. However, the total-, marketable- and cumulative yields, and mean spear weight were significantly lower than for a 'normally' harvested crop. The normal spring harvest produced thicker and heavier spears than mother fern treatments. Spears from the latter were also more seedy than those from norm al harvest. Environmental factors (insufficient moisture level, decreasing temperature) and possibly correlative inhibition may have been the causes of the reduced production of the mother fern system.

UC 157 produced higher yields than Rutgers Beacon. The latter produced a large number of thin spears, which resulted in a high rejection rate. The follow up experiment did not show any marked treatment differences in total yield and number of spears.

The experiment conducted in controlled climate growth cabinets studied the effects of temperature and harvesting systems (normal harvest and mother fern system) on spear and fern growth. Potted, one-year old plants, cvs. UC 157 and Jersey Giant, were grown at constant temperatures ranging from 15°C to 35°C at increments of 5°C. Spears (>8mm basal diameter, with closed tips) were harvested from these plants and used to visually assess postharvest shelf life at 20°C.

The relative spear growth rate, spear production rate per plant increased with rising temperature from 15°C through to 30°C, beyond which they declined. Relative spear growth rate, spear production rate per plant and average basal spear diameter of mother fern plants were lower than for those under the normal harvest. Average spears diameter did not show any trend with respect to growing temperature. Correlative inhibition and respiratory activity of the fern, including the production of new roots and buds may have led to a reduction in reduced performance of the mother fern plants. The relative spear growth rate of Jersey Giant was higher than UC 157.

The postharvest storage life of spears stored at 20°C in unperforated polythene bags averaged seven days. Growing temperature, harvesting system, cultivar did not influence the storage life of spears.

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GENERAL INTRODUCTION

Vegetable asparagus (*Asparagus officinalis* L.) is a dioecious, herbaceous perennial plant belonging to the Lilliaceae family. It is a member of about 300 genera of Asparagus and appears to be the only species grown predominantly for food, whereas *A. plumosus* and *A. meyerii* are cultivated as ornamental house plants. It is a native of many places including South-Central Europe, Western and Central Asia and North Africa where it may still be found growing in sandy places (Douglas 1990; Feher 1992; Falavigna and Nichols 1995).

Asparagus was originally grown and thought to be a temperate crop. However, its production has recently been distributed throughout many climatic zones world-wide (Burrows *et al* 1989; Feher 1992), though it still remains predominantly a temperate crop. The world production area was estimated to have been 120 724 ha and 122 610 ha in 1974 and 1986, respectively (Feher 1992). In 1995 it was estimated that there were 160 000 ha in the world, worth approximately US$1000m at the farm gate (Falavigna and Nichols 1995).

Asparagus is valued for numerous uses: previous reports indicated that it was recognised as a herbal medicine in Europe, especially the rhizome which was used as a diuretic and herbal laxative. The greatest component of trade in asparagus is the spear, a gourmet food (Carpenter 1996). Spears are the vegetative shoots or stems, consumed either fresh or processed (e.g. frozen, canned or in soup powders). Nutritionally asparagus spears are rich in essential elements and have a low calorie content.

Economically, asparagus is a high value export cash crop, and constitutes a good source of foreign exchange earnings in several countries. For instance, in 1994 in the USA asparagus exports to Japan grew from 35% in 1990-93, and along with broccoli contributed to about 90% of $102.6m of fresh vegetable exports realised within the first six months of 1994 (McNeil 1994a, b). In Lesotho asparagus is a foreign exchange earner and an income generating enterprise. It creates self-employment for approximately 3000 small-scale growers, more than 85% being women and provides seasonal employment to locals as factory workers.

A minor occasional benefit is the use of off-cuts and rejected spears as livestock feed, particularly for cattle.

Several researchers, (Brasher 1956; Nichols 1983; Poll *et al* 1990; Feher 1992) have noted that there is an all-year round demand, particularly for fresh green asparagus. A harvesting strategy that would prolong the harvesting period more than the current three months (depending on the age of the crop and region) in the temperate regions would thus appear advantageous. Harvesting longer would also compensate for the loss of product output due to a general decline in the total area under asparagus production caused by:

(1) Older plantings gradually reaching the end of their economically productive period

(2) The replant problem

(3) Unavailability of suitable new land to establish new plantings

Longer harvest would also provide product for processing over a longer period and thus extend the use of the expensive capital investment (cannery).

The success of the mother fern in increasing asparagus yield and marketable spears, prolonging the harvest period, reducing plant loss, stimulating formation of new roots and buds during harvest has been proven in the tropics. Previous experimental evidence in the temperate climate showed that the mother fern could extend the harvest season. Therefore, expectations and questions arise as to whether this system could be used over the full growing season to produce similar results.

In this research work, it was sought to:

i) Determine whether the harvest season could be extended using the mother fern in the temperate conditions.

ii) Determine whether spear quality and yield (weight) would be influenced by use of the mother fern.

iii) Evaluate the shelf-life of spears from mother fern in comparison to those from normal harvest system.

CHAPTER 1

REVIEW OF LITERATURE

1.1 Introduction

Over 95% of asparagus harvesting in temperate regions is concentrated in the spring (Kramer 1988). This involves harvesting the crop for a limited period and then letting it grow into a fern to produce the food reserves before a dormant winter period. The food reserves are required for the next season's spear production.

1.2 The normal spring harvest

Harvesting the crop from early spring to early summer each year is the traditional practice of asparagus produced in the temperate regions. Its has several alternative names including: traditional, conventional or merely a normal spring harvest. Asparagus is produced in spring in both the Southern and Northern Hemispheres, but this occurs at alternate periods, that is, September-December and March-June, respectively. The harvest duration usually ranges from 6 to 8 weeks (Brasher 1956; Reiners and Garrison 1989) or up to 3 months (McCormick 1990), depending on the physiological age of the crop and environmental factors in a given region.

The normal harvest involves cutting all spears that develop during spring upon reaching a length desired by a particular market (Nichols 1983). No spears are permitted to grow into fern during harvesting. An advantage of the normal harvest for green asparagus production is, it allows early identification and cutting of morphologically defective spears before they deplete or exhaust stored food reserves. This is not possible for white asparagus since spears develop underground until they reach harvestable length.

Harvesting of spears is terminated (also referred to as 'close up') in early or mid-December. The decision to stop appears to be based on growers experience rather than physiological principles (Robb 1993). For instance, the close up may be based on, a predetermined date, the closure of the factory or signalled by decreasing quality of spears (getting thin and seedy) (Nichols 1983).

Close up is followed by fern growing time from mid-summer until autumn when fern growth slows down and senesces due to decreasing temperature. In winter the plants enter dormancy for 4-5 months depending on the site, until resumption of growth in spring of the proceeding year.

1.3 Constraints associated with the normal harvest

1.3.1 Introduction

Despite being a reliable system in temperate regions, the normal harvest has several socio-economic constraints accompanied by yield reduction. Socio-economic constraints emanate primarily from a confined harvest period, whereas reduced yield and spear quality particularly during the second half of the harvesting season are probably linked to declining level of storage root carbohydrates.

1.3.2 Socio-economic constraints

Asparagus is one of the few vegetables that is unavailable in the fresh state for an extended period in a year (Brasher 1956). It is a highly perishable vegetable, hence it cannot be stored for a protracted period like controlled atmosphere stored apples. As a result its production is seasonal. Many countries exporting fresh asparagus, profit from high off-season prices in importing countries. For instance, high pre-Christmas prices have been reported in the

Northern Hemisphere (Nichols 1990; Poll *et al* 1990). This price incentive has made fresh asparagus more important than the processed product (Falloon *et al* 1989).

Unfortunately for the Southern Hemisphere, where most of the fresh asparagus would come from, this period coincides with the close up. This is, in part due to the short (three months) spring harvest, going beyond this period may lead to overharvesting, which in turn may result in serious economic losses (Nichols 1983).

Despite different production periods in the two hemispheres, a six-months gap in a year exists, during which fresh asparagus from temperate climate is a rare commodity in the market. This gap may be filled by asparagus produced in the tropical regions, but poor technology, high temperature and presence of diseases limit both productivity and quality of asparagus in the tropics and subtropics (Chen 1985; Nichols 1990).

Winter dormancy limits the growing period, and hence the length of the harvesting season, since at least three months for fern growing period must be allowed prior to winter to ensure that sufficient food reserves are produced. Conversely, there is no dormant period in tropical and sub-tropical regions, and all-year round production close to the equator is possible (Messiaen 1994). Perhaps, as technology advances, our knowledge of asparagus physiology improves and high temperature tolerant asparagus cultivars are bred, then the impact of erratic, season-dependent supply of fresh asparagus will diminish.

Asparagus has a fragile market associated with frequent price fluctuations. For instance, in New Zealand, domestic market prices over 'recent years' have declined by NZ$0.70c. Prices dropped from NZ$2.05 to NZ$1.80/kg, corresponding to 1994-95 and 1995-96 crop seasons (Barton 1996). Market forces, which includes oversupply, foreign competition, fluctuations in foreign exchange rates may account for significant changes in the prices of asparagus, in both national and international markets.

A short harvest duration results in loss of seasonal staff; intermittent cash flow; idling of equipment and facilities, which are likely to elevate fixed costs due to depreciation and obsolescence. For example, in Lesotho, asparagus is harvested and processed only for three out of twelve months, despite the high initial investment costs on infrastructure and agricultural machinery.

1.3.3 Reduced yield and spear quality

Following an increase in spear production stimulated by rising spring temperatures, the yield gradually decreases from early November, because the crop's capacity to produce more spears has reached a limit (McCormick 1990). Carbohydrates are removed during the harvest of spears and subsequently growing spears decrease reserves in the storage roots. Therefore, the decline in the total and marketable yield, including spear quality are thought to be effected by low root storage carbohydrates, smaller bud size or both. Generally, thinner spears are susceptible to premature seediness, and thus may be also promoted by high temperature and genetic factors.

1.4 Alternative harvesting strategies

The limitations of spring harvest has led researchers to investigate alternative harvesting strategies which either alter the time or extend the harvest season (Shelton and Lacy 1980; Sanders 1985; Reiners and Garrison 1994). These include: summer harvest (Takatori *et al* 1970; Robb 1986); autumn harvest (Jasmine and Lalirte 1962); split -summer/autumn harvest (Brasher 1956); alternate short and long harvests (Robb 1983); forcing out of season asparagus (Poll 1990) and asparagus mother fern (Robb 1986; Reiners and Garrison 1994).

However, not all strategies are successful. Limitations exist even for those which appear feasible. For example, either summer or autumn harvests are possible (Nichols 1983), but autumn yields are low, (only 50-70% of the normal) and the need to irrigate increases production costs (McCormick 1990), moreover, if autumn harvest is stopped prior to the season of production, there is a risk of exhaustion of the carbohydrate reserves (Nichols 1983).

In Germany, plastic row covers were used to force asparagus out of season just prior to harvest. This practice advanced the harvest by two weeks and extended the common 7-9 week-harvest period to 11 weeks (Poll *et al* 1990). This benefits asparagus consumers by providing a choice between fresh and processed asparagus, and supplies a fresh product during the period of scarcity.

Forcing has potential in areas with long growing seasons, but it has several disadvantages. These include; stress on crop recovery after harvest season, increased plant death, inferior spear size and quality compared to normal spring harvest, feathering (seediness) of spear tips and unacceptable stand reductions (Dufault 1996). Forcing is also an expensive operation.

The yield from harvest split between seasons, e.g. in spring and autumn depends on the local climate. For instance, in Bajio, Mexico the combined seasons' yield is 65% higher than spring harvest alone. This benefits the processing and fresh export market industries (Anon. 1970). Conversely, Brasher (1956) reported in Delaware (USA) that split harvest deprives the crop of sufficient time to rejuvenate its carbohydrates reserves before winter dormancy.

The alternate short and long harvests is considered feasible to extend the normal spring harvest. The technique involves extending the usual three-month spring harvest period by 25% in one season and allowing crop recovery in the following season by shortening the harvest by an equivalent time factor to compensate for depletion of carbohydrate reserves (Robb 1983, 1984; Nichols 1984). This would permit spear production for the Christmas market in the Southern Hemisphere. However, evidence is lacking whether this technique has a commercial value other than positive results obtained from experimental work. The success of mother fern has been reported in the tropical regions (Wang, 1965; Hung 1980; Tu 1995 ; Yen 1995), but little research has been done in temperate climate.

Reports indicate that mother fern may allow extension of the asparagus harvest in temperate regions (Robb 1986; Reiners and Garrison 1994). The latter's work examined the young (one year old asparagus cv. 'Centennial') crop's performance in a greenhouse environment, whereas the former conducted investigations under field conditions for a limited period of time, when the mother fern's yield equated to that of the normal spring harvest.

The main yielding period for asparagus is between the 3rd and 8th year of production or from the 5th to 10th year after planting (Hartmann 1985), thus, the response of the young plants used by Reiners and Garrison (1994) may vary from that of an older crop. Moreover, the greenhouse climate could be easily controlled compared to field conditions. On the other hand, no research has been done on mother fern in a temperate climate over the entire growing season (Nichols 1983).

1.5 Asparagus mother fern system

The mother stalk, mother stem and parent stem are alternative names referring to mother fern system (MF). In this study the term 'mother fern' is used. The MF technique was developed in Taiwan and adopted for production of both green and white asparagus in the tropical and subtropical regions. It is a method of harvesting asparagus spears which are produced on plants on which there are several shoots that have been allowed to grow into mature fern (Wang 1965; Hung 1980; Nichols 1983; Benson 1995).

1.5.1 The number of MFs to be retained

The number of MFs depends on the age of the plant and asparagus cultivar (Yen 1995). Preliminary investigation by Wang (1970) revealed that 3 per plant, on an unspecified aged asparagus crop, produced more yield than 2 MFs. The relationship between the number of MFs and cultural method (green or white spear production) is unclear. However, in the production of white asparagus, Yen (1995) suggested the following numbers: 2 -3 MFs per plant for young plants (2 years old), whereas 4-6 and 5-8 MFs per plant are retained for 3-4 and 5 years old plants, respectively. Hung (1983) suggested 3-5 MFs per plant for white asparagus, but did not mention the age of the plant. Working on green asparagus in New Zealand, Robb (1986) recommended 1 MF per plant or more with older plants.

On the contrary other workers recommended MFs without emphasis on the type of spears. For instance, only 1 MF was found optimal for 1-year old crowns (60-80g) of the cv. 'Jersey

Centennial' (Rieners and Garrison 1994), or more generally 3 MFs per plant (Messiaen 1994). The number of stalks allowed to grow into fern ranges from 3 to 6 MFs per plant for established beds (Benson 1995).

Messiaen (1994) argued that as the asparagus plants grow they intermingle and makes it extremely difficult to separate individual plants, thus the number of MFs per plant may not be easily determined, and suggested 6-7 MFs per metre row.

1.5.2 Photosynthetic activity and replacement of MFs

The success of the mother fern culture relies on the production of photosynthates by the retained fern. Once matured and established, the fern, mainly via the cladophylls resumes photosynthesis. Experimental work in Taiwan showed that asparagus seedlings absorbed $^{14}CO_2$ and translocated ^{14}CO-photosynthates within 6 hours, hence photosynthetic products from the MF are immediately provided for spear growth (Shen and Hung 1983). It is postulated that some photosynthates are distributed to other parts of the plant and some destined for root storage.

The MFs reach peak photosynthetic activity at three months of age. Thereafter, photosynthesis gradually decreases to its lowest point when the fern is five months old, by then its starts yellowing (Chen and Hung 1983). Therefore, the latter suggested that the ageing fern should be replaced by new MFs when five months old. The tropical climate growing season allows between two and three times mother fern renewal per year (Yen 1995).

1.5.3 Historical background

Benson (1995) noted that Wang C. S. of Taiwan was the first to describe the mother fern culture in white asparagus in 1965. However, evidence (Wang 1965) exists that the method was in use as early as 1955 at the Tainan District Agricultural Improvement Station (TDAIS). Since 1961 it became widely adopted by asparagus growers in Taiwan (Wang 1965).

The period from 1965 to 1970 saw extensive trial work, which involved comparative studies between the normal spring harvest and the mother fern. The experimental results at TDAIS indicated that both the quality and yield of asparagus spears increased in the mother fern blocks compared to the normal harvest (Wang 1965). This led to the conclusion that mother fern method was of great importance to asparagus grown in Taiwan (Wang 1965). It was demonstrated that the newly developed system had potential, because following its adoption, Taiwan became the top asparagus producing and exporting country in the world (Table 1.1) (Hung 1980).

The mother fern is currently (having superseded the normal harvest) used as a reliable harvesting strategy in the tropics and sub-tropics, but it has not yet been thoroughly evaluated in the temperate regions. However, crop physiology, breeding and other cultural practices like plant protection, crop nutrition, irrigation remain major research challenges (Yen 1995).

Table 1.1 The major countries producing canned asparagus between 1972 and 1977, 1000 cases 24/303's (24lbs).

Countries	1971	1972	1973	1974	1975	1976	1977
France	527	433	617	505	257	395	322
West Germany	106	142	101	67	42	44	43
Italy	97	114	280	165	190	92	64
Spain	2195	2205	2756	1977	2540	1929	1562
Canada	468	578	501	540	572	512	442
United States	5542	5860	5794	5643	3551	3609	3705
Japan	987	1122	1290	1351	1280	1295	1567
Taiwan, R.O.C.	6953	5443	5398	8312	5501	6443	6503

Source: After Hung (1980).

1.5.4 Origin and early development

Mother fern system was derived from the bamboo shoot culture (Hung 1980). Bamboo is produced in some Asian countries for its edible shoots arising from the rhizome (analogous to spears of the asparagus plant).

Introduction of asparagus in the tropics involved the use of cultural practices, particularly harvesting, common in the temperate regions. It later became clear that subjecting asparagus plants to the normal or traditional spring harvest in the new environment was not only an inappropriate technology, but economically not a viable option. The yield and quality of asparagus spears were disappointingly low (Wang 1965).

Lack of a rest period and high temperatures have been implicated for the low crop performance. Soil temperature is usually above 20°C which stimulates vigorous fern growth, and well developed buds, which make no contribution to marketable yield (Benson 1995). The continuous growth results in little or no rest period (dormancy) even in winter months (Hung 1980; Nichols 1984). Also under high temperature, plants are unable to store sugars produced during photosynthesis because of very high root respiration rate (Benson 1995). The may also be little or no storage at any time of the year in the tropics and subtropics. Therefore, seeking an alternative production strategy was inevitable.

1.6 Comparison between the normal spring harvest and the mother fern

1.6.1 Introduction

Table 1.2 summarises the comparison between the two systems. Features which further distinguish the two system include;

(1) Existence of fern

(2) Pattern of carbohydrates movement

(3) Concentration of spear production and formation of new roots and buds during harvest.

Table 1.2 Comparison between the normal and mother fern harvesting techniques.

Description	Mother fern culture	Normal harvest
Age of the seedling at transplanting	4 - 5 months	one year
Method of field establishment	Seedlings	Crowns/ seedlings
Cultural method during harvesting	Mother stalks	Non-top method
Adopted regions of the system	Tropics and subtropics	Temperate zone
Crown condition after few years	Rot in centre part	Less rot
Trimming of the fern top	1/3 or 1/2	Not applicable
Growing period in a year	10 - 12 months	Shorter (~8 months)
Time of first harvesting	Within the 1st year	2nd, or 3rd year
Harvesting period	Spring and Autumn	Spring (~3 months)
Average yield per hectare (kg)	7 000 - 8 000	3 000 - 4 000
Fertiliser applied	More required	Less required
Resting period	0 - 1.5 months	4 -5 months
Economically productive period	8 years	10 - 12 years

Source: Adopted and slightly modified from Hung (1980)

1.6.2 Existence of fern

The presence of fern during harvesting is a distinctive feature which differentiates the mother fern culture from the normal spring harvest. The latter system is characterised by bare ground without any plant cover.

1.6.3 The pattern of carbohydrates movement

Figure1.1(a) and (b) shows schematic representation of the depletion and rejuvenation pattern of root storage carbohydrates in both systems. At the beginning of the harvest season the root storage reserves are used as new spears are produced. In the normal spring harvest, the level of carbohydrates declines steadily until harvest stops, and then falls sharply during the initial stages of fern growth, followed by a steady increase during the recovery period as the fern becomes photosynthetically active (Figure 1.1a). In the mother fern (Figure 1.1b), carbohydrates decline slightly during the growth of the mother fern. The recovery period extends throughout harvesting period because of the retained fern, hence carbohydrates level does not decline as much as in normal harvest.

1.6.4 Concentration of spear production

Spear production is more concentrated in the normal spring harvest than the mother fern culture (Robb 1983; Chen and Hung 1983; Nichols 1983). This is because the first buds to break become the mother fern. The presence of mother fern may restrict bud break, hence reduces the rate of spear production. Carbohydrates are depleted to a lesser extend as less spears are removed during harvest in the mother fern as compared to the normal spring harvest (Robb 1983; Tu 1995). The retardation of bud elongation by the mother fern has the advantages of extending the harvesting period. Other advantages include, higher yields and more marketable spears, and reduced plant loss throughout the harvesting season compared to the normal harvest (Chen and Hung 1983; Tu 1995).

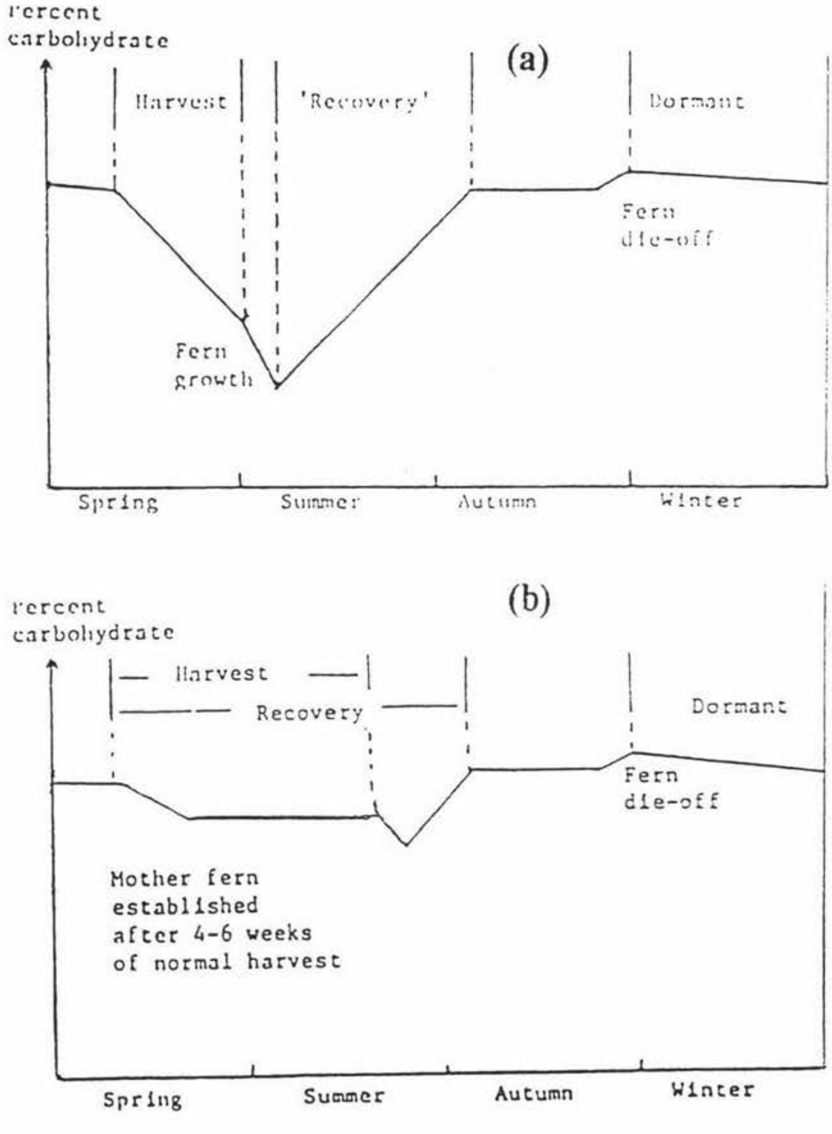


Figure 1.1 Schematic representation of the depletion and rejuvenation pattern of storage carbohydrates in, **(a)** The normal spring harvest, and **(b)** The mother fern culture

Source: After Robb (1983)

1.6.5 Formation of new roots and buds

Earlier evidence suggested that few buds and new roots are formed during harvest in the normal spring harvest (Tiedjens 1924). Tu (1995) argued that unlike the mother fern system a normal spring harvest resulted in a failure to produce new roots and buds during harvest. Although new buds and roots' formation under the normal harvest occurs during the same season. This mainly occurs during the postharvest fern growth period (Robb 1984). Work done by Haynes (1987) confirmed that the formation of these tissues occurred after harvest. The latter found that their formation began when the fern growth was under way and continued until the fern started to senesce.

1.7 Limitations of mother fern culture

Despite being commercially adopted as a cultural practice in the tropics, the mother fern has numerous drawbacks. They include: reduced bed life, ~8 years (Hung 1980; Benson 1995) and increased production costs, primarily due to fern maintenance which, requires trimming, stakes and wire support against lodging and wind damage, fertiliser application during harvest and periodical fern renewal during harvest. Moreover the fern impedes harvesting, increases crop susceptibility to pests and diseases, which may necessitates the use of chemicals during harvest (Hung 1980; Nichols 1983; Robb 1986; Benson 1995; Tu 1995).

In earlier investigations on green asparagus, Wang (1973) reported higher chlorophyll content of spears under normal harvest than the mother fern, probably due to a shading effect. This lighter green spears must also be taken into consideration for green spear production when using this system (Benson 1995).

1.8 Physiology of the asparagus plant

1.8.1 General physiology

The perennial nature of asparagus is reflected in the fact that as spears get removed through harvesting new buds continuously replace them over a number of years. The initiation of new buds relies on the carbohydrates reserves stored during the previous season (Shelton and Lacy 1980), particularly for temperate grown asparagus plants. Conversely, retaining the fern during harvest in the tropical mother fern system allows bud initiation to be supported by carbohydrates reserves produced in the current harvest season (Hung 1980; Tu 1995). In a temperate climate, few buds are formed during the harvest season (Tiedjens 1924), most are formed during the postharvest fern growing period (Robb 1984).

Shoot production precedes initiation of new roots and buds, which begins when the fern growth is under way and continues until senescence of the fern in autumn (Haynes 1987). The period of fern growth incorporates translocation of carbohydrates to stimulate bud and root initiation. The number of buds a plant produces is under genetic regulation, whereas the size to which the buds develop is influenced by the environment or the content of carbohydrates in the fleshy storage roots (Tiedjens 1924).

1.8.2 Bud break and factors which affect it

1.8.2.1 Introduction

Whether in young or established asparagus plants, the growth of spears from buds follow a definite order. The emergence of spears from the older buds takes precedence over adjacent buds on the bud cluster.

1.8.2.2 Apical dominance

In most plant species the apical bud inhibits the development of the lateral (auxiliary) buds by a mechanism known as correlative inhibition, most likely apical dominance (Salisbury and Ross 1992; Robb 1984; Nichols 1983; Nichols and Woolley, 1985; Benson 1995). The presence of undeveloped buds is perceived to be essential for survival of the species, for if the apical bud is damaged or removed a lateral bud will grow and become the leader shoot (Salisbury and Ross 1992).

This appears true for asparagus plants, whereby in seedlings the second shoot cannot grow until the primary shoot has attained its full size (Brasberg 1939). Likewise, in established plants the next buds will not grow until the inhibitory spear on a given bud cluster has lost its apical dominance. The loss of apical dominance could be due to removal of spears through harvesting or the spear growing into a mature fern ('ferning-out') (Nichols 1983). Therefore, it would appear that the ever presence of developing mother fern correlatively inhibit the growth of spears.

1.8.2.3 The relationship between abscic acid (ABA) and growth of lateral buds

ABA is a plant hormone involved in many processes, such as signal transduction in plants undergoing physiological stress, normal embryogenesis, and the formation of storage proteins (Salisbury and Ross 1992). It was first considered to be an abscission-stimulating hormone (Kojima *et al* 1993).

As far as asparagus is concerned two facts have emerged concerning the roles of ABA. First, it is proposed that ABA is casually involved in correlation inhibition of lateral buds, thus inhibiting shoots from growth (Zeevat and Greelman 1988). Secondly, it has been proposed that ABA has a key role in the regulation of assimilate accumulation for the growth of lateral buds, by strengthening sink activity due to enhanced phloem unloading (Kojima *et al* 1993). It was originally thought ABA had a negative role in reproductive development, but recently, Kojima *et al* (1993) demonstrated in tomato fruits that ABA has a promotive effect in sink tissue, hence claims that it functions to accumulate assimilates.

ABA, IAA and Asparagusic acid may be synergistically involved and contribute to the extraordinarily fast growth rate of spears, although other hormones and growth substances may be also involved. Higher ABA and IBA levels have been found in green than in white asparagus spears.

As far as bud break is considered Kojima and colleagues (1993) reasoned that an increase in ABA content prior to sprouting contributes to their release from apical dominance. Besides ABA, other exogenously applied growth regulators have been shown to stimulate bud break. For instance, Mahotiere (1976) used 2-chloroethyel phosphate acid (Ethephon) to dip crowns before planting. This treatment led to an increased number of buds and root production. In recent work, Mahotiere *et al* (1989) reported that dikegulac sodium (Atrinal) solution used as sprays in 9-month-old seedlings increased sprouting. Nagano (1995) found that autumn foliar application of benzyladinine (BA) promoted sprouting and enhanced spear thickness. However, the fall application of this chemical caused a slight decrease in yield the following spring. The role of plant hormones and plant growth regulators require further clarification, especially in relation to spear growth.

1.8.2.4 Other factors affecting bud break

Environmental factors, cultivar, age of the plant, content of root storage carbohydrates (Robb 1984), salt balance, previous season's bud initiation (Dufault 1996) may all influence bud break. Perhaps, temperature and moisture are the most notable environmental factors which greatly influence bud break. For instance, heated beds or glasshouses are used to force out-of-season asparagus by provision of warmth which stimulates bud break during cooler periods or off-season (Poll 1995). A degree day system was proposed by some workers to facilitate predictions of the first spear emergence using 5.8°C or 4.4°C as the base temperature (Culpepper and Moon 1939).

Drought-induced dormancy by withholding irrigation is a well known technique in asparagus produced in the desert or semi-arid places. Irrigation is withheld and the fern browns off to allow a rest period. When harvest is required the fern is cut off and irrigation applied to stimulate spear production. Manipulation of asparagus harvest season using irrigation is popular in Peru. This demonstrates that water is an essential ingredient for bud break. Most environments tend to have adequate soil moisture in spring, which does not limit the growth of spears (Robb 1984). Conversely, lack of moisture appears to limit bud break as reflected by reduced number of spears whenever soil moisture levels become low (Robb 1983).

1.8.3 Spear growth

1.8.3.1 Introduction

Asparagus spears are metabolically active and heterogeneous plant tissues (Lill *et al* 1990). Anatomical examination of spears revealed that the spear tip comprises actively dividing meristematic cells graded into a zone of cellular elongation, whereas the butt consists of more matured cells where elongation has ceased and vascular tissue is lignifying (Lill *et al* 1990).

Spears exhibit an extraordinarily fast growth rate (Kojima and Sakume 1988). It is generally agreed that the growth rate of asparagus spears is strongly dependent on temperature. Their growth is more rapid in warm (Nichols 1983) than in cold growing environments. The optimum range of temperature for dry matter accumulation (or growth) of asparagus is 25-30°C (Robb 1984; Messiaen 1994). Low temperature slows down plant growth rate and temperatures above 30°C are undesirable. At high temperatures plants deplete stored food reserves more rapidly due to an increased respiratory activity (Benson 1995), because the respiratory consumption of stored carbohydrates may be quite substantial (Wareing and Patrick 1974). This implies that plants may partition less reserves into the storage organs at high temperature (Benson 1995), hence the competition between respiration and spear growth.

1.8.3.2 The influence of soil and air temperature on spear growth

Keulder and Reidel (1996) noted that investigations on the effect of temperature on the growth of spears date back more than five decades. Both soil and air temperature are considered important for the growth of spears. Soil temperature increases crown activity, and controls spear emergence rate, though its effect may be limited by crown and bud vigour (Dufault 1996). Spears emerge in spring when the soil temperature at the crown depth is between 8°C and 10°C (McCormick 1990). Since the crown does not grow at a greater depth, soil temperature measurements at 15cm depth could be relied upon to make a general prediction of the time for first spear emergence in spring to facilitate the scheduling of labour for harvesting and marketing of asparagus (Dufault 1996).

Soil temperature is less erratic and fluctuate gradually as compared to air temperature (Dufault 1996). This difference between soil and air temperature may be a disadvantage for spear growth. For example, in early spring emergence of spears stimulated by warm soil are often killed by frost (McCormick 1990). This is likely because, the zone just below the spear tip (exhibiting maximum growth) has a high sensitivity to temperature compared to the basal end of the spear (Culpepper and Moon 1939; Robb 1984). This makes air temperature more critical for post-emergence growth of asparagus spears than soil temperature.

1.8.3.3 Relationship between spear growth rate and temperature

Asparagus spears grow continuously during both the day and night (McCormick 1990; Blumenfield *et al* 1961), however, growth is more rapid during the day than at night, due to the difference in temperature under field conditions (Blumenfield *et al* 1961; Yen 1996). Depending on temperature, the growth of spears may be fast or slow. Poll (1996) reported a mean daily growth rate of 1.1cm/day at 6°C as compared to 11.5cm/day at 20°C. The spear growth rate in response to temperature was also influenced by genotype.

In earlier studies, Culpepper and Moon (1939) reported that the elongation of spears may double for each additional 10°C increase in temperature for a limited range of temperatures.

Unlike fern growth which exhibits a sigmoidal function, the research work of Nichols and Woolley (1985) and Yen (1996) showed that the growth of spears follows an exponential function. They established that the taller the spears, the faster they grew, and they illustrated a linear relationship between log spear length and time over the temperature range from 10 to 30°C , for spears from 1cm to 20cm high.

1.8.4 Root and rhizome (crown) growth

1.8.4.1 Root growth

Fleshy roots originate from the base of the crown. The development of new roots is closely linked to and takes place when a bud develops into a shoot (Tiedjens 1924). The growth of roots, as in shoots, is marked by three phases of cellular development, that is, cell division, cell enlargement and cell differentiation (Salisbury and Ross 1992). There is spatial arrangement of cells involved in each phase. For instance, dividing cells are located in the apical meristem or the root tip, whereas elongating cells are found away from the tip and differentiating cells even further away from the dividing root tip cells. Roots growth vertically and laterally. In a conducive environment root growth rate may be very high. For instance, roots of young asparagus plants may attain up to 1m length during the first growing season (Brasberg 1939). Root length measuring 2.75m has been reported (Feher 1992). In the natural habitat, comprised of sandy soils roots of asparagus may extend up to 4m deep and up to 3m laterally (Dawbin 1968).

Their thickness range from 2 to 6mm depending on age, nutrition and genetic factors (Brasberg 1939). Unlike most monocotyledonous plants the diameter of storage roots increases intensively through cell division in the cortex region (Brasberg 1939), perhaps this plays an important role for enlargement of the root volume which is important for storage. Storage roots are produced prolifically, such that they soon form a thick matt in the soil. This growth habit affects the growth of subsequently formed roots and development of crown. The root matt causes newly formed roots to grow above old ones and crown is mechanically inhibited from horizontal expansion. As a result the crown tends to grow towards the soil surface (Brasberg 1939).

The life-span of storage roots is not known. Their longevity is thought to depend on nutrition and genetic factors. Assessment and monitoring of underground plant parts is complex, thus, it is not surprising that root longevity is unknown. However, one could imagine that by use of modern technology, including hydroponics root life-span may be estimated.

Unhampered growth and development of fleshy storage roots is considered important for crop longevity. Long roots increase root volume and capacity to store more carbohydrates. Therefore, a deep and well drained soil is essential. Soils with a high water table within a depth of one metre may effect premature demise of the roots and buds, and prevent shoot growth (Dawbin 1968; Robb 1983). Therefore, both a hard pan and high water table are undesirable for good root and shoot growth and development.

Attached to each storage root are numerous feeder roots or root hairs. They are short-lived and their number declines from the top soil as the plant ages (Robb 1984). The loss of roots during growth is thought to be the result of several factors including, depletion of nutrients in the topsoil, changes in the structure of the topsoil and root toxins. The death of roots has two implications. First, if the number of roots in the topsoil die without compensation, yield would most likely be affected due to reduced root surface area for water and nutrient absorption. Secondly, instead of recycling nutrients or forming the much-needed organic matter during decay, dead asparagus roots are allelopathic. Laboratory tests revealed that dead root extracts release soluble autotoxins which reduce radicle elongation of asparagus seedlings and inhibit germination of lettuce seed (Schoefield 1991). Poor soil structure may enhance the accumulation of autotoxic substances by increasing root decay and preventing leaching. Despite the importance of underground root system for overwintering and initiation of growth in the spring, Robb (1984) noted that the response of asparagus roots to temperature has not been studied. It would be expected that the response of root differs from that of shoot growth.

1.8.4.2 Rhizome (crown) growth

The rhizome of asparagus is a thick, ligneous, horizontal underground shoot with a slow sympodial development (Feher 1992). Figure 1.2 shows a schematic illustration of the development of an asparagus rhizome. Two types of buds, that is, axial and lateral buds influence the manner in which the crown grows and develops. Commencing from the seedling stage and during the first year, the crown elongates along the longitudinal (main) axis as new buds are formed from the base of the scale leaves. This growth pattern is predominantly due to the influence of the axial buds whereas the lateral buds remain dormant (Brasberg 1939). As figure 1.2 shows the crown may be develop and grow along the main axis in opposite directions.

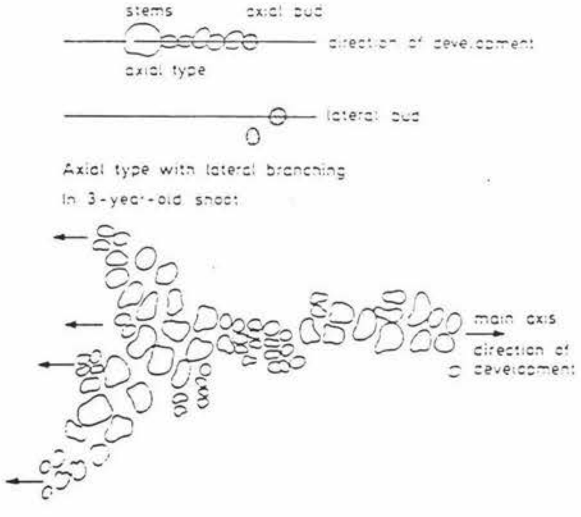


Figure 1.2 Schematic representation of rhizome development.

Source: After Feher (1992).

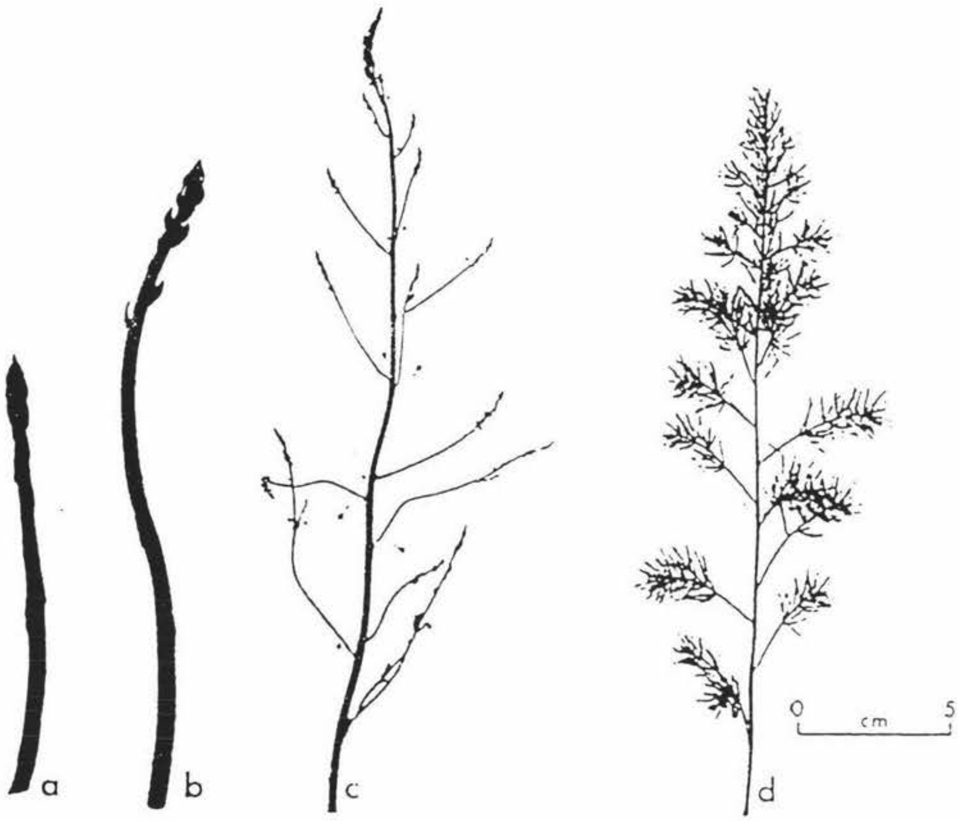
The spatial arrangement and the distance created as axial buds grow farther away from the proximal end of the main axis, and from the lateral buds, result in independent bud clusters. The number of bud clusters, which become separate identities, behave like separate plants and increase as the plant matures (Nichols 1983). It is on account of the existence of several bud clusters that from a single plant many spears may be harvested at the same time, since apical dominance affects individual buds in a given bud cluster not the plant as a whole. The independent development of axial and lateral buds not only enables extensive branching of the crown but results in high productivity.

The dead scar tissue marks the location on the rhizome where the spear or the dead fern has been removed. In old established plantings crown elongation up to 1m long has been reported (Feher 1992). It is a characteristic feature that bud formation along the axis alternate positions from left to right. This results in double rows of spear scars or buds.

1.8.5 Growth of asparagus into fern or mature plant

Asparagus spears are vegetative tissues whose progressive growth culminate in a fern-like foliage, hence the term fern. Anatomically, spears or shoots consist of tightly appressed scale leaves that arise at the nodes, in fact scale leaves are the true leaves of the plant. The shortening of the internodes toward the apex causes the scale leaves to overlap and form the spear tip (Lipton 1990). Between 17 to 20 scale leaves occur in young unelongated buds, and an average of 36 scale leaves per spear have been reported (Brasberg 1939).

Scale leaves enclose buds which are formed at the axils. If the spear harvest is delayed or not done at all, scale leaves open and buds grow into branchlets which elongate as the spear matures (Lipton 1990; Feher 1992). Opening of spear bracts is also knows 'feathering' (Lipton 1990). The term, 'seediness' is used to denote spear quality at an advanced stage of maturity which may be accompanied by internal lignification (Lipton 1990). Terminals of branchlets bear many fine, cylindrical and needle-like structures called cladophylls. Section 1.9.1 discusses the importance of cladophylls for production of photosynthates. Figure1.3 depicts a stage-wise developmental process of an asparagus spears into a fern.



(*a*) Spear in commercial form. (*b*) Spear with head losing compact structure. (*c*) Pre-fern stage resulting from extensive elongation of main stem and side branches in head region. (*d*) Fern with fully developed cladophylls. (*c*) and (*d*) show only the topmost portions of the developing fern.

Figure 1.3 Representative illustration of opening up of the spear into a fern.

Source: After Downtown and Torokfavly (1975)

1.9 Carbohydrates metabolism

1.9.1 Photosynthetic process

Carbohydrates production depends primarily on the photosynthetic process. Investigations by Downtown and Torokfavly (1975) showed that asparagus has a C_3 photosynthetic pathway. They found that stomata frequency of the spears was 96, 32 and 25 per mm^2 for the tip, mid- and basal regions, respectively. The fern had 128, 54 and 44 stomata per mm^2 corresponding to the cladophylls, upper and basal parts of the main stem. Chlorophyll content was found to increase ten fold from the spear to the fern stages and net photosynthesis became measurable once spears had assumed a fern-like shape (Downtown and Torokfavly 1975). Although all the green (chlorophyllous) plant tissues photosynthesises (Sawada *et al* 1962), these findings led to the conclusion that photosynthesis occurs predominantly in the cladophylls.

1.9.2 Photosynthetic products

Not all vascular plant species produce starch and sucrose as the major carbohydrates synthesised by photosynthesis (Pollock 1986; Salisbury and Ross 1992). Asparagus is one such plant, which stores fructans (previously fructosans) as an alternative to 'normal' storage carbohydrates. All members of the Lilliaceae family, cereals, many grasses in temperate and cold regions and some families e.g., Iridiaceae, store fructans.

Fructans are the third most important storage carbohydrates after starch and sucrose (Kuhbauch and Schnyder 1989). The fructans identified in asparagus roots are fructo-oligosaccharides, consisting of 90% fructose and 10% glucose (Haynes 1987). Compared to other polymers they contain very many fructose units. They are water soluble and readily release fructose on hydrolysis in weak acid. Fructans from different sources vary markedly in size and structure. As result, their chemical structures are not known, hence, a need arises for a detailed structural analysis in wide range of species (Pollock 1986). 'Our knowledge about fructans' chemistry and synthesis in different species is limited' (Salisbury and Ross 1992).

Unlike grasses and cereal crops which store fructans in vegetative tissues such as leaves, internodes or reproductive tissues (*Allium cepa*) (Shiomi *et al* 1985), asparagus stores them only in roots (Pressman *et al* 1989).

Generally, fructans are stored in vacuoles, where apparently they perform other functions other than being required as food reserves. For instance, it has been postulated that they increase frost tolerance in a number of species, whereby the existence of soluble sugars in cytoplasm lowers the freezing point, and alters osmotic potential, and hence may change turgor pressure (Pollock 1986).

1.9.3 Carbon partitioning in the mother fern and normal spring harvest during the harvest season

1.9.3.1 The pictorial model

The production and utilisation or distribution of assimilates under the normal and mother fern harvesting strategies are represented in Figure 1.4. The arrows indicate that assimilate utilisation in the normal harvest follow a single route, which results in progressive depletion of stored reserves until the fern growing period occurs. Conversely, there are two arrows in the mother fern to illustrate that assimilates are simultaneously being produced and used during harvesting. However, this only occurs once the mother fern has undergone the transitional period from a net importer to a net exporter of assimilates.

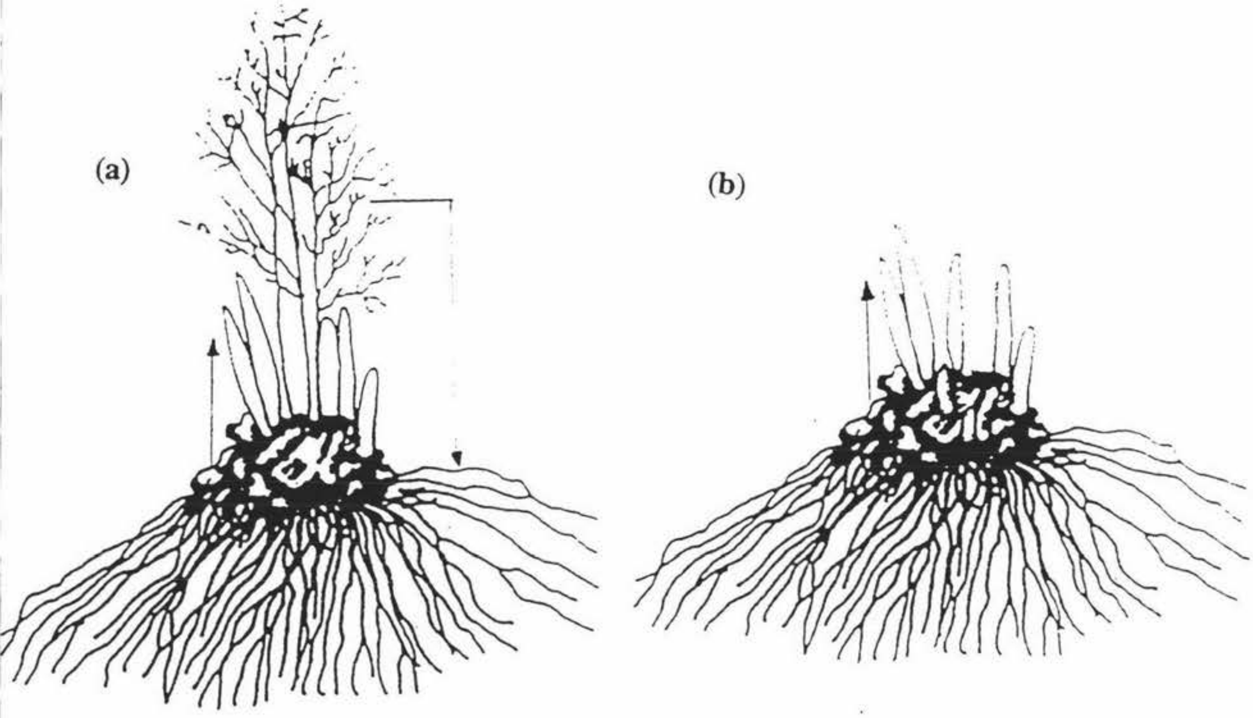


Figure 1.4 Diagrammatic representation of assimilates source and use in (**a**) The mother fern, and (**b**) The normal spring harvest.

1.9.3.2 Source-sink relationship

The source-sink relationship is a concept used to describe the process of assimilate partitioning at the whole plant, cellular and biochemical levels of organisation (Hughes 1993). This is based on the fundamental principle that the production and utilisation of dry matter within the plant depend on each other, although the dry matter partitioning into different organs is independent from production of assimilate (Ho 1988).

The definitions of a source and sink may be based on direction of assimilate transport, morphological plant part, or to designate a gain or loss of carbon. In the first case, assimilate move from the source (a net exporter) to the sink (a net importer); in the second, plant tissues such as leaves are designated as source organs whereas sink organs would include fruits, actively growing mersistems, roots, expanding storage organs, etc. Finally, a loss or gain of carbon has been proposed to correspond to the source and sink (Warren-Wilson 1972). Therefore, growing spears and the mother fern prior to resumption of photosynthesis would be referred to as sink organs and the storage roots as source organs.

1.9.3.3 Characteristics of sink organs

(a) Utilising and storage sinks

Sink organs use assimilate for growth, maintenance and storage. They also differ in their ability to import assimilate. Two kinds of sink organs exist, namely, utilising and storage sinks. Utilising sinks, e.g. meristematic tissue (spears) are characterised by use of assimilate mainly for growth and a small quantity may be stored.

On the other hand, storage sinks import and accumulate substantial amounts of dry matter (Ho 1988). Storage roots, crown and berries (reproductive sinks) in the asparagus plant would represent assimilate storage sinks.

(b) Reversible sink organs

Although the spears of asparagus may be designated as utilising sinks and fleshy storage roots as storage sinks, their role change with season and stage of growth, hence they should be regarded as reversible sink organs. This is so, because storage roots do not continuously store (import) food reserves in their life cycle. During the growing season and prior to winter dormancy the crown and storage roots import assimilates, which they remobilise (export) during spring into growing spears. Spears in turn develop into mature fern which then synthesises reserves exported to the roots. Therefore, there exists a reciprocal flow of assimilate flow between the source and sink organs in asparagus plants.

1.9.3.4 Source and sink strength

When the growing environment for the crop is optimised the asparagus yield depends on the level of carbohydrates in the storage roots or that is produced by the mother fern. According to the source-sink hypothesis either the export or import of assimilate depend upon source and sink strength.

Source strength is referred as the ability of the source organ to produce assimilate, which may be written as follows:

Source strength = *leaf area per plant* x *net assimilation rate per unit area*

Similarly, sink strength has been suggested to denote the ability of the sink organ to import assimilate and is quantitatively expressed as follows:

Sink strength = *Sink size* x *Sink activity*

On the other hand, potential sink strength has been proposed to refer to the total assimilate imported by the sink including the respiratory use of assimilates and assuming supply is not limited and no competition among sink organs occurs, hence;

Potential sink strength	=	*sink*	*x*	*Gross sink activity*
(Weight/time)		*(weight)*		*(weight/weight/time)*

1.9.3.5 The regulation of assimilate partitioning

The transport and distribution of assimilates between the source and sink occurs within the phloem tissue. Assimilate translocation is thought to occur by Munch's Pressure Flow hypothesis (also called mass flow) model. The model proposes that assimilates are translocated en masse along a turgor pressure gradient which is regulated by phloem loading and unloading.

CHAPTER 2

A FIELD COMPARISON OF ASPARAGUS MOTHER FERN CULTURE VERSUS THE NORMAL SPRING HARVEST

2.1 Introduction

During the off season, fresh asparagus is an uncommon commodity in the temperate regions. Its supply may be limited during summer and non-existent in winter months until early spring. This scarcity and consumers' demand during the off-season are the likely driving forces which attract a premium price for fresh product that may be supplied to the market. The pre-Christmas period has been identified to offer better prices than during the on-season (Nichols 1983; Poll *et al* 1990). Therefore, harvesting longer would convinciably prolong the harvesting season, lead to an efficient utilisation of production resources (labour, land and machinery) and perhaps increase growers returns on invested capital.

It is generally accepted that prolonged harvesting in consecutive years using the conventional spring harvest results in reduced crop stand, productivity and serious economic losses. This suggests the use of alternative harvesting strategies. However, certain strategies, such as forcing out-of-season asparagus, is costly and produces low quality spears (Poll 1996). The shifting of harvest from spring to either summer or autumn produces low yields and increases costs due to the requirement for irrigation as compared to the normal spring harvest (Robb 1983; McCormick 1990).

In the tropics the mother fern system has replaced the normal harvest because of better performance including; high yield, stimulation of root and bud growth, and sustenance of food reserves during harvest (Wang 1965; Hung 1980; Tu 1995). This investigation was carried out to determine whether the mother fern could extend the harvesting season in a temperate climate without a reduction in quality and yield of spears.

2.2 Materials and Methods

2.2.1 Site

This study was conducted at Massey University, Plant Growth Unit (PGU) commencing in spring of 1995/96 and continued for one month in spring of the following cropping season (1996/1997). It was conducted under field conditions without irrigation.

2.2.2 Plant Material

The experiment involved use of an established block containing an eight-year-old asparagus planting with two cultivars, which were:

a) Rutgers Beacon, a polycross hybrid developed by Ellison at Rutgers State University, New Jersey, USA.

b) UC 157, a single-cross hybrid developed at the University of California, USA.

The cultivars were planted in separate plots alongside each other, with six rows per cultivar. They were not harvested during 1994/95 (the season preceding the study period), and hence had an uninterrupted fern growth period from spring through to autumn. The plants were grown on raised beds. The inter- and intra-row spacing was 1.5m and 0.30m, respectively, which gave a plant population density of approximately 22,000 plants per hectare.

2.2.3 Experimental design and Layout

A random complete block (RCB) experimental design with three treatments was used. The treatments (Plate 1) and related abbreviations were as follows:

i) The normal spring harvest (**NH**).

ii) The mother fern harvest system was harvest from spring till autumn (**MF**), and *iii)* The mother fern system, harvested from December to autumn, following fern growth from spring (**MD**).

Asparagus plants in the mother fern treatments, were thinned to a final stand of ten (10) stalks per metre of row. This number of the mother ferns was selected because of the age of the plants. The number was based on a per metre row basis not per plant because individual plants were not easily identified.

For each cultivar, the treatments were replicated six times, which gave eighteen experimental units (3 treatments x 6 replications). The plot dimensions were 12m x 1.5m with guard plants at the headland.

2.2.4 Crop Management

2.2.4.1 Fern removal

The senesced fern from the previous season was mowed and left as surface mulch on the asparagus beds in July.

2.2.4.2 Chemical sprays.

i) Herbicides application

Weed control was achieved by pre-harvest and spot (during harvest) sprays of the following herbicides:

1. Atrazine (510 g/l a.i./ha) for control of some annual and most broad-leaf weeds (15/9.95).
2. Glufosinate (200g/l a.i./ha) for control of most grass and broad-leaf weeds (15/9/95).
3. Glyphosate (360g/l a.i./ha) for control of annual and broadleaf weeds (27.7.95).

4. Paraquat (125g/l a.i./ha) and Diquat (75g/l a.i.) a non-selective herbicides for control of broad-leaved and grass weeds (15/5.95).

ii) Fungicides

Metalayxl (Ridomil 10 G, 100g a.i./ha.) was applied before the start of harvest as protectant against *Phytophthora* spear rot.

2.2.5. Mother fern management

2.2.5.1 Staking and wire support

Asparagus plants have weak stems, which during windy conditions predisposes the plants to lodging and damage. The damaged fern has reduced photosynthesis and increases the chance of secondary infection.

Therefore, wooden posts were placed in the ground at the middle and at either end of each row supporting a double line of plain wire which provided support to the fern. Cross wire tiers were used at regular intervals to secure the fern in place.

2.2.5.2 Trimming of the mother fern

The tall mother ferns were liable to wind damage and were cut back to maintain a fern height of 1.2m above the ground.

2.2.5.3 Fertiliser application

BASF, Nitrophoska fertiliser composed of Nitrogen (12%), Phosphorus (10%), Potassium (10%) and Sulphur (2%) was applied at the rate of 5kg/13metre row during harvest (January) of the mother fern and at close up (December) for the normal spring harvest.

2.2.6 Data collection

2.2.6.1 Harvesting

Harvesting was carried out in the morning on a daily basis. It commenced on 22 September, 1995 and continued until 31 March, 1996. The harvesting duration for individual treatments followed as:

i) Normal harvest (NH) was harvested for 80 days (22 September- 10 December),

ii) Spring mother fern (MF) was harvested for 165 days (18 October-31 March), and

iii) December mother fern (MD) was harvested for 111 days (11 December -31 March)

2.2.6.2 The rationale for once a day harvesting

Daily harvest as used in this study comformed to the commercial practice in New Zealand. It aimed at the production of high quality spears for fresh export. Previous experimental evidence showed that daily cutting increases spear quality and raises the yield of export grade spears.

The first season spears from UC 157 began to emerge as the soil temperature increased during the second to last week of September. Thus, harvesting of normal spring harvest treatment commenced on 22 September. Allowing the development of the mother fern delayed harvesting until 18 October for the spring mother fern, and the harvest of the summer mother fern begun on 11 December following a period of fern growth.

2.2.6.3 Method of harvesting

A knife designed for asparagus harvesting was used to cut all the spears that had reached the harvestable length (more than 220mm). Spears were cut just below the soil surface. Harvested spears were bunched and transferred from the field immediately after harvest for recording.

2.2.7 Measurements

The measurements performed mimicked the commercial practice and standards for an asparagus product destined for overseas markets as a fresh product.

2.2.7.1 Spear count and weight data

The total weight of spears was given as the direct measurement prior to grading and trimming to 220mm. Three times weekly, a detailed harvest was performed. This involved recording both spear numbers and total weight and grading of the spears based on the basal diameter as outlined by McCormick and Littler (1990). Table 2.1 shows the four categories into which the spears were classed based on their basal diameter.

Table 2.1. The categories of asparagus spears based on the basal diameter.

Category	Basal diameter size (mm)
I	>20
II	14 - 20
III	8 - 14
IV	>8

Butts and rejected spear weights were also recorded. Spears were rejected on the basis of misshapenness (croocked), seediness, (open-tipped), and the presence of physical damage or disease.

2.2.7.2 Marketable yield

The marketable yield was determined as the yield of spears with a basal diameter ranging from 8mm to 20mm. This determination followed the protocols of reduced treatment sampling outlined by McCormick and Littler (1990).

2.2.8 Data analysis

The yield data (spear weights) were automatically recorded into a spreadsheet program, (Lotus 123 version 2.1) using a top balance connected to the computer with the results saved daily for further analysis. The data from the two experiments were analysed separately. An analysis of variance (ANOVA) was used to determine the treatments effects on the performance of the two asparagus cultivars. The PROC GLM of SAS software release 6.10 was used.

2.3 Results

2.3.1 Spear production trends

Spear production, expressed as both the number ('000/ha) and yield (t/ha) showed an increasing trend in all the harvesting treatments from the beginning of the harvest season despite weekly fluctuations (Figure 2.1a-d). However, a decline was encountered in all the treatments later in the season. The decrease was gradual in the mother fern treatments until the end of harvesting season (27th week or end of March). A sharp drop occurred in the normal spring harvest (NH) shortly after the 11th week from the beginning of harvest. While spear production was increasing during this period in the other treatments, the abrupt drop in the normal harvest was due to close up, hence the low spear count and yield for the few (10) days of harvest in December.

Peak spear production period occurred on the 6th and 13th week (16th week on the graphs) from the beginning of harvest for the December mother fern (MD) and Spring mother fern (MF), respectively. On the contrary, the normal harvest could be assumed to have peaked at close up (2nd week of December) because of high spear production on the 11th week. This yield was significantly higher than the highest weekly yield of the other treatments. The December mother fern, showed a steady upward trend in spear production from the start of its harvest until peak production. Comparison between the cultivars (UC 157 and Rutgers Beacon) showed very similar spear production trend.

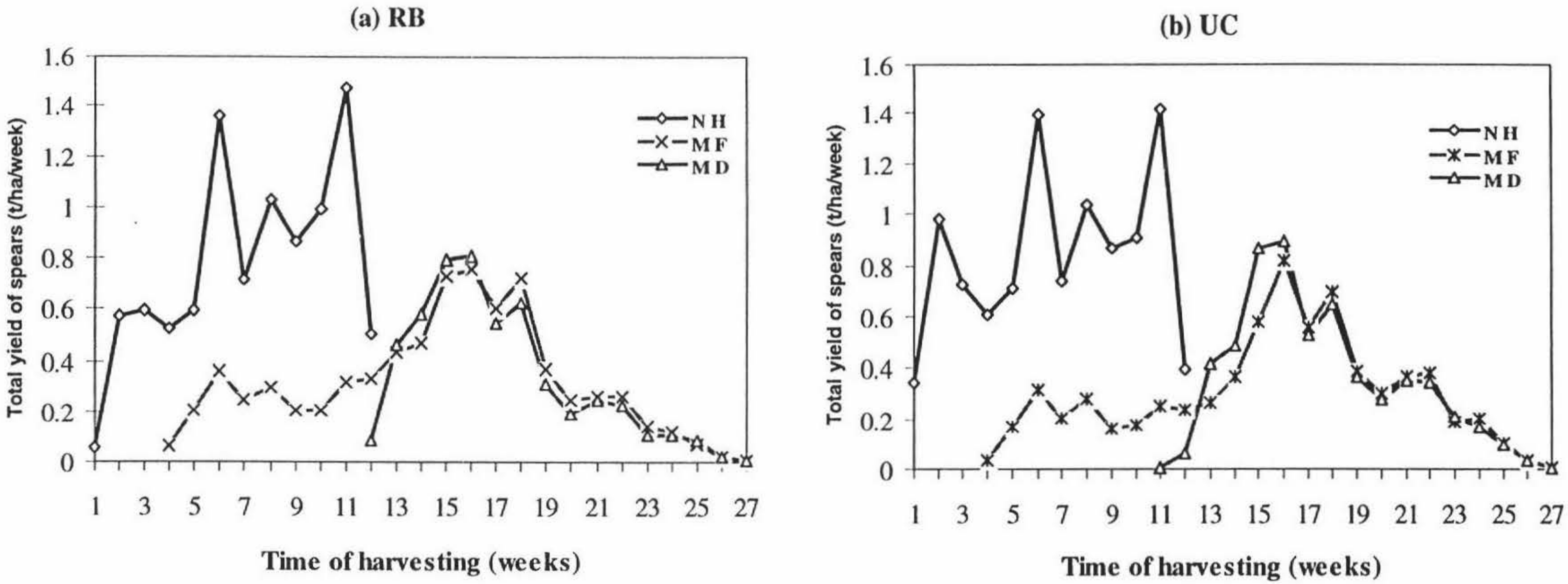


Figure 2.1a The overall spear yield production pattern (t/ha/week) of two asparagus cultivars **(a)** Rutgers Beacon (RB), and **(b)** UC 157 (UC) under three harvesting strategies (treatments); normal spring harvest (NH), Spring Mother fern (MF), and December mother fern (MD).

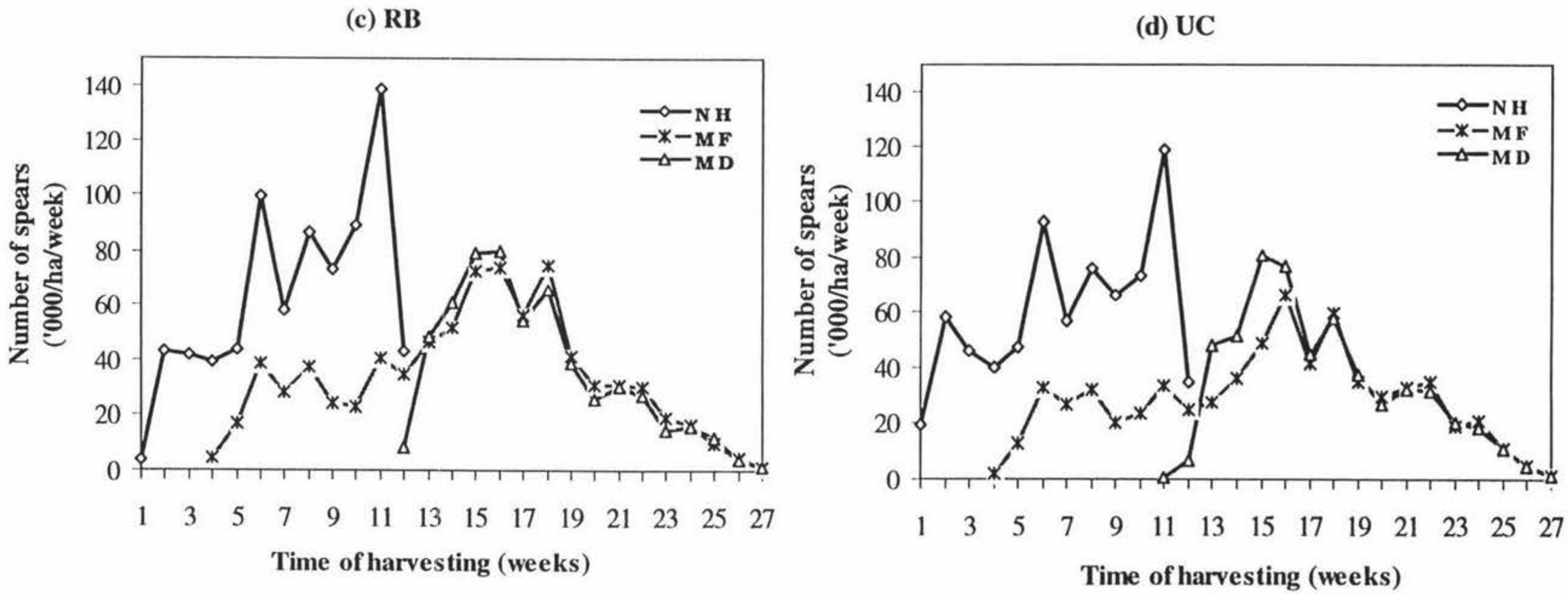


Figure 2.1b The overall production pattern ('000/ha/week) of asparagus two asparagus cultivars, **(c)** Rutgers Beacon (RB), and **(d)** UC 157 (UC), under three methods of harvesting (treatments), normal spring harvest (NH), Spring mother fern (MF), and December mother fern (MD).

2.3.2 Spear yield

2.3.2.1 Total spear yield

The total yield of spears (t/ha) over the entire harvesting season was higher for the normal spring harvest than the mother fern treatments (Figure 2.2). The total yield from the normal harvest was 1.25t/ha (25%); 1.77t/ha (77%) and 1.42t/ha (42%); 1.73t/ha (73%) times higher than the Spring and December mother fern, for Rutgers Beacon and UC 157, respectively. The lowest total yield was obtained from mother fern treatment harvested from 11th December up to the end of March.

With the exception of the MF treatment, UC 157 out-yielding Rutgers Beacon. Though, there was no significant difference in spear numbers between NH and MF, except for MD, Rutgers Beacon produced a higher number of spears than UC 157 (Table 2.2).

Table 2.2 The spear count ('000/ha) under different harvesting strategies.

Treatment	Rutgers Beacon	UC 157
NH	761	728
MF	808	675
MD	568	549
SEM(5 df)	*43.79*	*36.25*

The duration of harvesting varied among the treatments (Table 2.3). This could not have explained the differences in the total yield among the treatments. The data showed that irrespective of a limited harvesting period relative to other treatments, the NH exhibited a superior performance.

Table 2.3 The length of asparagus cutting season based on three methods of harvesting.

System of harvesting	Duration of harvesting (weeks)
Normal spring harvest (NH)	11.1
December mother fern (MD)	15.9
Spring mother fern (MF)	23.6

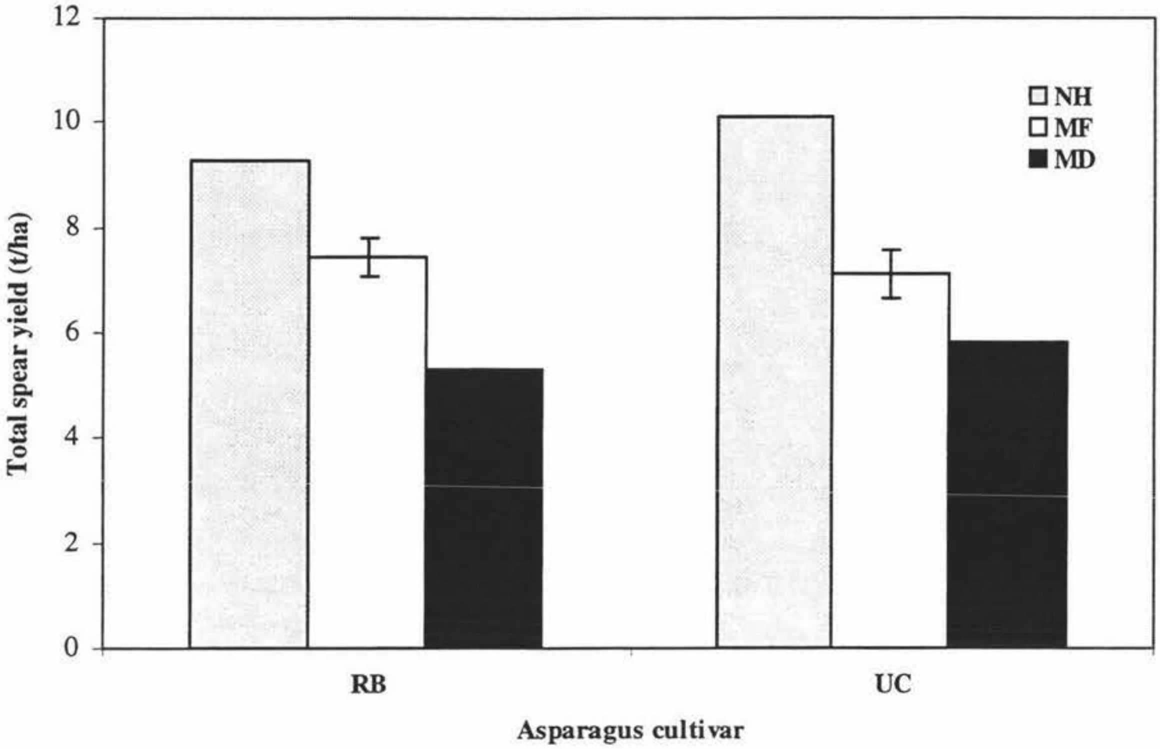


Figure 2.2 Total yield of two asparagus cultivars; Rutgers Beacon (RB) and UC 157 (UC) under three strategies of harvesting; normal spring harvest (NH); Spring mother fern (MF) and December mother fern (MD).

2.3.2.2 Cumulative yield (t/ha) and number of spears

The cumulative yield (t/ha) and number of spears for the harvesting strategies is shown in Figure 2.3a-d. The analysis was based on the first eleven weeks of harvest, which corresponded to the duration of the normal harvest. It was intended to determine whether treatment differences existed between the latter and the mother fern treatments.

The results indicated that although at the end of the season the MD produced the lowest yield of all the treatments (Figure 2.2), its cumulative yield up to 11 weeks from the first day of harvest was higher than the spring mother fern and appeared to have had a declining trend, while the latters's yield maintained an upward trend. By the end of 11 weeks the yield difference were large between normal harvest and mother fern treatments, whereas it was smaller between the two mother fern treatments.

2.3.3 Marketable yield

Marketable yield was determined as the spears trimmed to 220mm length, tight tips, free from diseases, physical damage, misshapenness and with a basal diameter not less than 8mm, as detailed in Table 2.1.

Significantly higher marketable yield was produced by harvesting the crop using the normal spring harvest rather than Spring or December mother fern techniques (Figure 2.4). Although the lowest marketable yield for the two cultivars was obtained in the December mother fern, this treatment did not significantly differ from the Spring mother fern.

The highest proportion of marketable yield was obtained in all treatments when the total yield was at maximum. The peak marketable yield in all the mother fern treatments occurred in January irrespective of cultivar. Conversely, the peak marketable spear production of the NH influenced by cultvar. An earlier peak yield (October) was recorded for UC 157 proceeded a month later by Rutgers Beacon. Thereafter, the former's yield declined gradually compared to an accelerated drop of the latter (data not shown).

There was a marked difference in the proportion of marketable spears between the cultivars (Figure 2.4). UC 157 produced more marketable spears than Rutgers Beacon. Comparison between the cultivars' marketable yield in response to the harvesting treatments showed a clear-cut domination of UC 157 over Rutgers Beacon by 29%, 36% and 79% corresponding to NH, MF and MD, respectively.

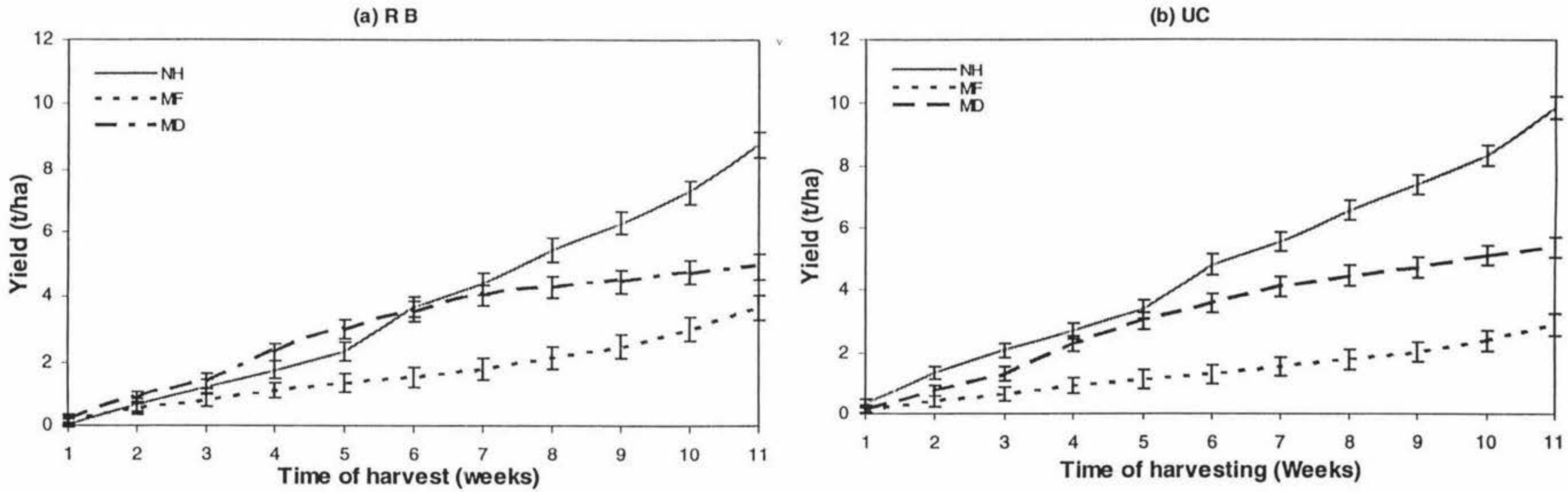


Figure 2.3a The cumulative yield (t/ha) of **(a)** Rutgers Beacon, and **(b)** UC 157 under the normal harvest (NH), the spring mother fern (MF) and the December mother fern (MD).

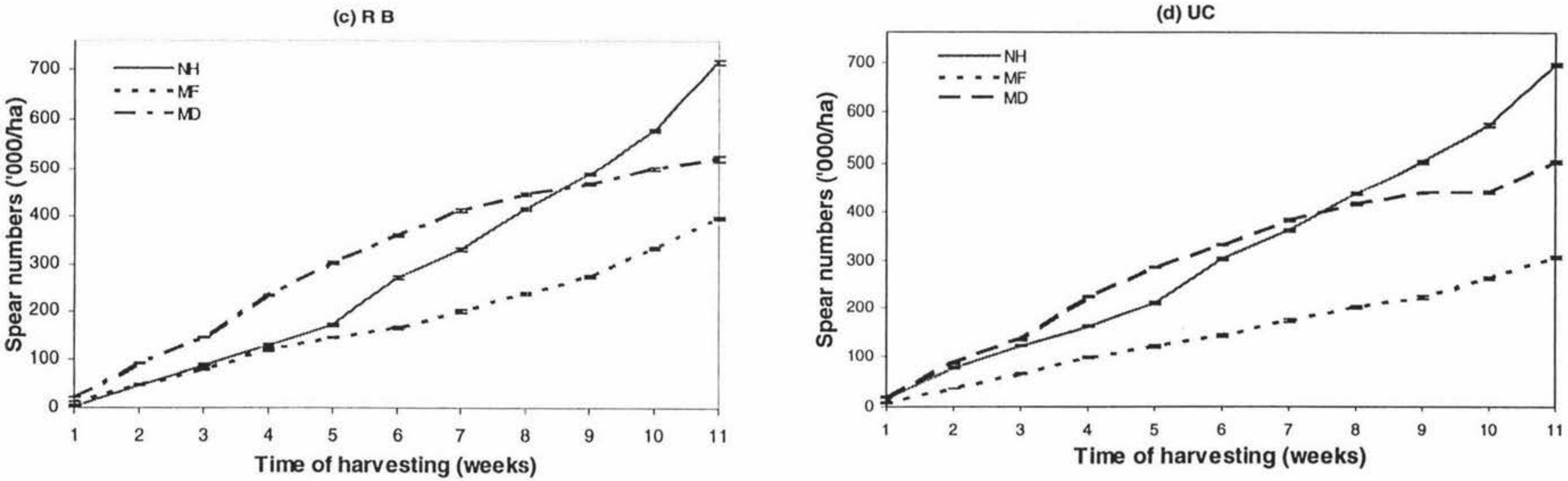


Figure 2.3b The cumulative yield (number of spears per hectare) of two asparagus cultivars, **(c)** Rutgers Beacon and **(d)** UC 157 under the normal harvest (NH), the spring mother fern (MF) and December mother fern (MD).

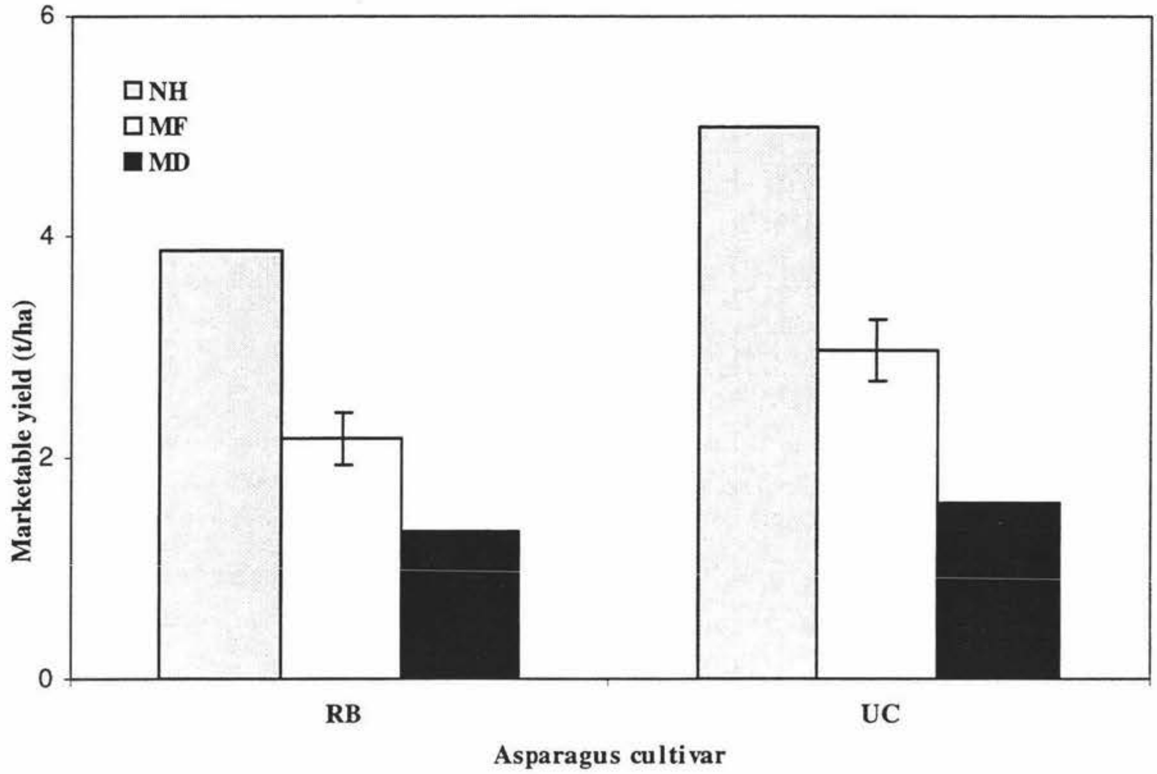


Figure 2.4 Marketable yield (t/ha) response of asparagus cultivars; UC 157 (UC) and Rutgers Beacon (RB) under the normal spring harvest (NH), Spring mother fern (MF) and December mother fern (MD) harvesting treatments.

2.3.4 Mean spear weights (MSW)

The two cultivars differed in the mean spear weight (MSW) (figure 2.5). In all the treatments UC 157 produced heavier spears than Rutgers Beacon, thus the total yield difference observed between the cultivars may be explained by the MSW of individual cultivars, rather than the number of spears produced, per se.

Significantly heavier spears were produced by both cultivars under the normal spring harvest than the mother fern. The MSW differences between the two cultivars were in the order of 1.81g, 1.45g and 1.58g for the NH, MF, and MD, respectively. Light weight spears were produced by the MD treatment, although they were not significantly different from MF for both cultivars.

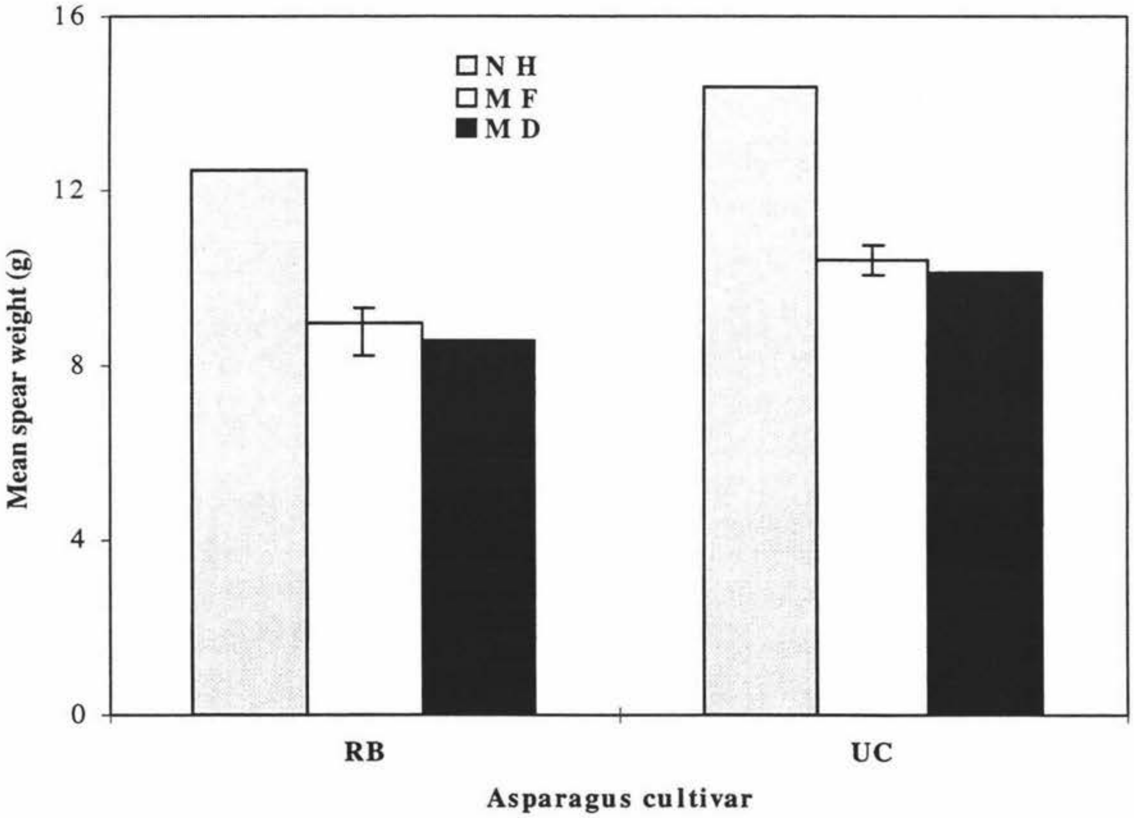


Figure 2.5 Mean spear weight (g) of the cultivars; UC 157 (UC) and Rutgers Beacon (RB), under the harvesting treatments; Normal spring harvest (NH), Spring mother fern (MF) and December mother fern (MD).

2.3.5 Spear size distribution

The results showed a highly significant (P<0.0001) interaction between the harvesting technique (treatments) and the spear category (size), expressed as proportion of the total of spears in that category (Figure 2.6). The interaction was the reversed order of treatments in the various grades. No spears >20mm were produced by either of the two cultivars. Spears produced by both cultivars were concentrated in the 8-14mm category followed by <8mm and finally 14-20mm categories.

Harvesting the crop using the normal spring harvest resulted in a greater proportion of marketable spears (8-20mm), whereas there was a tendency, consistent for both cultivars, by the mother fern treatments to produce thinner spears (<8mm) than the normal harvest.

Comparison between the two cultivars indicated that more spears of good quality and marketable value were produced by UC 157 than Rutgers Beacon (2.3.3). A larger proportion of UC 157 spears than Rutgers Beacon spears for all the treatments was attributed to >8-14mm spear category. More thinner spears (<8mm) were produced by Rutgers Beacon than UC 157 in all the harvesting treatments.

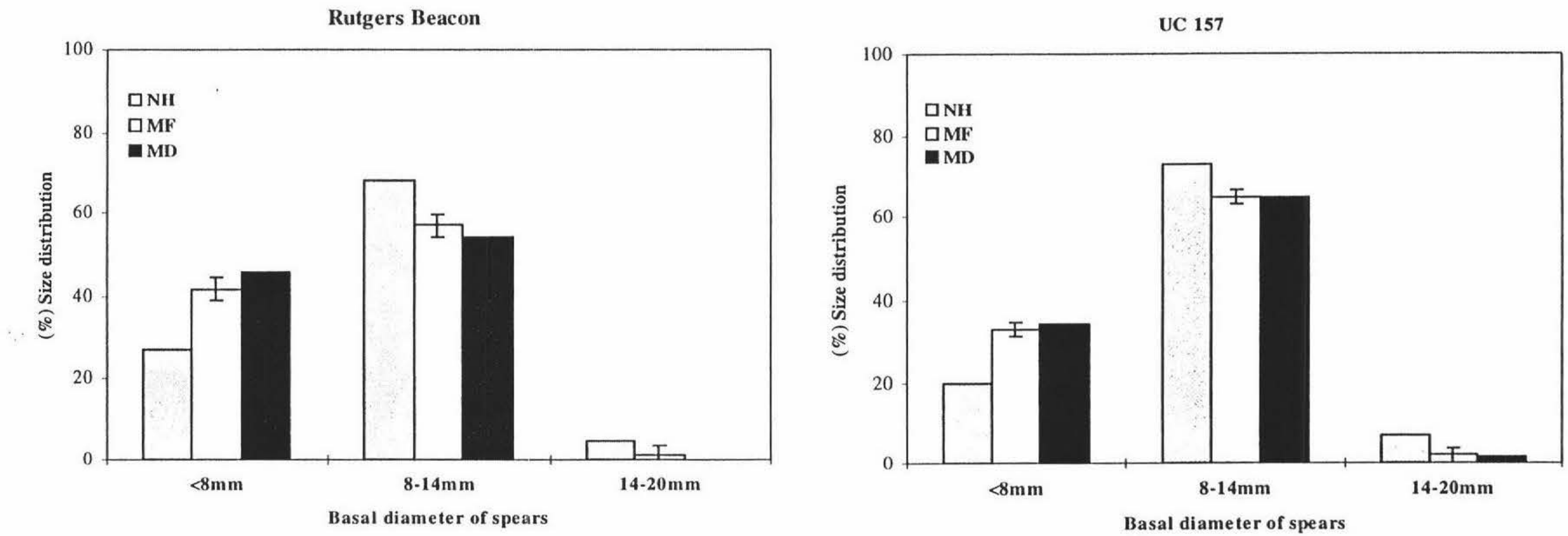


Figure 2.6 The spear size distribution of asparagus cultivars (Rutgers Beacon and UC 157) under the normal harvest (NH), the Spring mother fern (MF) and the December mother fern (MD).

2.3.6 Reject yield

The normal harvest produced significantly lower quantity of reject yield than the Spring and December mother fern treatments particularly for Rutgers Beacon (Figure 2.7). Although a similar trend occurred for UC 157, there were no significant treatment differences. The highest (5.52t/ha) recorded reject yield was from the Spring mother fern (RB).

The largest contribution to reject yield was due to seediness or defective spears followed by butts. Premature seediness of spears was associated more with the mother fern treatments than with the normal harvest. Conversely, there was an increased proportion of the butts in the normal harvest. Butts weight were 54% and 49% of the rejected weight for UC 157 and Rutgers Beacon, respectively.

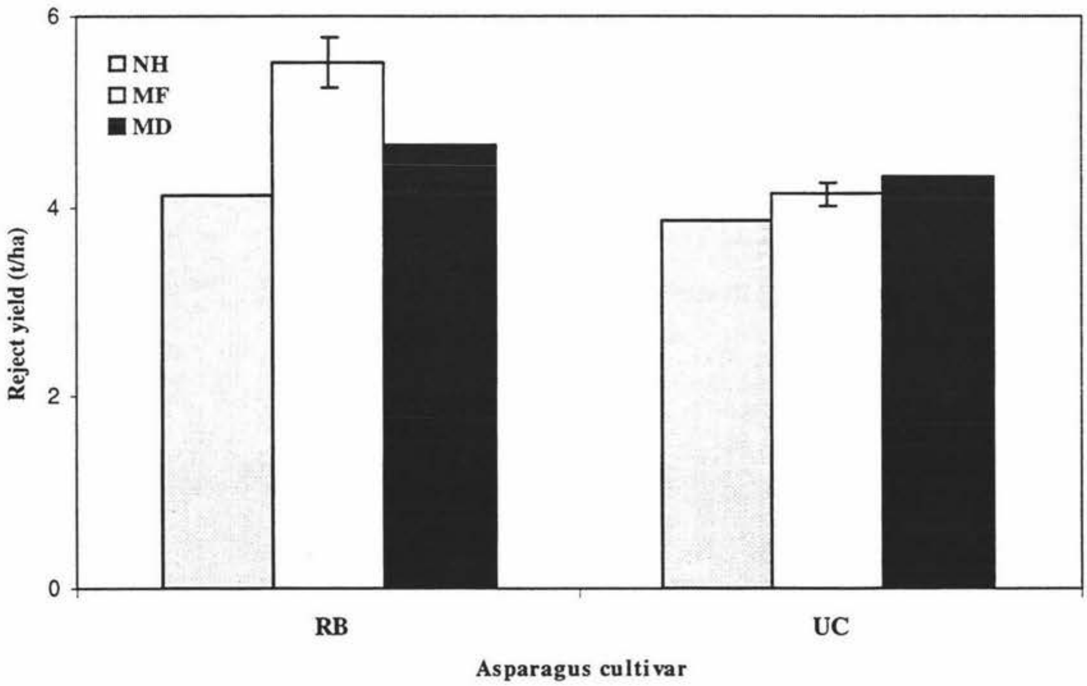


Figure 2.7 Reject yield of asparagus cultivars; UC 157 (UC) and Rutgers Beacon (RB) under three harvesting strategies; normal spring harvest (NH); spring mother fern (MF), and December mother fern (MD).

2.4 Discussion

2.4.1 The mother fern and extension of the harvest season

In the temperate regions the normal spring harvest of the asparagus crop is restricted to less than four months in a year. Harvesting the crop without adequate time for fern growth exhausts the plants and culminates in reduced economic lifespan and productivity. Therefore, consideration is given for carbohydrate accumulation, by ceasing harvesting in late November or early December (Robb 1986; Haynes 1987).

This study sought to evaluate the performance of the mother fern to extend the harvest season beyond the normal spring harvest. Either the mother fern (Robb 1986 and Reiners and Garrison 1994) or the summer harvest (Robb 1986) were suggested as two options for production of asparagus beyond the common close-up season. Robb (1986) found that one and three mother ferns extended the harvest season beyond the normal spring harvest by 10-14 days and 6 weeks, respectively.

In this investigation the mother fern treatments extended the harvest season by 15 weeks over the normal spring harvest. The length of harvest for the longest mother fern treatment was a month longer than that of an asparagus crop produced under a similar system in the tropics, particularly Taiwan, where harvesting lasts for six months (Messian 1994). However, the crop was harvested continuously in this experiment without any breaks allowed between harvesting periods (April to June and August to October) in the tropics. In Taiwan, during the hottest months harvesting has to stop to avoid exhausting of the plants, whereas winter slows plant growth (Messiaen 1994).

2.4.2 Spear production trends

Spears were produced continuously throughout the harvesting season though not at a constant rate (2.3.1). With all the treatments there was an increasing trend in the production of spears as the season advanced. This was in agreement with McCormick's (1990) notion that daily spear production rates and yield increase with rising temperature until the crop's capacity to produce spears is reached.

There were, however, short term (daily or weekly) fluctuations in the rate of spear production in all the treatments, despite the upward trend from early spring. The daily yield of asparagus closely follows changes in the mean temperature throughout harvest (McCormick 1990). The climatic data shown in Table 2.4 confirmed that during the period of yield depression (particularly from end of September to November) both the air and soil temperature were lower than the following six months of harvesting. The decrease in temperature, hence yield, was attributed mainly to heavy rainfall which increased from September to the maximum record in October (Table 2.4).

In investigations involving irrigated asparagus, several workers (Cannell and Takatori 1970; Takatori *et al* 1970; Wilcox-Lee 1987; Roth and Gardner 1989, 1990) established that wet irrigation treatments have a negative effect on the rate of spear production due to lowering of the soil temperature. The depression of spear emergence occurs right after irrigation (Roth and Gardner 1989) and may thus be considered to have a short term effect. On the contrary, the effect of several rainy days prolong the period of crop exposure to low temperatures. Moreover, excess rain during early spring may decrease the accumulated yield of asparagus (Cannell and Takatori 1970) probably due to low temperature in spring. Indeed, the highest number of rainy days over the entire harvest period was between September and November, (averaged 16 days) and this may have accounted for the decrease in the yield of the crop over this period.

The peak yield in January for either mother fern treatments coincides with the time when Sudjatmiko (1993) found that a change in partitioning of dry matter from the shoot to the root took place. Therefore, it appears that increased partitioning of assimilate into roots rather than the shoots is a crop's natural response to continue spear production in the next season. As discussed below another contributing factor could have been the fall in temperatures from January onwards.

Following the peak spear production rate in January (Mother fern treatments), spear production begun to decline. At the close-up the Normal spring harvest did not show a reduction in spear production as generally hypothesised. The dramatic drop observed in Figure 3.1a-d, was due to just a few days' harvest in December making it appear as if yield had decreased. It was uncertain how long an increasing trend would have been maintained. McCormick (1990) reported that the crop's capacity to produce spears, most likely under the normal spring harvest occurs in early November in New Zealand. This notion could not be confirmed in this study and this might have been due to adequate food reserves as the crop had not been harvested in the season preceding the study period.

The rate of spear production rate fell from 282g/m^2/day in January to 113g/m^2/day in February and 31g/m^2/day in March for the spring mother fern. In the December mother fern a similar drop occurred resulting in values amounting to 286g/m^2/day, 102g/m^2/day and 30g/m^2/day, corresponding to January, February and March. The reason for declining spear production would have been, in part due to decreasing temperature. Compared to peak spear production in January, there was a general decline in both air and soil temperature from that month onwards (Table 2.4). Previous investigations showed that the growth of asparagus slowed as temperatures dropped. Hughes (1993) reported that cooler air temperature in March than January and February resulted in reduced fern growth. Likewise, a very low rate of spear production at a similar period was reported in a summer harvested crop in two sites in Palmerston North, whereas at Levin, spear production was limited after mid-March, greatly reduced by mid-April, and ceased in late-April (Robb 1986). Therefore, it was likely that the declining rate of spear production in March was inevitable because, in New Zealand, the growth of asparagus declines in autumn, and the fern dies back about April or when killed by frost (McCormick 1990).

Harvesting the crop in March on daily basis did not appear practical because of greatly reduced number of ready to harvest spears. The commercial implication this has is on labour costs, which are often high, suggesting that the total physical product must be of high value to offset high financial expenditure on labour costs.

2.4.3 Crop yield

2.4.3.1 Total yield

In this study the total yield (t/ha) in the Normal spring harvest was 1.33 and 1.73 times higher than in the spring and December mother fern treatments, respectively (2.3.2.1). These results were different from conclusions reached based on investigations carried out in the tropical regions. The mother fern is reported to yield more than twice the normal spring harvest. Although recent factual data are lacking, an earlier report by Hung (1980), indicated that in 1971 and 1972 the mother fern yielded 278g and 885g/m^2 higher than the normal spring harvest. Wang's (1965) and Tu's (1995) contention that the mother fern yields higher than the normal spring harvest had no supporting factual data.

Reiners and Garrison (1994), working in a greenhouse environment in New York obtained results which suggested that the mother fern could extend the harvest season and increase the yield more than that of the normal harvest. They established that initially the yield from normal harvest was higher than that of the mother fern treatments. However, the mother fern's yield levelled off six weeks after harvest and continued an increasing trend as that from the normal harvest declined. Eventually, the mother fern's cumulative yield ten weeks after harvest was higher than the normal harvest.

Reports are consistent in that the yield from a normal harvest increase, but may later decline as the level of root storage carbohydrates decrease. This hypothesis was confirmed and demonstrated by the Reiners and Garrison's (1994) investigation. They found no differences in the crown dry weight between the normal and mother fern harvests at the end of five weeks, but five more weeks later the crowns from the latter system were heavier than the former suggesting a progressive accumulation of dry matter from the mother fern. Despite this convincing evidence, the measurement of crown dry weights was beyond the scope of this study. Moreover, the hypothesis that once established the mother fern yields higher than the normal harvest could not be sustained in the present investigation.

Not all experimental work showed that the mother fern yields more than the normal spring harvest. Work done by Robb (1984) resulted in no differences in yield between the two systems because the mother fern was terminated when its yield equated to that of the normal harvest. The main objective of her study was to determine the possibility of extending the harvest season using the mother fern, possibly without a depression in yield and quality of asparagus. It was not however, a direct comparison between the performances of the two systems.

The decreasing temperature during late summer to autumn may not have been the only factor which contributed to low yield of the crop. This is because biological organisms are simultaneously affected by many growth factors which may alter their response (Gomez and Gomez 1984). The asparagus's yield response depends on light, temperature, nutrients, water, biotic and abiotic factors, whereas age and sex determine the yield of individual plants (Lampert *et al* 1980). The possible role of environmental factors and the manner in which the mother fern was maintained, in effecting lower yield than the normal spring harvest could not be disregarded.

The rainfall data (Table 2.4) showed that the February and March received the least rainfall as compared to the previous months. Since no irrigation was used in the experiment, it is likely that reduced soil moisture content during summer time might have had a stressful effect on the growth of spears and metabolism of the mother fern in a manner, which might have been translated into a reduction in total yield.

The presence of the mother fern as opposed to the normal harvest, not only represent a photosynthetically active component, but also constitutes a region of most water loss. This suggests that although irrigation is required during dry months, the mother fern is likely to require more water to compensate for evapotranspiration losses. Irrigation may not be required during the rainy period, but it would lead to increased production and better quality of asparagus during the harvesting period (Bussell 1985; Tu 1995).

Furthermore, fertiliser application is required during harvesting by the mother fern either, with sufficient soil moisture to dissolve it. However, lack of irrigation meant that fertiliser application, especially in January, had to be timed with rainfall in order to dissolve and be made available to the plants. High fertiliser application rates (700-180-250 NPK units/ha) used to increase yields from 7 to10t/ha/year in the tropics (Messiaen 1994). The application of fertiliser in conjunction with irrigation is recommended in the mother fern system during the harvest period (Tu 1995). Therefore, it is important that future research with the mother fern system should consider the use of irrigation during the harvesting period when required.

Table 2.4 The total monthly rainfall, air and soil temperature data during the experimentation period (Aguast 1995 - October , 1996).

	Rainfall (mm)		**Mean air temperature °C)**		***Soil temperature**
Month	**Monthly total**	**Rainy days**	**Maximum**	**Minimum**	**(°C)**
August	728	22	12.5	4.8	7.3
September	1064	15	15.2	7.2	9.8
October	1396	19	16.7	8.6	12.9
November	1024	15	18.1	9.1	14.7
December	1010	12	21.9	13.0	18.0
January	505	7	23.0	14.6	19.4
February	1287	13	22.8	13.8	18.5
March	791	13	20.0	10.6	15.5
April	1604	17	19.0	11.6	15.0
May	1146	15	15.0	7.0	11.1
June	985	18	12.4	4.7	7.6
July	1048	24	12.3	5.8	8.0
August	823	20	13.2	4.7	8.1
September	1028	13	16.8	8.0	11.5
October	956	13	17.2	8.9	13.7

Source: ***Agresearch, Palmerston North: Station E05363; 40.23 S Latitude and 175.37E longitude.***
***Soil temperature were recorded 9.00am**

It should be noted in this study, that the comparison was made between crops which had been harvested for a number of seasons as spring harvest or mother fern crops. This may account for the results obtained here being different from other researchers.

2.4.3.2 The possible role of assimilate competition between spears and berries and its effect on the yield

Among several factors which were implicated in the reduced yield of the mother fern was the sex of the plants. Some of the retained fern of female plants produced berries. This was not applicable to the normal harvest as the spears were harvested prior to ferning out. The cultivars UC 157 and Rutgers Beacon used in this investigation are dieocious hybrids.

The drawback of berry bearing mother fern stalks is the competition for assimilates between the vegetative (spears) and reproductive (berries) sink organs. Generally, heavily fruiting or tuberising plants experience reduced growth of vegetative sinks because of high mobilising ability and competitive ability (Hughes 1993; Ho 1988; Gifford and Evans 1981; Patrick and Wareing 1974). With the aid of labelled ^{14}C Hughes (1993) found that female plants produced dry matter more efficiently than male plants, yet, they retained 25% of it in berries. Removal of the berries led to approximately 80% increase in crown dry weight, due to an increase in the photosynthetic tissue. Conversely, the removal of berries reduce the net efficiency of assimilate production (Hughes 1993), suggesting an assimilate production mechanism by the source is both sink-controlled. Therefore, it would appear that berry producing females under the mother fern treatments might have had a negative effect and contribution to reduced yield of this system. Selection of male only mother ferns in the field would, thus seem advisable, although the distinction between the sexes may not be easily accomplished at the spear stage until the plants had started flowering.

Despite provision of the stakes to support the heavy weight of the mother fern against strong winds, lodging of the plants was encountered. Not only were such stalks liable to injury or damage, but both the mobilising ability and competitive ability of damaged fern is very low compared to uninjured plants (Hughes 1993).

2.4.3.3 The effect of renewal and cutting back of the mother fern on yield

During the entire harvesting season the mother ferns were not renewed as suggested by the tropical literature. The reasons were; one, the mother fern was reported to reach highest photosynthetic activity when three months old, and the right time to replace old stalks with new ones is when they are five months old and starting to yellow (Lin and Tsai as cited by Hung 1980). Therefore, (1) without measuring the photosynthetic activity of the mother fern, renewal fern could be visually determined by yellowing signs of the old fern. (2) Due to decreasing late summer temperatures the growth of the mother fern would have been slow, which would have meant a failure to undergo a complete transition from sink to a source of assimilate. Thus, the storage carbohydrates would have been drained without replenishment with the onset of winter dormancy.

Some of the mother fern plants in this study had started showing yellowing of the cladophylls during the beginning of February, particularly in the Spring mother fern, where harvesting commenced two months earlier than the December mother fern. Previous investigations have shown that as the fern begins to senesce carbohydrates are remobilised into storage organs and or berries (Hughes 1993; Haynes 1987). Remobilisation concurrently occurs with the decreasing dry weight of the fern (Hughes 1993). Evidently, assimilate partitioning and sink priority during senescence of the mother fern were diverted away from the growth of spears, hence the yield of spears could not be stimulated and as a result increase from February to March.

Although the renewal of the mother fern had been modelled after the five-months renewal period, a shorter duration has been proposed by other workers. According to Messiaen (1994) the mother fern starts to turn yellow after three months, hence should be replaced with new ones every two to four months (Hung 1980). Conversely, the fern had remained green from October until beginning of February when few plants started yellowing, and instead a regrowth was observed from the cut tops during December and January, presumably to compensate for the cut-off tops. Moreover, if the fern was too old the MD would have yielded more in February/March, in fact the two curves were similar.

The tops of the mother fern in this study were cut back. Tall mother ferns are liable to wind damage, apt to lodging which shorten their life span (Hung 1980), thus cutting them alleviate such problems. The fern must also be cut at a very young stage to avoid too much nutrient loss from the plant (Hung 1980). Despite having considered the available evidence at the time this experiment was carried out, recently received evidence indicates that trimming of the mother fern is an incorrect cultural practice. It is argued that higher yield is obtained from untrimmed than the trimmed plants (Tu 1995).

2.4.4 Mean spear weight (MSW)

The MSW (2.3.4), was affected by harvesting method. Heavier spears were produced under the normal spring harvest than the mother fern treatments. A similar trend was observed for both UC 157 and Rutgers Beacon. The MSW difference between the Spring mother fern and Normal harvest might have been attributed to the large number of spears produced by the former than the latter. The increase in spear number is inversely related to MSW (Ellison and Scheer 1958; McCormick and Thomsen 1990), suggesting that the higher the spear number a plant produces the thinner they become.

On contrary, spears number may not be the only factor which affects the MSW. This is because despite having produced less number of spears than any other treatment the MSW under the December mother fern was low. It is likely that the MSW decreased due to less assimilates partitioned into spears from January onwards as reported by Sudjatmiko (1993) and the accompanying lower temperatures. Clearly, MSW may also be influenced by the genotype of the cultivars, as evidenced by heavier spears produced by UC 157 than Rutgers Beacon.

2.4.5 Spear quality and marketable yield

Spears of high quality, hence marketable yield, in this study comprised spears 220mm long, between 8-20mm basal diameter, with tight tips, and without blemishes or physical damage. The spear quality was higher in the normal harvest than in either of the two mother fern treatments (2.3.3). The physiological basis of the treatment differences could not be established except the differences in the total yield, spear size and weight of spears. All the three attributes were lower in the mother fern treatments than the normal harvest. The results showed that the marketable yield in all the treatments increased as the total yield increased. A similar relationship between the marketable and total yield was reported by McCormick and Thomsen (1990). Therefore, this implies that the higher total yield from the normal harvest resulted in a proportionally higher marketable yield relative to the mother fern treatments in which the total yield was low.

The treatment differences in relation to spear quality were influenced by spear size and weight (2.3.5). Although a plot of spear size distribution indicated a high proportion of spears in the 8-14mm category for all the treatments, the normal harvest was superior, and this applied to the 14-20mm spear category in which few spears were produced. Conversely, the mother fern treatments produced more thinner spears (<8mm) than the normal harvest. This might have been due to the higher number of spears produced in the case of the spring mother fern since spear size tend to decrease as the number increase (Yen 1993), whereas in the summer time low rainfall, or possibly high temperature might have been stressful to the plants.

2.4.6 Reject yield

There was no significant treatment differences in the total reject yield except for the mother fern system which produced significantly higher reject yield for the cultivar RB. This appeared to have been an inherent character imparted by the cultivar concerned. Even though the results were not significant in other treatments the latter cultivar produced a higher of reject yield than UC 157.

The spears were rejected mainly due to the seediness, but butts also contributed to the reject yield. Crop losses due to rejects may be alleviated by frequent harvesting interval. It guarantees cutting the crop at the required length and diminishes the wastage due to either butts or seediness. When the cutting length exceeds the market length the wastage in butts and unsalable spears increases (McCormick 1990). Moreover, when a longer spear is cut to length it is not as heavy as the one cut at ground level because the thicker butt portion is wasted.

In this study harvesting daily reduced the wastage due to butts. Seediness contributed more to the total reject yield than butts did. Premature development of the lateral buds effects seediness, which in turn is dependent upon the cultivar, cutting height of the spears, and promoted by high temperature.

The results showed that Rutgers Beacon produced more seedy spears than UC 157. The latter is known for production of spears with tight heads (Nichols 1989). It was shown that when increasing the cutting length from 190mm to 250mm UC 157 produced better longer spears than Mary Washington and Rutgers Beacon, and comparable to Jersey Giant (McCormick 1990). Open tips or loose heads are cultivar specific, and therefore due to genetic factors (Hartmann 1988).

The varietal differences obtained in this study might have been also accentuated by cutting the spears at 220mm. Spears tend to open as height increases (Nichols 1989; McCormick 1990). Although increasing the cutting length can increase the crop's marketable yield by up to 30%, it is not profitable with all varieties (McCormick 1990). Thus the results obtained in this study suggested that at 220mm the less wastage from UC 157 contributed to higher marketable yield than Rutgers Beacon.

CHAPTER 3

THE CARRY-OVER EFFECT OF THE MOTHER FERN TREATMENTS DURING THE SUBSEQUENT HARVEST SEASON.

3.1 Introduction

The first experiment (Chapter 2) unexpectedly showed that the full season mother fern system yielded less than the normal spring harvest. The response of the asparagus crop during the subsequent harvesting season(s) following the mother fern harvest is of major importance. Therefore, the two asparagus blocks were harvested for a period of one month in the spring of 1996. The aim was to determine whether there had been any marked treatment carry-over effects between a crop harvested using the normal spring harvest and the mother fern system, in terms of yield and yield components (spear number and average weight of spears).

3.2 Materials and methods

3.2.1 Design of the experiment and data collection

This experiment was conducted on the site of the first experiment. Details of the site and the design of the experiment are detailed in section 2.1.3 and 2.2.1. The method of harvesting and data collection for the present experiment was as follows:

(a) The use of the normal spring harvest to replace all the mother fern treatments,

(b) Harvesting frequency was reduced to three times a week, and

(c) Only the total yield and spear count data were recorded.

3.2.2 Crop management and data analysis

The stakes and wire which were used to provide support to the mother fern treatments during the previous season were removed to enable the mowing of the senesced fern. No herbicides were used, but Mesurol slug and snail bait and Ridomil, a protectant spray against Phytophthora were applied in the rates as described under the main experiment.

Harvesting commenced on the 11 September. Spears in excess of 220mm, were cut just below the ground level. Spear weight and number (count data) were recorded and saved in Lotus 123 (spread sheet program). The analysis of variance (ANOVA) was performed to determine the previous treatments' carry-over effects on the total yield, spear numbers and mean spear weight using SAS release 6.10.

3.3 Results

3.3.1 Total weight of spears (t/ha)

Harvesting the asparagus crop "normally" for a period of one month 1996 did not result in any significant difference in the total yield between the 1995 normal harvest and mother fern treatments (Figure 3.1).

The response was similar for both cultivars, though UC 157 yielded higher than Rutgers Beacon by 59%, 74% and 79% for the normal spring harvest (NH), Spring mother fern (MF) and December mother fern (MD) treatments, respectively.

3.3.2 Spear number

Spear number was significantly higher for the normal spring harvest than either of the two mother fern treatments for UC 157 (Figure 3.2). A similar but not significant trend was obtained for Rutgers Beacon. Although a higher number of spears were harvested in the December mother fern than Spring mother fern the results were not significant for either cultivars.

3.3.3 The mean spear weight (MSW)

The mean spear weight, computed as the total weight over the number of spears, expressed in grams (g), is shown in Figure 3.3. Significantly lighter spears were produced by the normal harvest than the mother fern treatments. The results showed that for both cultivars more spears were produced by the NH harvest relative to the MF and MD treatments, hence the lower MSW. No significant differences in the MSW occurred between the two mother fern treatments. UC 157 produced heavier spears in all the treatments than Rutgers Beacon.

The MSW compared to the previous season's MSW was consistently higher in all the treatments. The data revealed an improvement of 19%, 82% , 104% and 39%, 143% and 149%, in the NH, MF and MD treatments for Rutgers Beacon and UC 157, respectively.

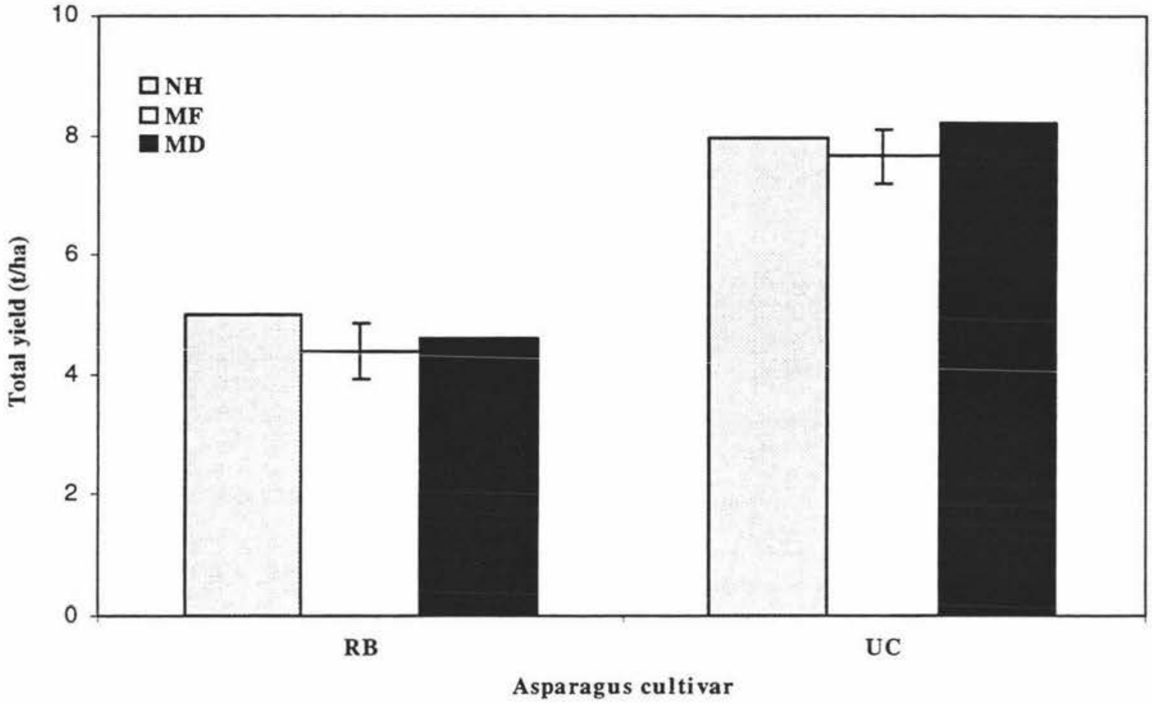


Figure 3.1 The total yield (t/ha) of two asparagus cultivars; UC 157 (UC) and Rutgers Beacon (RB) after one month of harvest following normal spring harvest (NH), spring mother fern (MF) and December mother fern (MD) harvesting in the previous season.

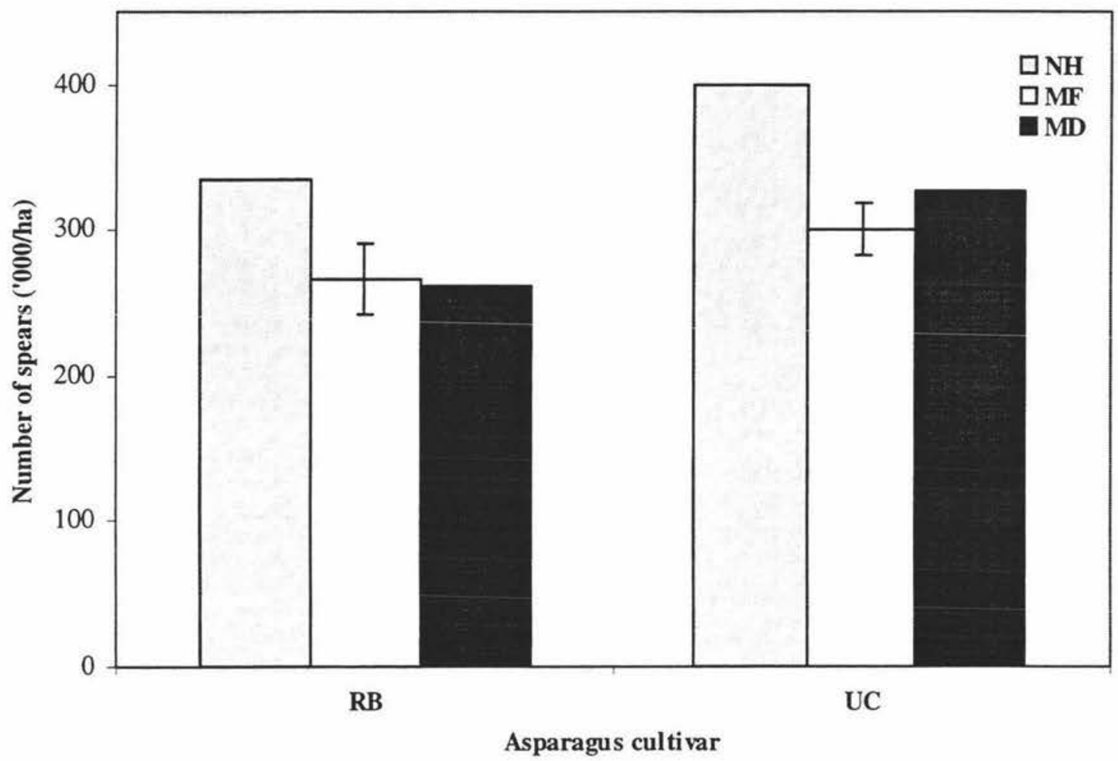


Figure 3.2 The number of spears produced ('000/ha) by, UC 157 (UC), and Rutgers Beacon (RB) as a response to one month of spring harvest in 1996, following normal spring harvest (NH), spring mother fern (MF) and December mother fern (MD) harvesting in the previous season.

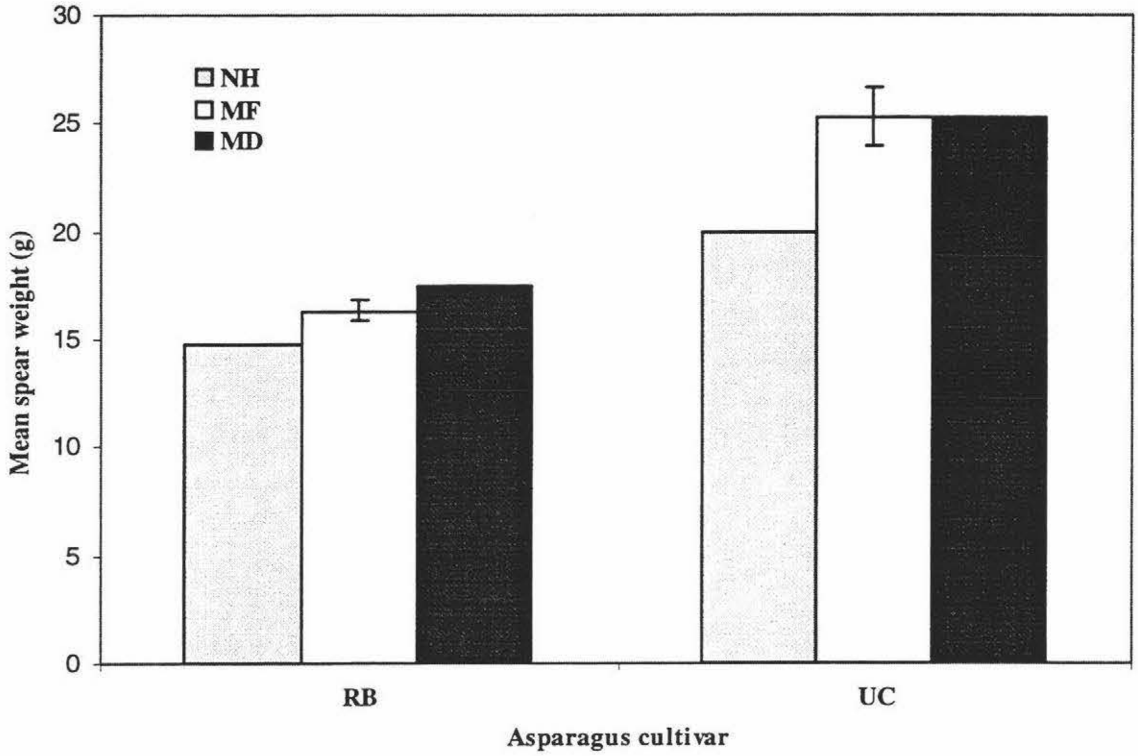


Figure 3.3 The mean spear weight, MSW (g) of UC 157 (UC) and Rutgers Beacon (RB) under the normal spring harvest in 1996, following normal spring harvest (NH), spring mother fern (MF), and December mother fern (MD) in the previous season.

3.4 Discussion

3.4.1 Total yield

In the 1996/97 cropping season the results did not show any significant differences in the total yield between the normal harvest and the former mother fern treatments. It was suspected that treatments differences would recur during the subsequent season when only the normal harvest was used.

Lack of differences in total yield (t/ha) of spears indicated that there was no carry-over effect of mother fern treatments. Harvesting the crop earlier in the season for one month was considered sufficiently sensitive to detect any major treatment differences, but it was uncertain whether a similar trend would have been maintained until close-up. The lack of yield differences might be explained by the level of root storage carbohydrates.

The yield of asparagus depends primarily on the previous season's food reserves. Hence, it is quite likely that in both systems sufficient storage carbohydrates were accumulated prior to winter dormancy. This was made possible in the normal harvest by allowing a fern growing period for rejuvenation of food reserves prior to winter dormancy. Thus, irrespective of the heavy yield produced in the previous season the plants were able to recover sufficiently. On the other hand, two factors could have contributed to the mother fern resulting in a similar yield to the normal harvest during the subsequent season. First, in the previous season the low yield and rate of spear production implied less use of food reserves compared to the normal spring harvest, as proposed by Hung (1980) and Tu (1995). Secondly, the ability of the mother fern to produce and store carbohydrates during harvest meant that the level of food reserves was not exhausted at close-up.

A higher number of spears was produced by the normal harvest than the former mother fern treatments. This might have been caused by more bud clusters or an advantage of having had an earlier rest period and carbohydrates production after harvest, compared to the mother fern treatments in which harvest continued until the late summer. Moreover, the longer period of harvesting of the mother fern might have led to the removal of vigorous apical buds compared to the smaller terminal buds which emerge relatively slowly.

3.4.2 Mean spear weight (MSW)

The mean spear weight (MSW) was lower in the normal harvest than either of the two mother fern treatments. This resulted from high number of spears produced by the normal harvest due to an inverse relationship between the two. Compared to the previous season, there was an increase in the MSW in all the treatments. This might have been due to the fact that spears harvested early in the season under the normal harvest are presumed to benefit from an abundant supply of food reserves compared to late season harvested spears when the carbohydrates reserves is low.

Comparison between the cultivars indicated a superior performance of UC 157 than Rutgers Beacon in terms of total yield and MSW for all the treatments. Both the large number and heavy weight (MSW) of UC 157 spears led to an increased total yield of this cultivar. The increase in yield becomes more pronounced in plants with many large stalks than small ones (Ellison and Scheer 1958). UC 157 is also an inherently early season cultivar compared to Rutgers Beacon which explained a larger number of spears than Rutgers Beacon. This also contributed to high yield of this cultivar.

CHAPTER 4

A STUDY ON THE INFLUENCE OF TEMPERATURE ON THE GROWTH OF ASPARAGUS SPEARS

4.1 Introduction

Research on the effect of temperature on spear growth has been of particular interest in the temperate regions. This is because temperature regulates spear growth rate, hence crop yield. Generally, as temperature rises from early spring to summer, both spears production and rate of growth are expected increase. However, the promotive effect of rising temperature on spear growth may be masked or negated by the diminishing level of food reserves. The asparagus crop reaches its limit and capacity to produce more spears and yield in November, beyond which spear yield drops until close up (McCormick 1990; Hughes 1993), probably due to declining carbohydrate reserves. These findings were reported for asparagus grown in temperate regions, hence, it is certain that normal spring harvest was used.

Questions arise as to whether, the mother fern system, which is thought to continuously replenish carbohydrates levels during harvesting season, -along with suitable temperature- would synergistically stimulate the growth of spears for crops harvested normally and for crops grown using the mother fern system.

The objective of this study was to investigate the effect of temperature on the growth of spears under controlled climate conditions, to provide information which might explain the physiological behaviour of spears growing in field conditions.

The aims of the study were:

a) To determine whether there were treatments (mother fern and normal harvest) and cultivar (UC 157 and Jersey Giant) differences in the growth of asparagus spears response to constant temperature levels of 15°C, 20°C, 25°C, 30°C, and 35°C.

b) To determine whether the postharvest storage life of the spears would be influenced by the treatment (system of harvesting: the normal harvest and mother fern culture) and temperature.

4.2 Materials and Methods

4.2.1 Site and time of study

This study was carried out in the controlled climate growth cabinets in Level One, Block A, Department of Plant Science, Massey University, Palmerston North. It was run from April to July, 1996.

4.2.2 Plant material

One-year old asparagus plants were used. The plants were grown in 10 litre containers filled with decomposed pine bark. The crowns were produced in a temperate environment.
The cultivars were:
i) UC 157 - a single cross hybrid consisting of both male and female plants, from University of California, USA.
ii) Jersey Giant (known also as 56 x 22-8) - an all male clonal hybrid developed by Ellison at Rutgers State University, New Jersey, USA.

The plants were initially grown in a greenhouse environment. Water was supplied daily, and nutrients (in the form of slow release osmocote) were supplied to the growing medium. Four to five weeks prior to the beginning of the experiment a drought-induced rest period was imposed on the plants in the greenhouse. This caused the demise of the fern, which was removed. Subsequently, the plants were transferred to the controlled climate cabinets.

4.2.3 Temperature treatments

The study comprised five constant temperature regimes, from 15°C through to 35°C at 5°C increments , with a 12 hour photoperiod .The experiments were conducted in four controlled climate cabinets. The irradiance levels expressed as photosynthetically active radiation (PAR) differed slightly in the growth cabinets as shown in table 4.1.

4.2.4 Experimental design

The study was run as a series of separate experiments arranged in a split plot experimental design. The harvesting strategies comprised the mother fern, which was run first, then followed the normal harvest. Each experiment at a given temperature level consisted of the harvesting system and the two cultivars. Sixteen potted plants per growth cabinet constituted the experimental units, with eight replications per cultivar allocated spatially in a complete random design.

Table 4.1 The temperature treatments, irradiance level and harvest duration.

Temperature	**Irradiance**	**Duration of harvest (Days)**	
(°C)	*($m\ sec^{-1}\ m^{-2}$)*	*Normal harvest*	*Mother fern*
15	1000 x 0.550	22	37
20	1000 x 0.550	16	52
25	1000 x 0.650	21	52
30	1000 x 0.620	27	52
35	1000 x 0.450	36	52

4.2.5 Growing conditions for evaluating spear and fern growth at different temperature levels

No nutrients were supplied during the harvest period. The plants were watered regularly to maintain moisture content of the growing medium at or near field capacity to avoid moisture stress and desiccation, particularly at the higher temperatures. The first two sturdy spears to develop were allowed to grow into a fern in the mother fern system. Later on the tops of the mother ferns were stopped at 100cm as they reached the glass roof of the growth cabinets. This alleviated the problem of shading by excessive fern growth which would otherwise expand and curl underneath the glass cover.

4.2.6 Data collection

4.2.6.1 Plant measurements

Transferring the plants into the controlled climate cabinets stimulated the first spear emergence within the first week between 20°C -35°C, and between 12 -14 days at 15°C, but spear production varied from plant to plant. It was observed that spears were produced prolifically at high temperature levels, 25-35°C compared to 15°C and 20°C, and that UC 157 spears emerged earlier than Jersey Giant.

The height of each spear above the ground level was measured by a ruler twice daily (in the morning and afternoon), except for the plants grown at 15°C, which were measured once per day. The basal diameters of individual spears were measured by a digital vernier calliper. The experiments were run for different lengths of times (Table 4.1).

4.2.6.2 The relative spear growth rate (RSGR)

The data were obtained from spear growth rate measured as an increase in the height of spears over time. The raw data of the spear height were handled following the method developed by Nichols and Woolley (1985). They showed that when the growth of the spears (height) is exponential it could be expressed as follows:

$$\text{Height} = ae^{bt} \qquad (1)$$

Where a = intercept; b = constant of proportionality; and t = time.

Then, by taking the natural logarithms (Log_e) of the spear height, plotted against time (t) equation (1) could be shown as follows:

$$\text{Log}_e \text{ height} = \text{Log}_e \, a + bt \qquad (2)$$

A straight line is obtained and the slope of the line (b) represents the 'relative spear growth rate' (RSGR). Thus, the differences in the rate in which a spear grows can be represented by a single value or RSGR (Nichols and Woolley, 1985; Hughes, 1993). The relative spear growth rate, is defined as the increase in height of spears per height over time expressed as (cm/cm/time).

Therefore, relative spear growth rate (RSGR) of the spears was computed as an output from the regression of Log_e(spear height, cm) against time (days) represented as follows:

$$\text{Log}_e(\text{spear height}) = \text{Log}_e(a) + (\text{RSGR x time}) \qquad (3)$$

The maximum height of spears considered for the RSGR calculations was restricted to 270mm, spears beyond this height exceeded a linear growth function. Time was based on the number of days from emergence.

4.2.6.3 Fern growth

The mother fern height measurements were recorded from the spear stage through to the fern stage. The upper limit was one metre high as further vertical elongation was restricted by the roof of the controlled climate cabinets. The height measurements were expressed as the natural logarithm of fern height (Log_e fern height) against time (days). An average of Log_e fern height of the two mother ferns growing in each container was taken. Then, Richard's growth function was fitted to the height measurements to estimate the constants of the function.

From the general equation describing the increase in fern height with time expressed as:

$$H = (f)t \qquad (4)$$

Where: H : denotes fern height

t : denotes time or age of the fern in days.

f : denotes a some functional relationship.

the Richard's Growth equation is written as follows:

$$H = \frac{H_i H_f}{(H_i^N + (H_i^N - H_i^N)e^{-kt})^{\frac{1}{N}})} \qquad (5)$$

Where H_i: Initial fern height.

H_f : Final fern height.

N : Type curve parameter.

K: a constant by which H (fern height) increases with time.

The relative fern growth rate (RFGR) was determined as:

$$\text{RFGR}=\frac{K * e(H - kt))}{(N * (1 - e(H - kt)))} \qquad (6)$$

4.2.7 Data analysis

Spear growth

Analysis of variance (ANOVA) was performed using SAS version 6.10 Proc GLM to determine the effects due to temperature and treatments (harvesting systems) on the relative spear growth rate (RSGR), the rate of spear production per plant per day (SPRPD), number of days spears took to reach harvestable length from 1cm, between the two asparagus cultivars (Jersey Giant and UC 157).

Fern growth

In the mother fern system, final heights attained by the fern (asymptote) were analysed (employing the ANOVA) to determine the effect of temperature on fern growth and to determine whether there were differences in the final height (asymptote) of the mother fern growing in different levels of temperature.

4.3 Results

4.3.1 Relative spear growth rate (RSGR)

The growth of asparagus spears was slow at low temperatures, but increased with rising temperature, as was expected. The 5°C temperature increment increased the relative spear growth rate from a minimum rate of 0.07cm/cm/day at 15°C to a maximum rate of 1.03cm/cm/day at 30°C. Although growth increased throughout this range a sharp upward trend occurred between 25°C and 30°C. Beyond 30°C the growth of the spears begun to decline as the temperature increased to 35°C, suggesting that higher temperature were unfavourable (Figure 4.1).

There was a significant harvesting treatment and temperature interaction. The relative spear growth rate was higher under the normal harvest than the mother fern. Despite this difference the pattern of spear growth as influenced by temperature was similar for both treatments (Figure 4.1). The growth of spears was maximum at 30°C, but it declined as temperature rose to 35°C. The mother fern spears showed a marked reduction in the growth rate at the highest temperature compared to those under normal harvest.

The overall effect of cultivars was not significant, interactions between treatment and cultivars, cultivars and temperature were significant. This suggested that the cultivars' spear growth rate was not independent of either temperature and treatment. Figure 4.2 shows that spears from both cultivars did not grow as fast under the mother fern treatment as they did in the normal spring harvest. The cultivars' growth rates were 2.1% and 17% higher under the normal harvest for UC 157 and Jersey Giant than the mother fern culture.

Except at two temperature levels (15°C and 30°C) the growth rate of UC 157 was higher than that of Jersey Giant (Figure 4.3). The sensitivity to high temperature varied between cultivars. The relative spear growth rate of UC 157 begun declining earlier but gradually from 25°C and above, whereas that of Jersey Giant spears declined at 30°C and very sharply (Figure 4.3).

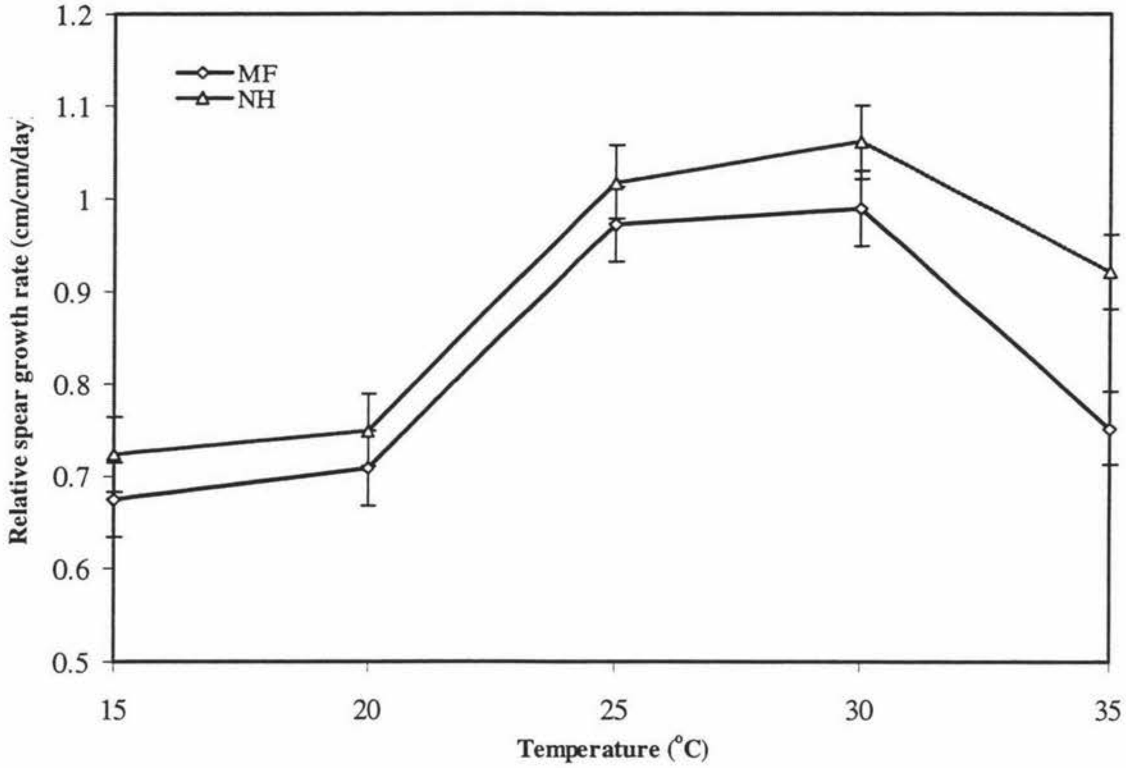


Figure 4.1 Relative spear growth rate (RSGR) given as a mean of harvesting treatments; normal harvest (NH) and mother fern(MF) and temperature.(Mean of two cultivars).

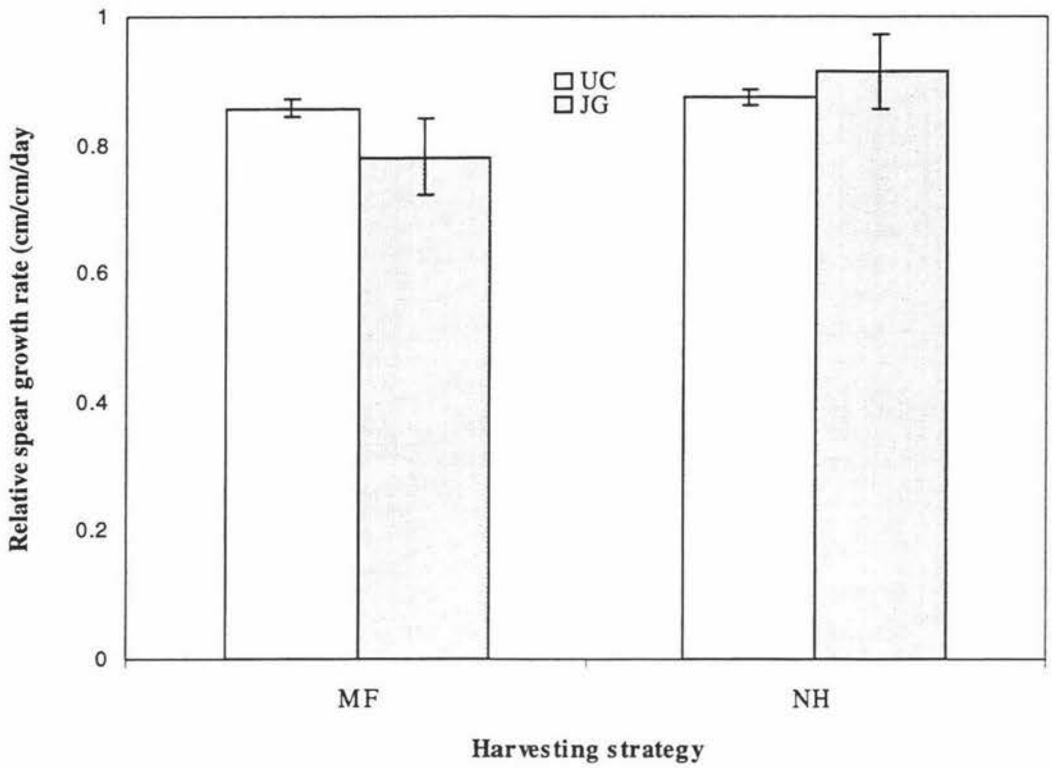


Figure 4.2 Relative spear growth rate shown in relation to cultivars; Jersey Giant (JG) and UC 157 (UC) and harvesting techniques; mother fern (MF) and normal spring harvest (NH). (Mean of five temperatures).

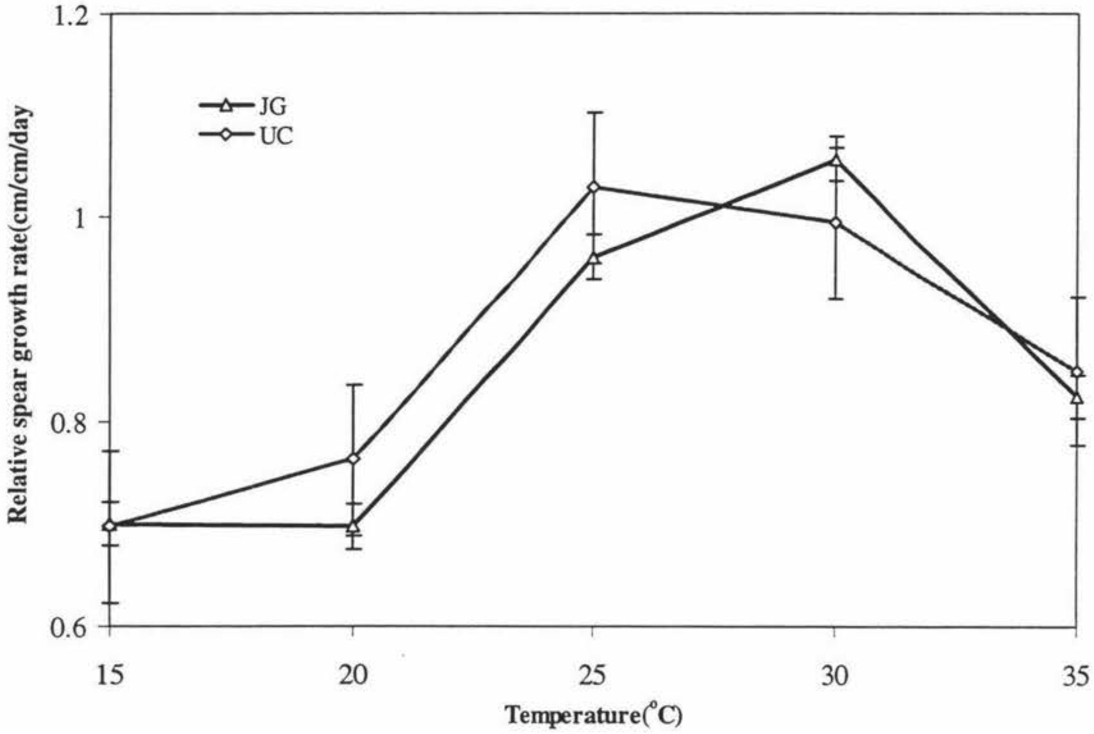


Figure 4.3 The influence of temperature on the relative spear growth rate of Jersey Giant (JG) and UC 157 (UC) cultivars.(Mean of mother fern and normal harvest).

4.3.2 Time taken to reach harvestable length

The results showed that the time taken by spears (from 10mm) to reach harvestable length (270mm) was influenced by temperature, treatments (harvesting system), cultivars and their interactions. Increasing temperature from 15°C to 35°C reduced the time to harvestable length, but its effect dependent upon cultivar and the system of harvesting. There was however, a slight increase in the time taken at 35°C.

Spears growing under the normal harvest reached the harvestable length earlier than those under the mother fern system (Figure 4.4). This supported the data (Figure 4.1), in which the growth rate of spears was higher in the normal harvest than that of the mother fern.
The faster growth of Jersey Giant spears resulted in less time taken to harvestable length compared UC 157. The exception was at the lowest temperature (15°C) in which UC 157 took less time than Jersey Giant (Table 4.2). A similar response occurred in both cultivars in which time to harvest increased at highest temperature (35°C).

Table 4.2 The length of time (in days, from 10mm height) to reach harvestable length (27mm) of two asparagus cultivar as influenced by air temperature.

	Number of days taken		
Temperature (°C)	**Jersey Giant**	**UC 157**	***SEM***
15	3.04	1.80	.24
20	1.36	1.62	.24
25	1.12	1.20	.24
30	1.02	1.05	.24
35	1.35	1.41	.24

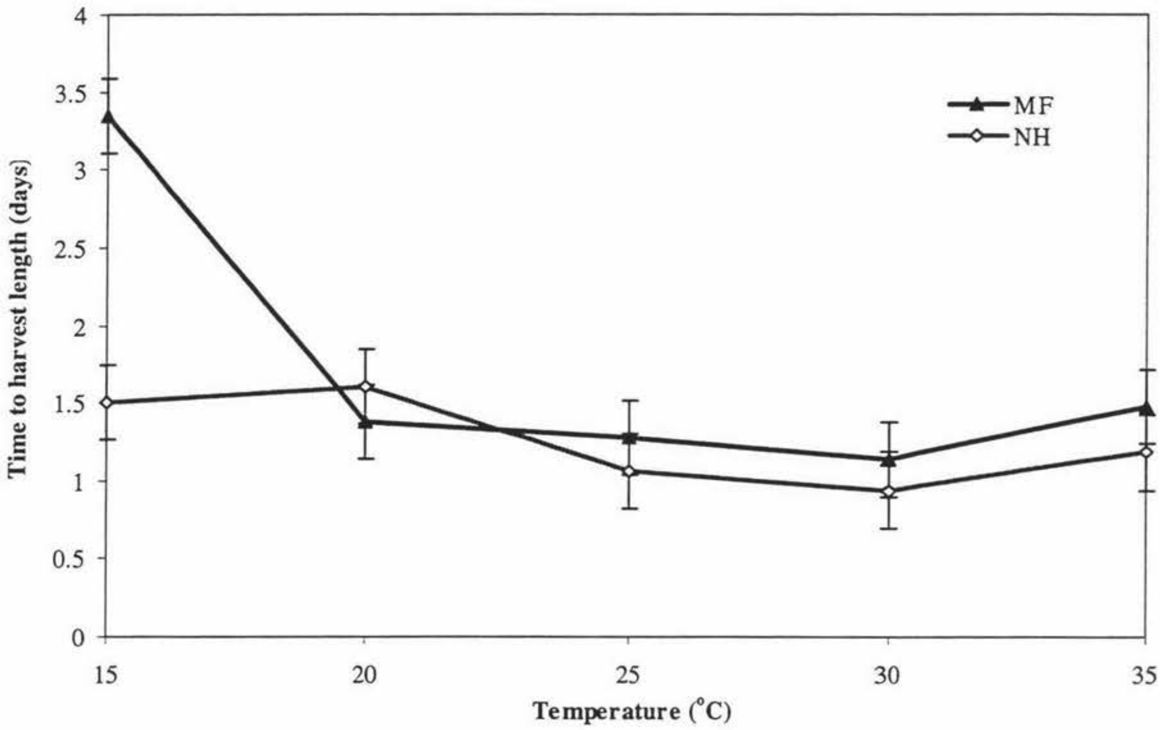


Figure 4.4 Time (days) taken by spears to grow to harvestable length (>220mm) as influenced by temperature and systems of harvest, normal harvest (NH) and mother fern (MF).

4.3.3 Spear production rate per plant per day (SPRPD)

The rate of spear production rate was determined as the number of spears produced per plant per day from the first spear emergence until the last day of harvesting (days). The rate at which spears were produced increased with rising temperature. However, there was a slight initial drop in SPRPD from 15°C to 20°C, following which it steadily increased to a peak at 30°C. Thereafter, SPRPD began to fall until 35°C was reached (Figure 4.5).

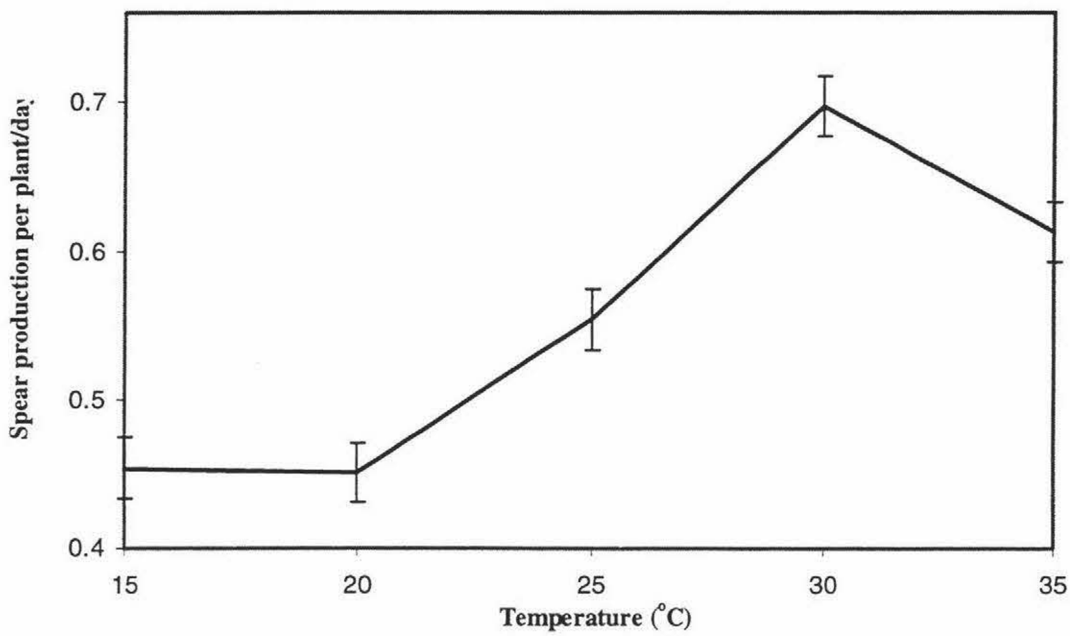


Figure 4.5 The overall effect of temperature on the rate of spear production per plant.

There was a highly significant difference in the rate of spears production between the harvesting strategies. The plants growing under normal harvest were more prolific in spear poduction than those under mother fern. The rate was 2.33 times higher in the former system than the latter system (Table 4.3).

Table 4.3 Spear production rate under the mother fern (MF) and the normal harvest (NH).

Treatment	Spear production per plant per day
MF	0.332
NH	0.776
SEM(7 df)	0.081

There was a significant treatment-temperature interaction. Apart from a drop in the spear production rate from 15°C to 20°C, the mother fern treatment consistently maintained an increasing production trend over the entire temperature range. On the contrary, SPRPD increased up 30°C but decreased as temperature rose to 35°C in normal harvest (Figure 4.6). The rate at which the normal harvest produced spears was higher than that of the mother fern at all the temperature levels.

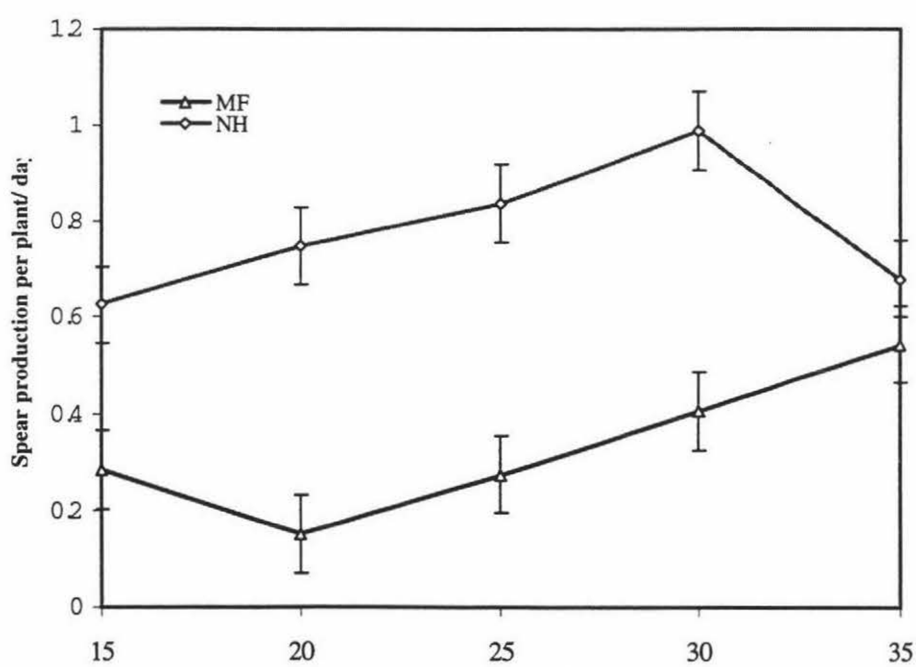


Figure 4.6 Comparison between the normal harvest (NH) and the mother fern (MF) spear production under different levels of temperature (Mean of cultivars).

4.3.4 The average basal diameter of spears (ASD)

The diameter of butts from the spear tip is a characteristic feature important for sorting and grading of spears into different sizes. The measurement of butt diameter showed significant treatment and temperature main effects but not for cultivar. Excluding treatment-cultivar, there were significant interactions between treatment and temperature, cultivar and temperature.

The average spear diameter (ASD) increased in both treatments with rising temperature but decreased at 20°C (NH), and 25°C (MF) (Figure 4.7). Generally, spears from the mother fern treatment were thinner compared with those from the normal harvest at levels of temperature except at 20°C. The highest ASD values recorded were 7.24mm (at 25°C) and 6.84mm (at 20°C) for the normal and mother fern harvesting systems, respectively.

The differences in ASD between the cultivars was influenced by temperature. When temperature was low (15°C) both cultivars produced thin spears, with Jersey Giant spears have been thinner than UC 157 spears. As temperature rose thicker spears were produced by both cultivars. The 20°C - 25°C temperature range produced relative thicker spears than any other range in both cultivars. However, while ASD stagnated between this range for Jersey Giant, that of UC 157 began to decline from 20°C (Figure 4.8). The ASD tended to increase as temperature approached 35°C in both cultivars.

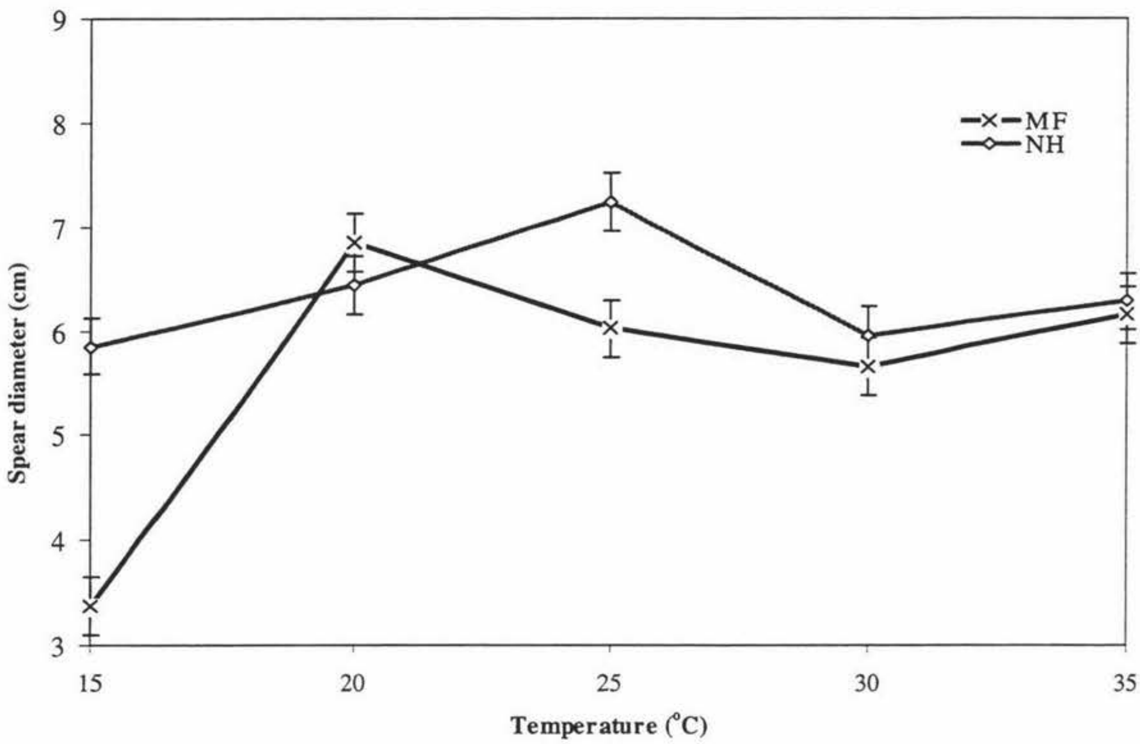


Figure 4.7 The relationship between temperature and harvesting treatments on the average basal diameter of spears. Treatments were normal spring harvest (NH) and mother fern harvest (MF).

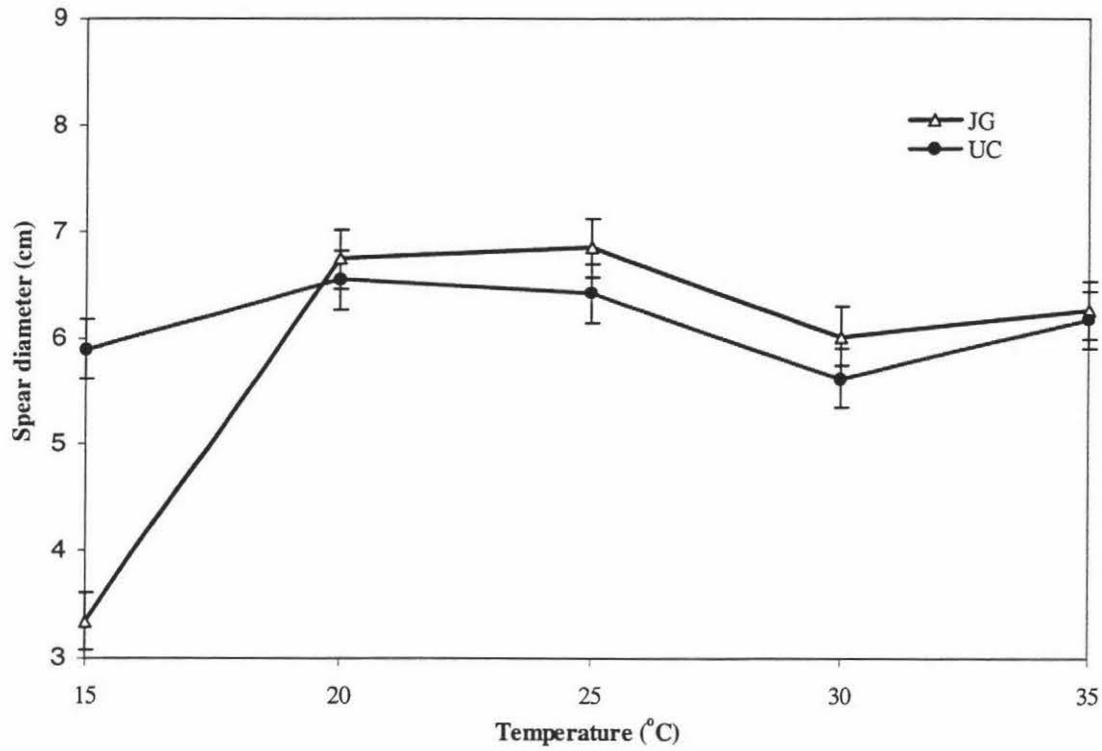


Figure 4.8 The effect of cultivars Jersey Giant (JG) and UC 157(UC) and temperature on average spear diameter of spears.

4.3.4 The growth of the mother ferns

The ultimate acquisition of a more or less constant maximum size during the growth of an organism denotes the asymptote. Following the fitting of Richard's growth function, Figures 4.8a and b were produced. They show a relationship between fern height (cm) and the time (or age of the fern), at different levels of temperature. The curves of plants growing at the optimum temperature range 25-30°C were higher than in other levels of temperature. An analysis of variance was performed to compare the asymptotic fern height of plants growing at different levels of temperature.

Both the main effects, temperature and cultivars and their interactions were significant. The final (asymptotic) height of UC 157 was higher than that of Jersey Giant at all temperature levels. Whereas, most of the asymptotic values were not more than 5.6, a large value was recorded for UC 157 at 20 °C. At the highest temperature (35 °C) the asymptote of both cultivars was low. In general, no distinct trend may be observed in relation to rising temperature (Table 4.4).

Table 4.4 The asymptotic height of fern growing at different levels of temperature.

Temperature (°C)	Jersey Giant	UC 157
15	4.9777	5.5777
20	5.2927	8.1574
25	5.2319	5.2650
30	5.2881	5.3067
35	5.1485	5.2054
SEM (df 5)	0.276	0.276

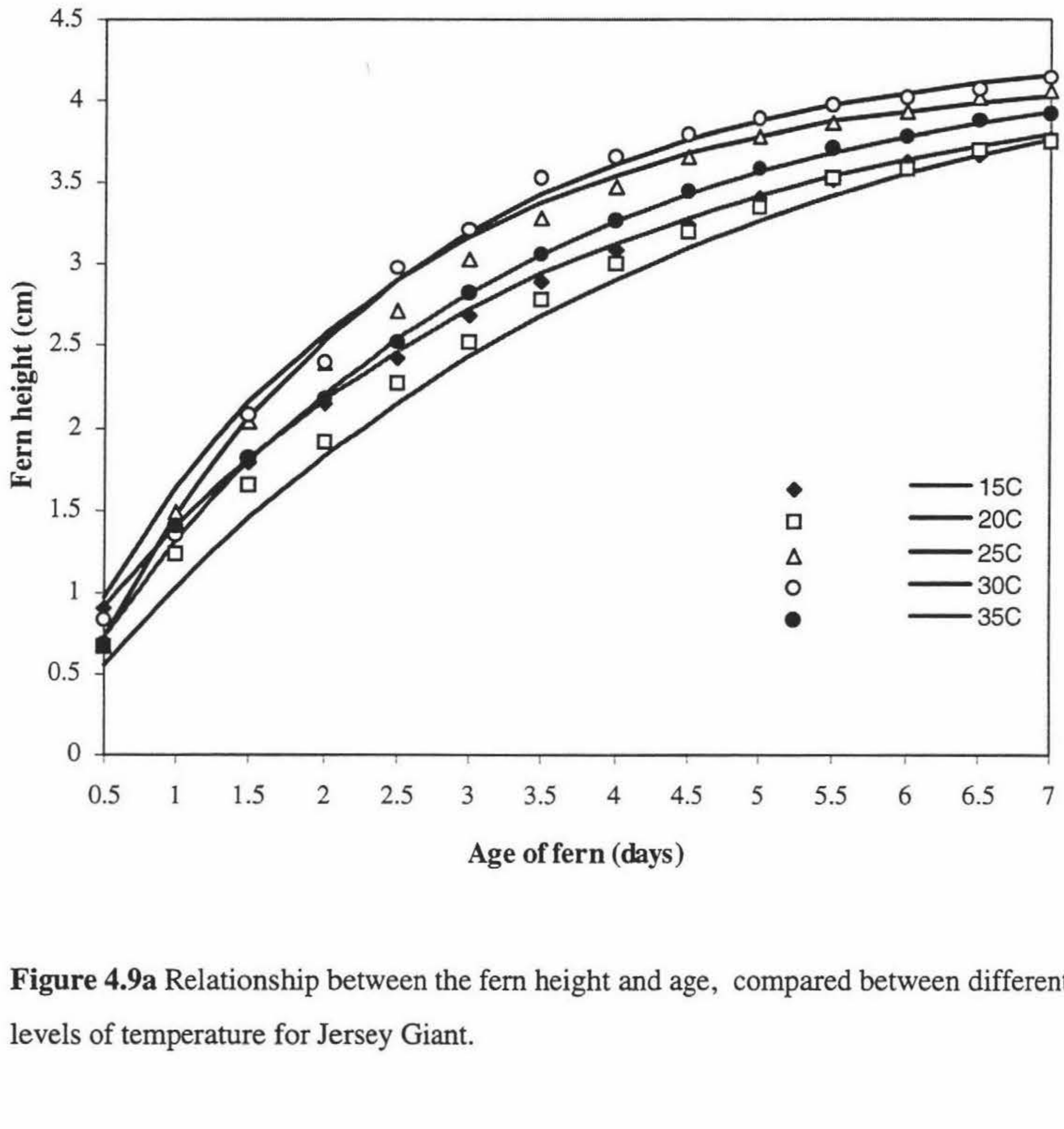


Figure 4.9a Relationship between the fern height and age, compared between different levels of temperature for Jersey Giant.

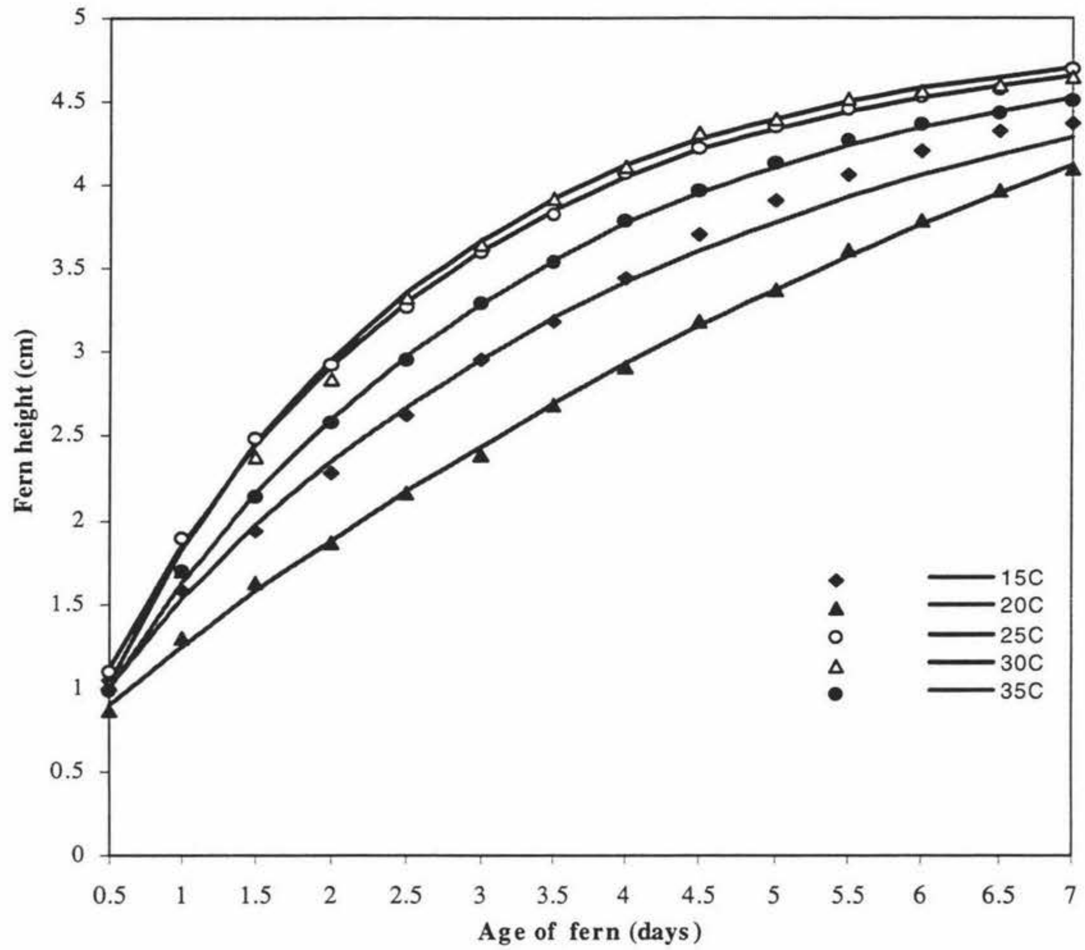


Figure 4.9b Relationship between fern height and age, compared between different levels of temperature for UC 157.

4.4 Discussion

4.4.1 The effect temperature on relative spear growth rate

4.4.1.1 Temperature response curve

The rate of spear growth showed a strong reliance upon air temperature. It increased with rising temperature from 15°C, but declined beyond 30°C. This pattern of growth conformed to the temperature response curve (TRC) which is similar in all plant responses to temperature (Heins 1990). TRC is characterised by: lack of, maximum and decreasing plant responses at base, optimum and superoptimal temperatures, respectively (Heins 1990; Salisbury and Ross 1992). The optimum temperature for growth asparagus is 25°C to 30°C (Nichols 1983; Robb 1984) and below the optimum range plant growth is slow (Heins 1990). These data (Figure 4.1) showed that the rate of spear growth increased with increasing temperature between 20°C and 25°C. The temperature above the optimal level reduced the spear growth rate. This was not unexpected because plant growth falls abruptly at superoptimal temperatures (Berry and Raison 1988). Although growth may be fast at high temperature, few plants grow properly above 30°C, particularly in growth chambers (Downs 1975). This notion was confirmed in the investigation carried out by Yen and co-workers (1996), in which 28°C was reported the most favourable regime for spear growth, whereas 33°C and 36°C reduced most of the measured growth parameters.

The order in which temperature enhanced the growth of spears was; 20-30°C > 30-35°C > 15-20°C, thus, even though the relative spear growth rate (RSGR) declined at high temperature it still remained higher than at the low level.

4.4.1.2 The physiological basis of spear growth dependence on temperature

Cellular aspects, such as cell division and elongation and physiological process such as photosynthesis, assimilate translocation, ion uptake and water absorption, which contribute to spear growth respond to changes in temperature, in a way which may alter spear growth .

(i) Cellular aspects of growth

Plant growth is manifested at the cellular level by relying on cell division. The latter process supplies unextended cells which ultimately increase in size and volume (Geiger and Sovonick 1988), which constitute growth. Geiger and Barlow (1988) described shoot meristems as populations of daughter cells which grow away from the parent cells following cell division. Thus, cell division is considered a limiting process for plant growth (Paul 1985). This contention has the support of Geiger and Sovonick (1988) who reported that low plant growth rate may result from: low rates of cell division and expansion, temporal cessation of cell production, production of small cells, and combination of one or more factors.

Evidence exists that the rate of cell division is highly regulated by temperature and the size of the genome replicated (Francis and Barlow 1988). In work involving flowering ornamental plants, Heins and Ewrin (1990) noted that plant height (the number and length of internodes) increases rapidly as temperature increases. The changes in temperature effect patterns of cell division and extension during growth which culminate in visible phenotypic modifications or plant form. For example, plants growing at low temperatures or climates have a small stature and have reduced leaves sizes compared to those growing in warmer temperatures, primarily due to reduced cell number but not cell size (Geiger and Sovonick 1988; Pollock and Eagles 1988). Clearly, temperature has a dominant effect on the way in which meristematic cells are organised in organogenesis.

From these conclusions, it was evident that the relative spear growth rate (RSGR) was altered in response to the surrounding temperature. In which case, RSGR was reduced at low- but increased at high temperatures.

(ii) Temperature effects on growth related physiological processes

The interrelationship between the growing temperature and physiological processes of photosynthesis, assimilate translocation, ion and water uptake plays a critical role in determining whether the growth of spears is fast or slow.

Berry and Raison (1990), Hendry (1987) and Pollock (1986) pointed that the overall process of photosynthesis shows temperature dependence, but responses vary among species. Photosynthesis provides the raw material (dry matter), which is the main constituent component of actively growing plant parts, thus, if it were to be inhibited, logically plant growth would as well be affected.

However, a link between spear growth and photosynthesis during normal harvesting is not a direct one. Spears draw their supplies from root stored carbohydrates reserved long before harvest. Hence, spear growth is supported by carbohydrates in the storage roots. Growth is likely to be affected if photosynthesis did not produce sufficient reserves in the previous season. Consequently, there is no relevance on the effect of temperature on photosynthesis under the normal harvest system during harvesting.

The presence of photosythetically active fern during the harvest season under the mother fern makes it possible that temperature may affect photosynthesis. However, no experimental evidence exists that shows how temperature and photosynthesis may affect the growth rate of spears. Conversely, it is known that the growth process is more temperature-sensitivity than photosythetic process. This suggests that spear growth is bound to respond quickly to changes in temperature prior to any detection of temperature effects on photosynthesis.

Plant growth rate depends on partitioning of assimilate between roots and shoots (Geiger and Sovonick 1990). The net partitioning of assimilates in the whole plants is influenced by temperature (Lloyd et al. 1988). For instance, compartmentation of carbohydrates in the vacuoles and metabolism of sink organs may be fast or slow depending on temperature (Farrar 1988; Lloyd et al. 1988; Pollock 1988).

Low temperature decreases plant growth through interference with carbohydrates metabolism. A series of events occur in response to temperature. These include, accumulation of non-structural carbohydrates because of more sensitivity of growth than photosynthesis to low temperature and differential sensitivity of carbohydrate metabolising enzymes; phloem transport is reduced due to the change in viscosity and displacement of the contents of sieve elements (Farrar 1988). The alterations of enzymatic response, transport of assimilates across membranes and limitations of diffusion may affect the import of assimilates by the sink organs (Lloyd *et al* 1988; Farrar 1988 and Pollock 1986).

The main constituent component of asparagus spears is sucrose. Therefore, it is likely that interference with its hydrolysis would limit RSGR. Unlike fructan synthesising enzymes (Sucrose-sucrose fructosyl transferase - SST and Fructan-fructan-fructosyl transferase - FFT) which continue to operate under low temperature, the activity of invertase for sucrose hydrolysis is reduced Pollock (1986). This evidence might explain the reduced RSGR at 15°C and 20°C in the present investigation. Studies with potatoes revealed that cooling increases the content of soluble carbohydrates and imparts sweetening to the tubers (Pollock 1986).

4.4.2 Temperature effect on harvesting strategies

The data (section 4.3.1 and Figure 4.1) indicated that the RSGR increased with rising temperature but it differed with respect to the system of harvest. The spears growing under the normal harvest (NH) grew faster than those under the mother fern harvest. It

was evident that retaining the fern (MF) during the harvest period contributed, in part or entirely low to a low RSGR in this system.
Possible explanations for different rates of growth rates between the two systems may relate to the differences in correlative inhibition, respiratory activity and or modification of the growing environment.

(i) Correlative inhibition

In work involving asparagus seedlings, Nichols and Woolley (1985) reported the following observation:
(a) A 12- hour difference in the initiation of growth by buds led to a very slow growth of the late emerging spears until the earlier spears were removed.
(b) Simultaneously produced spears had a similar growth rate, but that of other spears on the same crown was extremely slow until the first spears were removed.

Thus, in asparagus crop where the growth of shoots follow a definite order, the presence of apical dominant fern or spears might have led to the suppression in growth of subsequently formed shoots (Hughes 1993; Falavigna and Nichols 1995).

The work of Dedolph and others (1963) in which asparagus spears were decapitated resulted in reduced growth rate, but application of Naphthaleneacetic acid (NAA) stimulated it. This suggested that in intact spears the endogenous growth regulators, probably auxins increase with spear growth (Yen 1993), and promotes apical dominance, which inhibits rapid growth of subsequently produced shoots. Conversely, in the normal system the periodical removal of ready-to-harvest spears implied that apical dominance was not maintained for longer periods.

However, temperature appears to have had an overriding influence on RSGR than correlative inhibition, since RSGR (MF) increased with rising temperature. For example, spears growing at high temperature (30°C) grew faster to reach the harvestable length earlier than spears growing at lower temperature (Figure 4.1 and Table 4.2).

(ii) Respiratory activity

Competition occurs for the use of stored food reserves between the processes of respiration and growth. It has further being reported that respiration and photosynthesis proceed simultaneously but in opposite directions and their rates are affected by temperature (Butt 1968).

Respiration contributes to large losses of storage sugars resulting from photosynthesis (Benson 1995; Hughes *et al* 1990). The amount of energy expended on respiration is large as temperature increases. Thus, for spears growing at higher temperatures assimilate partitioning would seem to be diverted to respiratory maintenance to the detriment of spear growth. Whereas at low temperature correlative inhibition may be a dominant factor than the rate of respiration.

Two factors account for differences in the respiratory activity between the MF and NH, gas exchange properties of the aerial tissues (fern and spears) and surface area of the respiring tissue, namely. The asparagus fern exhibits a higher respiring surface area and gas exchange properties than the spears. Spears have a low density of stomata, which increases resistance to gas exchange and lead to between 50-100% reassimilation of the respired CO_2 (Downtown and Torokfalvy 1975). In contrast, the fern has both a large respiring surface area and good gas exchange properties, hence it loses most of the respired CO_2.

Hughes *et al* (1990) interpreted that relative growth rate of asparagus plants growing between 10°C and 20°C was reduced because night respiration was more important than light/photorespiration.

(iii) Modification of the growing environment

An early report by Wang (1965) indicated that asparagus mother fern blocks the sunlight and moderates (lowers) the soil temperature especially during sunny days. This was considered ideal for spear elongation and quality. Since this early report no investigations appear to have been done in this area. However, one would expect that shading could lead to etiolation or poor colour development of spears beneath the canopy ! In which case, the etiolated spears could resemble white asparagus spears, which have a lower ABA and IAA levels than green spears (Makus and Quinn 1992). Hence, the high IAA levels found in green spears is consistent with their greater elongation than white spears (Mukas and Quinn 1992).

However, the environment beneath the growth cabinets is comparable to field conditions and spear colour did not appear different between the two systems. Therefore, modification of the growing environment by the fern seem too remote to explain the differences in RSGR between the two systems.

4.4.3 Spear diameters

In this investigation, the average spear diameter was less that 10mm, which is -depending on market specifications - a minimum diameter size recognised for fresh export. Thin spears are undesirable for two reasons. First, peeling of thin spears is more difficult compared to thick spears (Poll *et al* 1990). Peeling is commonly done in white asparagus to remove the fibre from the product to make it edible, but it is not applicable to green asparagus. Secondly, price is positively related to spear diameter (Poll *et al* 1990) and too great proportions of thin spears have little value (Wood 1980).

Thinner spears were produced by the crop under the mother fern compared to the normal harvest. In the optimum range of temperature (25-30°C), Jersey Giant spears were thicker than those of UC 157. The age and growing conditions were possible reasons for the differences in ASD between the treatments and temperature levels.
The plants used in this investigation were only one-year-old, thus they had not reached full genetic potential. According to Hartmann and Co-workers (1987) evaluation of young asparagus plants may be done to a limited extent until they have reached full genetic potential, which is after the third year of harvest. Secondly, restriction of root

volume and the planting depth by the containers might have had a negative bearing on the spear size. A large root volume is essential for increased storage of food reserves whereas deeper planting reduces spear number, but increases spear weight and diameter (Takatori *et al* 1974). This has the support of previous work done by McCormick and Thomsen (1990). They reported a 20% spear number reduction and an increase in spear weight by an equivalent amount. Therefore, 10*l* pots used in this investigation might have too, restricted root growth and planting depth.

In view of growing conditions, thin spears obtained in this study resemble those of a forced asparagus crop. In their investigation involving forced asparagus plants in the Netherlands, Poll *et al* (1990) observed that the bulk of spears produced were between 10-16mm and very few exceeded 16mm. However, no reasons were suggested .

Besides environmental factors spear diameter may be influenced by, cultivar, plant sex, plant density and the number of spears produced per plant. Cultivar differences are notable between F_1 Hybrids and open pollinated cultivars, in which case in the latter's spear size is more variable as compared to the former.

In relation to plant sex, male plants produce a large number and thinner spears than female plants (Moon 1976; Castanon 1990). In addition, mean spear diameter is negatively correlated with number of spears per plant (Ellison *et al* 1959), thus increasing spear number decreases mean spear diameter (Greiner 1990).

On the other hand, increasing plant density increases the number of spears produced but both the weight and the diameter of spears decline (Takatori *et al* 1975), probably due to interplant competition. It is also thought that thinner spears may result from low levels of root storage carbohydrates as observed from spears produced at the end of the harvest season. It is possible that formation of new roots and buds (Plate 2a,b) in the mother fern had a negative effect on reduction of spear diameter.

4.4.4 Spear production rate per plant

The spear production rate per plant per day (SPRPD) rather than the number of spears per plant was used to make comparisons between treatments, temperature and cultivars. This was meaningful than spear number because of the different duration of running the experiments (Table 4.1).

The overall effect of temperature led to an increase in the SPRPD. However, the rate at which spears were produced was influenced by the treatment as indicated by a significant treatment-temperature interaction.

The results showed :

(a) Increased SPRPD with rising temperature in both treatments,

(b) Higher SPRPD in the normal harvest than the mother fern, but there two were exceptions. The SPRPD decreased in the mother fern treatment from 15-20°C, whereas this occurred at the higher temperature range (30-35°C) for the normal harvest. The higher SPRPD from the normal harvest than the mother fern confirmed earlier reports. It is generally agreed that the rate of spear production under the mother fern system was less concentrated than that of the normal harvest (Hung 1980; Benson 1995). It is postulated the mother fern produces auxins from the apical portion, which are translocated to the crown and retard the growth of buds into spears (Benson 1995; Robb 1983).

On the other hand, removing apically dominant spears triggers the growth of new buds. Bouwkamp and McCully (1975) noticed that cutting spears longer than 3-5cm stimulated a new flush of buds. Therefore, cutting apically dominant spears enhanced frequent spear emergence in the normal harvest at rate a higher than in the mother fern, probably due to having retained the fern longer than spears.

Though SPRPD increased with rising temperature, there was a fall at 20°C from 15°C in the mother fern treatment. This was unexpected because warm temperature should have enhanced the rate of spear production more than low temperature. For instance, at the 20°C in which SPRD fell, previous work by Hughes (1993) showed a continuous pattern of budbreak for Rutgers Beacon, Jersey Giant and UC 157. The last two cultivars were used in the current investigation. Therefore, it was presumably due to individual plant differences (number of buds per plant, sex of the plant, etc.) than treatment or temperature effects which effected this irregularity.

An interesting pattern was observed at higher temperature (30°C and above), in which the mother fern's SPRPD continuously increased while that from the normal harvest decreased. It was probable the normal harvest's depression was caused by its inability to rejuvenate carbohydrate reserves such that the depletion rate was accelerated at higher temperature by fast growing spears, or perhaps increased respiration losses. According to Yen (1993) higher temperature may stimulate photosynthesis slightly, but it has a negative effect of speeding plant development, senescence and shortening the duration of plant growth to the detriment of the yield.

4.4.5 Fern growth

The growth of the mother ferns showed response similar to that of spear growth to temperature. Low temperature below 20 °C was not effective for enhancing the elongation of the fern as compared to temperature between 25 °C and 30 °C. The reduced Relative fern growth rate in temperature levels outside this range is indicative of reduced crop performance, probably due to negative effects of both low or high temperature. Low or high temperature may disrupt the metabolic processes of the plant, which may be translated into visible symptoms such as reduced growth rate. The responses to temperature differed between Jersey Giant and UC 157, suggesting the importance of genotype to adaptation to extremes of temperature.

In a recent investigation, in which asparagus plants were grown at high temperature, Yen *et al* (1996) reported that fern diameter, individual fern dry weight and total fern dry weight were depressed by high temperature. Asparagus plants grown at high temperature show a rapid growth rate, short elongation period, which results in small size of fern at maturity (Yen *et al* 1996).

CHAPTER 5

POSTHARVEST SHELF LIFE EVALUATION OF ASPARAGUS SPEARS

5.1 Introduction

Freshly harvested asparagus spears deteriorate rapidly and become unsaleable after 5 days at shelf temperature of 20°C (King *et al* 1993) or 3-5 days at ambient temperature (Lipton 1990). This rate of deterioration is 15 times higher than that of apples (Gariepy *et al* 1991). This is a cause of great concern in the product marketing chain particularly during shipping to distant markets. For instance, the low cost of sea freight for fresh asparagus exports to Japan and U.S.A. from New Zealand cannot be exploited (Lill 1980; King *et al* 1986). While air freight may be faster, temperature fluctuations in transit accentuate the rapid deterioration of fresh asparagus (Lill 1980). Conversely, deterioration is of little or no concern if spears are utilised immediately after harvest, and are not intended for storage or marketing (Lipton 1990).

Several physiological changes occur after harvesting of asparagus, which in part may account for its rapid deterioration. Early metabolic stress symptoms occur when the spears are cut because of an interrupted flow of water and nutrients from the crown (King *et al* 1990; Lill *et al* 1990 and Lill *et al* 1994). These symptoms include: reduced respiration rate; loss of soluble carbohydrates; changes in the pools of amino acids and major changes in the protein content. In addition to flavour deterioration, harvested spears lose chlorophyll (green spears), ascorbic acids (Lipton 1990) and cellular integrity (King, *et al* 1990). They become flaccid and susceptible to diseases (King *et al* 1993). Toughening occurs due to lignification in the fibre ring and vascular bundles (Chang 1985 and Lipton 1990).

Spears deteriorate faster at high than at low temperatures, hence, cooling is recommended immediately after harvest to remove field heat. High temperature enhances the rate of respiration, thus, the depletion of carbohydrates in the spear. This in turn accelerates loss of quality because perishability of harvested produce is generally proportional to the respiration rate and temperature (Kader 1992). It relates in part to the tissue type of the organ (Lill *et al* 1990). Although respiration rate of the spears declines after harvest the exposure of spears to high temperature might still enhance respiration and the activity of degrading enzymes.

Salveit and Kasmire (1985) found that the loss of soluble carbohydrates was in line with the rate of respiration and more sucrose loss occurred in the apical than either the mid or basal tissues of harvested spears. Spears tips consist of immature, actively growing tissues and are the first part to show deterioration symptoms (Hurst *et al* 1993a). Moreover, the compactness of spear tips affects the storage life of asparagus. Spears with compact heads store better than those with open loose tips (Barker and Morris 1936; Lipton 1968; Hurst *et al* 1993b).

Besides temperature and tip quality, harvest date may affect the postharvest shelf life of spears. Late-season harvested spears have only half the shelf life of early-season spears because of the decline in spear weight (Hurst *et al* 1993b). Although, the latter reported that there was a constant level of carbohydrates in spears throughout the harvesting season, it is well known that during late season spears get thinner possibly due to low level of root reserves or small sized buds.

The objectives of the this study were:

i) To investigate the effect of temperature and harvesting system (mother fern versus normal harvest) on the spear shelf life, and

ii) To determine the effect of harvest date on postharvest shelf life between early and late harvested asparagus spears.

The null hypotheses were:

There is no difference in the postharvest characteristics of UC 157 and Jersey Giant, of production temperature, of spears produced by mother fern and normal harvest and of early and late harvested spears.

5.2 Materials and Methods

5.2.1 Introduction

The spears of cvs. UC 157 and Jersey Giant grown at 20°C, 25°C, 30°C and 35°C were harvested and trimmed to 220mm. Spears were selected based on: straightness, tight tips and the absence of morphological defects and physical damage. The minimum basal diameter was 8mm because most spears produced were thinner than 10mm.

Trimmed spears were placed in transparent, unperforated polythene bags, to help to reduce water stress (Hurst *et al* 1993). Rubber bands were used for closing the open ends. Bags were transferred into a modified incubator set at 20°C, without lights although, neither light or dark storage conditions is considered to have an affect on the shelf life of asparagus spears (Hurst *et al* 1993). Spears were stored separately according to harvesting treatments and temperature level.

The harvest quality was based on a sensory assessment (performed daily) of the physical condition/appearance. An ordinal scale, with values representing the stage of spears' deterioration was used as described by Lill (1980) (Table 4.5). The limitations due to suitable spear production led to a sample size of ten spears, in which case each spear was considered as a replicate. Comparison between early and late harvested spear was not feasible, due to the limitation of spear production.

Table 5.1 An ordinal scale for visual assessment of spears.

Score	Description
1	As fresh
3	Slight wilt, very slight wrinkle on stem.
5	Browning of stem bracts, more pronounced wilting but still saleable
7	Soft rots starting to develop, some browning of spears, wilting and feathering of bracts, occasional spears with stem collapse, unsaleable.
9	More extensive rotting and stem collapse, bad wilting, browning of spears, unsaleable

Source: after Lill (1980).

5.2.2 Data analysis

The number of days it took the spears to reach score 5 was determined. The latter was considered as the cut off value from and beyond which spears were considered unsaleable, though still edible.

The number of days to score 5, were determined by fitting an equation of a straight line to raw data of individual spears. This done because plotting the scores against storage time (in days), gave a linear phase from the end of score 1 (which had lag phase) to score 9. Thus, in the following equation:

$$Y = a + bx \qquad (1)$$

the time to score 5 was determined by re-arranging the equation as:

$$x = (Y - a) / b$$

Where: x = Time

Y = Score 5

a and b = constants.

An analysis of variance (ANOVA) was performed to determine differences in the storage time between temperatures (20, 25, 30 and 35°C) and harvesting strategies (normal and mother fern harvest). Data from 15°C was omitted from the analysis because Jersey Giant did not produce any acceptable spears (Table 5.1). A Proc GLM of SAS for unbalanced design was used , due to unequal number of spears obtained.

Table 5.2 The number of suitable spears obtained for postharvest shelf life evaluation.

	Normal Harvest		**Mother fern**	
	Jersey Giant	***UC 157***	***Jersey Giant***	***UC 157***
Temperature (°C)				
15	-	10	-	7
20	10	3	10	10
25	9	10	10	10
30	6	3	7	9
35	9	3	9	8

5.3 Results

Besides a significant (P<0.05) cultivar and cultivar-temperature interaction, temperature, harvesting treatment and their interactions had no effect on the storage life of asparagus spears. Generally, it took up to seven days for spears to reach the cut off limit. However, differences occurred between cultivars.

The spears from Jersey Giant stored a day longer than UC 157 (that is, seven compared to six days) to reach an unsaleable condition (Score 5).There were, however no distinct trends in both cultivars in response to temperature in the spears were produced. For instance, except at 30 °C in which in took eight days to reach unsaleable condition, seven days were recorded for 20 °C, 25 °C and 35 °C for Jersey Giant. The shelf life of UC 157 spears growing at 25 °C and 30 °C were slightly reduced (one day) as compared to the seven days taken by spears growing at 20 °C and 35 °C.

Table 5.3 Number of days taken (shelf life) by spears at 20°C to reach a score of 5 as influenced by cultivar and growing temperature.

Growing Temperature	**Cultivar**	
(°C)	***Jersey Giant***	***UC 157***
20	7.6	7.4
25	7.3	6.4
30	8.3	6.3
35	7.1	7.2
SE	0.35	0.35

5.4 Discussion

Appearance (colour, size, shape, gloss, defects), and along with flavour, texture, and nutritive value influences product acceptability and marketability. For instance, commodity appearance is considered most important by produce distributors, whereas consumers base their purchases on appearance and feel (Kader 1985). Invariably, the visual appearance of asparagus at the point of sale is very important and the ratings for appearance largely govern useful storage life (Lill 1980). Thus, subjective sensory evaluation provides a useful information indicative of commodity shelf life especially in circumstances where carrying out objective measurements may not be feasible.

In this investigation the shelf life of asparagus was based on a sensory evaluation to determine the influences of temperature, harvesting systems and cultivars. The results showed that neither the growing temperature nor the system of harvesting (normal and mother fern) had effect on the storage life of spears. The cultivars differed only slightly, and did not show marked influence of growing temperature on shelf life.

Storage temperature and containers for storing asparagus influence its shelf life. It is feasible to store fresh asparagus spears in unperforated plastic bags for 4 weeks at 2-4C (Lill 1980). However, as temperature increases storage life decreases. For instance, using similar packaging materials spears could only be effectively stored for seven days at 20C in this investigation.

The first visible symptoms of spear deterioration in this study were observed from the basal region. The symptoms were manifested as small longitudinal wrinkles, which later extended upwards towards the spear tip. However, the spear tip did not show rapid deterioration as the rest of the spear did. Perhaps this was influenced by tip quality prior to storage and the use of unperforated plastic bags. For instance, it is generally agreed that spears with tight heads store longer than those with loose heads. Secondly, unperforated plastic bags create a substantial barrier for gas exchange between the produce and the surrounding air, in a manner which delays opening of spears bracts. Although perforated bags were not used in this investigation, in an earlier study, Lill (1980) found that rapid water loss in perforated bags led to feathering of the bracts and wilting of spears. Thus, it was concluded that the type of packaging material had an influence on appearance, in which case, the appearance was poorer for spears stored in perforated than unperforated bags.

The findings from this investigation should be considered inconclusive because the harvesting treatments were not of a sufficiently long duration to detect long term effects of changes in the level of root storage carbohydrates between the harvesting systems. Furthermore, the inability to secure sufficient quality spears may have impaired the precision of the experiment.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS FOR FURTHER WORK

6.1 Asparagus harvest season

Fresh asparagus is in demand all year round, but it is mainly supplied in spring from the temperate regions. Spring harvest appears preferable to either summer or autumn harvest. The reasons are, concentrated spear production and high yield, low costs, since spring rain supplies adequate moisture and irrigation is often not required. Pests and diseases problems may be low compared to summer and autumn.

Conversely, attempts to extend the normal spring harvest, in the short term, reduce the fern growing period. As a result yields may be low in the next season due to insufficient accumulation of storage carbohydrates. The long term effects lead to weakening of plants, reduction of crop stand and premature economic loss of commercial plantings.

6.2 Asparagus mother fern

The potential of the mother fern system to extend the harvest season was evaluated in the field and in controlled climate rooms. Crop performance was reduced under both growing conditions by using mother fern system compared to normal harvest.

In field the experiment, a normal spring harvest produced thicker and heavier spears than the mother fern. This might have explained the higher total -, marketable -, and cumulative yield of the normal harvest. The mother fern produced thinner spears, which were mostly seedy.

The study in controlled climate growth cabinets, showed that spear elongation depends on temperature. However, the relative spear growth rate was dependent on the system of harvest. Spears grew faster under normal than mother fern harvest. Fast growing spears reach harvestable length earlier. This stimulated a flush of new spears as the apically dominant spears were harvested. Thus, spear production rate per plant was higher for normal harvest than mother fern system. The average spear diameter for the mother fern system was lower than for 'normally' harvested plants.

Correlative inhibition and increased respiration by fern, and the formation of new roots and buds observed in the mother fern are possible reasons for the reduced overall performance of the mother fern system. In the field, the effect of these factors might have interacted with low moisture and temperature (late summer to early autumn) to accentuate a reduced performance of the mother fern system.

Selection of cultivars with high yield and quality of spears is critical for use with mother fern system. Despite mother fern having yielded lower than normal harvest, UC 157 had higher total -, marketable -, and cumulative yield than Rutgers Beacon. The spear quality (closed tips and thick diameter) were produced by UC 157, whereas Rutgers Beacon's spears were thinner and seedy. In controlled climate growth cabinets, Jersey spears grew faster than UC 157, and its spears were slightly thicker. There were no differences in the storage life with regard to growing temperature, cultivar, and system of harvest.

Extending the harvesting using mother fern is possible, but several reasons may account for its being economically not feasible. Fertiliser application, thinning, staking, fern renewal involve additional input costs compared to normal harvest. The low yield of the mother fern system compared to the normal spring harvest implies less economic returns.

6.3 Recommendations for future work

In this research work, the field experiment did not involve irrigation. In New Zealand, moisture stress may occur in the summer. Moisture stress would likely affect photosynthesis, nutrient absorption and partitioning of assimilates of mother fern. The fern is also liable to lose more water through evapotransipation. Therefore, investigations are required to examine the performance of mother fern under irrigation.

Trimming the fern as was done reduced apical dominance, but recent reports from the tropics discourage this practice. Further work with mother fern should consider the use of supports (stakes) only, instead of trimmimg the fern.

Studies are required to determine whether the formation of new roots and buds during the harvesting period depresses spear production and contributes to thinner spears by mother fern. Finally, a combination of mother fern and normal harvest at the completion of normal harvest in mid-December, may be worth investigating, as means of extending the harvest, while still obtaining the high yields from the normal spring harvest.

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Plate 1. A field experiment, showing plots for the normal spring harvest (bareground) and the mother fern treatments (with fern). The poles and a double wire line were used to support the mother fern.

Plate 2 (a). New roots and buds were formed (1st and 2nd rows from top) from UC 157 (blue labels) and Jersey Giant (yellow labels) under the mother fern system, but not under the normal harvest.

Plate 2 (b). A close view of newly formed roots and buds. The two stumps show positions of the mother ferns after being cut.