THE EFFECTS OF PRODUCTION TECHNIQUES ON THE YIELD AND QUALITY OF SOME LEAFY VEGETABLES

Submitted by

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DEDICATED
TO
MY MOTHER - IN - LAW

Mrs. Davinder Kaur

I certify that the thesis entitled **THE EFFECTS OF PRODUCTION TECHNIQUES ON THE YIELD AND QUALITY OF SOME LEAFY VEGETABLES** and submitted for the degree of **MASTER OF SCIENCE** is the result of my own research, and this thesis or any part of this thesis has not been submitted for a higher degree to any other university or institution.

Signed: [redacted]

Date: 17.12.97

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SUMMARY

An opportunity exists for Australia to satisfy the expanding Asian fresh produce markets, because of our climate, space and technology to expand and enhance production of fruit and vegetables. Growers always strive to obtain maximum yields of high quality produce from their fields. Many factors such as climate, suitable cultivars, cultivation practices, soil, availability of water and nutrients can influence yields of high quality produce. An important and effective method to reduce costs is to improve productivity while maintaining quality.

East Gippsland, the focus of this study, has a significant opportunity and potential for the production of fresh whole and fresh - cut packaged, branded vegetables for the domestic and export markets.

The aim of this research was to investigate the effects of current irrigation practices on overall yield and the occurrence of hollow stem in broccoli and to compare the outcomes from different irrigation systems.

Trials were conducted in the first year (1993 / 94) over three different seasons: spring, summer and autumn to identify the effects of seasonality and irrigation (amount of water volume applied), as well as nutrient uptake on broccoli hollow stem using the same cultivar (Marathon). In the second year (1995), trials were extended to three different irrigation systems i.e. drip irrigation, fixed overhead sprinklers (new to the region) and travelling irrigator (currently used by most of the growers). The yield, quality and hollow stem rating used three systems of irrigation were compared .

Results showed that the amount of water delivered to individual plants throughout the crop during irrigation was very uneven and that many plants were either under - watered or over - watered. Excess watering exacerbated both hollow stem and boron deficiency, which has been identified as a factor in promoting hollow stem. Nutrient uptake by plants was affected by the soil type and amount of water delivered. The results also showed the strong effects of different seasons on the occurrence of hollow stem in the same cultivar with summer being the worst season for hollow stem occurrence and severity, probably because this led to most rapid growth and exacerbation of underlying nutrient deficiencies.

Drip irrigation showed many benefits over the travelling irrigators. An important advantage of drip irrigation is water saving and ultimately reduction in cost.

Results of trials also showed that tensiometers, which are cheap, easy to install and cost effective to schedule irrigation, are an effective tool in achieving goals of better productivity and higher quality. In conclusion, it would appear that after scheduling irrigation and evaluating soil type, a perspective to apply water at a frequency and amount which generates the maximum harvestable yield and quality of crop can be developed.

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1. INTRODUCTION

Vegetable production is one of the major branches of horticulture. Australia has the climate, space, labour, capital and technology to expand and enhance production of many types of vegetables and fruit. Australia's location in the southern hemisphere, which leads to an unusual seasonality for most horticultural products, provides an opportunity to supply fresh produce to world markets in the northern hemisphere during their off season. Furthermore, Australia is close to an expanding Asian market with booming economies.

The total value of Australia's fruit and vegetable exports is small compared with that of many of its competitors and potential competitors, many of which are southern hemisphere countries. Reasons advanced to explain the perceived poor performance of Australian horticultural produce on exports markets include product perishability, low levels of commitment to export within industry and inadequate and unreliable transport services.

Victoria is the second largest producer of vegetables in Australia, behind Queensland (ABS, 1991). In 1991, the gross value of production of Victorian vegetables made up 26% of Australia's $ 1,413 m gross value of production of vegetables with Victoria's vegetable exports worth only $10.7 m or 15% of the total value of Australian vegetable exports (ABS, 1991). Vegetables are grown throughout the state with nearly half the production within 100 km of Melbourne. The other major vegetable producing districts are East Gippsland, Central Gippsland, Sunraysia, Goulburn Valley and along the Murray river areas with smaller volumes grown in Central Highlands and Central Gippsland areas (ABS, 1991).

East Gippsland, which is the focus of this study, has three major production areas centred on the Mitchell River at Lindenow, Snowy River at Orbost, around Maffra on the Avon River and the McAlister Irrigation Scheme. The mild climate resulting from its coastal location with relatively cool summers and mild winters makes the area suitable for growing a wide range of crops over extended periods (Belder, 1985).

A major impetus for the development of the vegetable industry in East Gippsland was the establishment of Gardenland Frozen Foods in 1985 which was subsequently

sold to Edgell - Birds Eye in 1988. Vegetable production grew rapidly from 728 ha in 1984 to 3, 929 ha in 1990/91, (ABS statistics, 1990/91).
The closure of the Gardenland plant in Bairnsdale in 1992 provided both a threat and an opportunity to growers and related industries in the region. A study commissioned by the East Gippsland Vegetable Industry Board (EGVIB) from Boston Consulting Group (1992) identified a number of factors responsible for inhibiting the vegetable industry in East Gippsland from becoming world competitive including: size of individual farms, irrigation, transport and handling procedures, post harvest crop care, yield and poor understanding of market chain. This study also showed that a significant opportunity existed in the region for the production of fresh whole and cut packaged - brand vegetables for domestic consumption and export.

The Boston Consulting Group study (1992) identified the need for a research and development program which was established by the EGVIB. The main objective of the EGVIB board was to provide a market - focused and commercially driven research and development program that ensured a competitive edge and the long-term survival of the vegetable industry in East Gippsland. A fresh vegetable company VEGCO Ltd, directly associated with this board has focused on marketing whole and precut produce such as broccoli, lettuce etc. for domestic and export markets.

One of the most effective methods for reducing unit costs of fresh produce is to improve production per hectare (i.e. productivity) whilst maintaining quality. One potential area for achieving this is via irrigation type and schedule. Currently travelling irrigators or movable pipes are used by most growers in the East Gippsland region. Although growers shifted from flood irrigation to overhead watering, there is still a potential wastage of about 50 - 70% of water applied (Bogle and Hartz, 1986, Locascio *et al*, 1985). Furthermore, current irrigation scheduling is mostly guesswork which appears to alternate between flooding and droughting. The aim of this study was to investigate the effect of current irrigation practises on the yield and quality of leafy vegetables - Broccoli and Lettuce.

In 1992, some of the agricultural issues of economic importance that affected the East Gippsland region are:

1. A large amount of broccoli is affected by hollow stem.
2. Over 10 - 20% of the lettuce crop is affected by "head rot".

3. There is concern over water use and water could become scarce in the future.

It has been found that these physiological disorders such as hollow stem in broccoli and head rot in lettuce are induced by nutrition deficiency (see literature review). Discussions with a number agronomists (Jeff Billing - Henderson seeds, Mike Meyer - SPS seeds and Dan Timboli - Yates) suggested that these disorders along with nutrition deficiency are probably exacerbated by local practices of current irrigation. This thesis has investigated the effect of irrigation on nutrient uptake and hollow stem in broccoli and head rot in lettuce. The study focused on three broad aspects:

1. The effect of volume of water on yield and quality of broccoli.
2. The effect of different irrigation systems on yield and quality of broccoli.
3. A preliminary investigation of the effect of irrigation and nutrient uptake on head rot in lettuce.

2. LITERATURE REVIEW

2.1 CULTURAL PRACTICES AFFECTING PRODUCTION:

2.1.1 Irrigation

The yield and quality of any horticultural product are strongly affected by crop management techniques. Best quality produce is produced by maintaining continuous and regular growth in the field. Any check in growth is likely to affect the quality and quantity of the yield (Lomman and Maier, 1988). Irrigation is one technique which can affect the quality and quantity of the product to a significant extent, especially in leafy vegetables. Progressive development and high yields are possible only when water distribution is as even as possible over the entire crop. The effect of soil - moisture deficit on plant growth and crop production has been the subject of much research. In leafy vegetables, where fresh weight and quality of the harvested plant parts are the important attributes, high moisture stress often decreases the crop yield.

Even in ancient agriculturally based civilisations irrigation played a major role (Bucks and Nakoyoma, 1986). The dominant methods of irrigation from these early times have been surface or gravity and sprinkler irrigation. Trickle / drip irrigation is a relatively new approach and was developed from sub - irrigation where irrigation water is applied by raising the water table (Bucks and Nakoyoma, 1986). Drip irrigation offers many advantages; e.g. reduced contamination of soil by fertilisers, reduced disease outbreak, less water usage and less waterlogging of soil (Hochmuth, 1992). Water is applied only to the root zone of the plant through controlled discharge emitters and at discrete locations along the plant rows resulting in limited irrigated areas (Clark, 1992). In the mid - 1960's through mid - 1970's it was considered an emerging technology with potential for application limited only to high - priced, speciality crops. Today, it is used on a wide variety of crops, even those that were initially considered unprofitable for management under drip irrigation.

Drip irrigation has many benefits, some of which are becoming more important in today's environmentally conscious world. One major benefit is the ability to conserve water and reduce fertiliser loss, in comparison with other irrigation and fertilisation systems. Water savings with drip irrigation can amount to as much as 80% compared with other irrigation methods (Bogle and Hartz, 1986; Locascio *et al*, 1985). This benefit of drip irrigation is extremely important for vegetable growers in urban areas and in areas with limited water supply such as East Gippsland.

Bogle and Hartz (1986) compared drip and furrow irrigation of muskmelon (*Cucumis melo L. Cultivar 'Perlita'*) and found that there was a trend toward early maturity and high total and marketable yields with drip irrigation. They also found that drip irrigation as practised in this study had a number of important cultural advantages such as, low weed competition and no restriction of the delivery of field operation due to wet furrows and water through the harvest season.

Vegetable growers in East Gippsland tend to use travelling irrigators or movable pipes which makes irrigation slow and difficult to get around a large acreage (or a number of paddocks) quickly, or as required, resulting in increased likelihood of moisture stress, particularly at crop establishment, where seedlings often are left 24 hours before "watering". Furthermore, irrigation is often scheduled by growers in East Gippsland on the basis of convenience rather than need. Previous work has shown that soil moisture stress can effect broccoli and lettuce yield to a great extent (Singh and Alderfer, 1966; Sale, 1966). Broccoli was found to be most sensitive to moisture stress during head formation and enlargement, although moisture stress during any period of growth reduces final yield and quality. Singh and Alderfer (1966) also found that total yield, individual head weight and quality of lettuce were decreased when a soil moisture stress greater than 100 KPa at 12.5 cm in the row developed during any period of growth.

Inefficient water use can also reduce aeration, slow growth, and restrict root development. Better irrigation practice is a key to better dollars for East Gippsland farmers. Drip irrigation and fixed overhead sprinklers are alternative methods that could potentially improve water use efficiency while minimising the cultivation problems associated with current irrigation practices in East Gippsland.

Most lettuce and broccoli in Australia are grown using sprinkler irrigation. While this has been largely successful there are several reasons why farmers should consider more efficient systems. Sutton and Merit (1993) found that maintaining the root zone of lettuce at field capacity with drip irrigation gave better yields than for sprinkler irrigated plants, and the water requirement per harvested plant was almost halved.

Drip irrigation is an important irrigation method in the crop production areas of the world, particularly in arid areas or areas that have a high competition for available water resources and is becoming common practice for many vegetable crops in Florida (Hochmuth, 1992). Micro - irrigation (fertigation), is another application of drip irrigation, where solution is dispensed to the crop via small plastic tubes or drip type emitters. Dangler and Locascio (1990a and 1990b) found that tomato fruit quality improves when nitrogen and potassium are applied by drip irrigation compared with applying all fertiliser preplant.

Increased efficiency with micro - irrigation not only saves production costs, but also reduces the potential for ground water pollution due to fertiliser leaching with large amounts of rain or periods of excess irrigation (Hochmuth, 1992). Water does not come in contact with plant foliage with drip irrigation, which reduces susceptibility to foliar disease outbreak and leads to an associated reduction in fungicide use.

While drip irrigation has many potential benefits, it also presents some challenges. The system must be carefully designed and installed so that fertilisers and chemicals can be applied in a safe, legal and efficient manner (Clark, 1992; Clark *et al*, 1988, 1990 b). Significant technical skills and management are required to operate these systems for peak efficiency.

Most vegetable crops are adaptable to drip irrigation, especially those produced on bedded systems using polythene mulch. Drip irrigation, when used in conjunction with plastic mulch creates a closed system containing an environment suitable for maximum vegetable crop growth / yield, and if used effectively, minimal labour and chemical leaching (Lamont, 1992).

In summary, efficient irrigation is very important for the cost effective vegetable production. If irrigation is scheduled correctly using an efficient irrigation system, the yield, quality and quantity of produce can be improved.

2.1.2 Tillage

Another factor which can affect the yield and quality of produce is tillage. Previous work has shown the potential of reduced tillage for increasing the production of crops (Lal, 1979; Bandel, 1983). Reduced tillage, especially with organic residues retained as a mulch, conserves soil structure and organic carbon (Tisdall and Adem, 1986). Reduced tillage of tropical soils controls run - off and erosion, improves tilth and porosity of soil and reduces excessive soil surface temperatures during the early stages of plant growth (Falayi and Lal, 1978; Lal, 1979). Similarly, reduced tillage of irrigated silt soils from temperate regions increases infiltration, available water and macro-porosity (Cockroft and Martin, 1981; Tisdall *et al*, 1984).

Ridge tillage is the term used for any cropping system in which plants are grown on ridges in rows, with one or more rows per ridge (Tisdall and Hodgson, 1990). Ridges may be temporary or permanent and receive varying degrees of tillage. Ridges are alternatively referred to as raised beds or lands.

Ridge tillage has been used successfully in Australia for vegetables production. Many farmers are maintaining permanent ridges to improve soil structure, save time and reduce costs (Tisdall and Hodgson, 1990). Better yields from crops grown on ridges compared with flat tillage were attributed mainly to better soil aeration and better drainage (Tisdall and Hodgson, 1990). West and Black (1969) showed that the mean oxygen flux in the top 0.2 m in non-irrigated ridges in Knoxfield, Victoria was up to 24 times that in the flat or unraised plots, leading to higher yields.

A good seed - bed provides close contact between seed and soil, and yet provides soft stable aggregates of soil that do not limit the growth of emerging seedlings and roots (Collis-George and Lloyd, 1979). The Tatura system of permanent beds, where soil is manipulated a minimum number of times, allows permanent beds of soil to be used year after year (Adem *et al*, 1982). One advantage of the Tatura system over the commercial system of preparing seed-beds is that in the Tatura system the seeds are sown into wet soil; the seedlings emerge without further irrigation, thereby reducing the risk of heavy rain forming a crust before seedling emergence (Adem *et al*, 1984).

Tisdall and Adem (1988) developed a surface soil management system (Tatura system) used for irrigated double-cropping in south-eastern Australia. Under the Tatura system ten crops were direct-drilled in six years on permanent furrow-irrigated raised beds. These beds were mulched in summer, traffic-free and irrigated by capillarity from shallow water in the furrows. The cumulative yield of multiple crops under the Tatura system was far higher than that from those under traditional systems, which allow no more than three crops in three successive years (Tisdall and Adem, 1988). This research indicates the potential of using the custom prescribed tillage concept to develop a management system, for a combination of soil, crop(s), and climate which can lead to increased and sustained productivity.

Multiple cropping, in which two or more crops are grown on the same field in one year, is common in warm parts of the world at all levels of agricultural technology (Andrews and Kassam, 1976). Vegetable growers in Victoria use this method to produce 3-4 crops per year. Total productivity per year is increased with less risk of all crops failing. Because the land may be covered with a crop for most of the year, multiple cropping can improve soil structure, increase the amount of organic carbon in soil, and reduce erosion. Relay cropping is one form of multiple cropping, in which a second crop is sown after the first crop has reached its reproductive stage but has not been harvested (Andrews and Kassam, 1976). Machinery has been designed specifically for relay cropping in south-eastern Australia which has enabled maize to be successfully sown into wheat crops. When sown 2, 4 and 5 weeks before wheat was harvested maize yielded more than when sown one day after harvest (control) and when grown traditionally as sole crops in northern Victoria (Tisdall and Adem, 1990).

In summary, tillage practices can have an effect on crop performance through their effects on soil porosity and aeration. It is likely there is an interaction between tillage and irrigation on subsequent crop growth. It is also likely that current practices of irrigation and tillage in East Gippsland can be successfully replaced by new techniques which will increase and sustain productivity.

2.2 BROCCOLI: Quality and Quantity of Production

Broccoli is a well - known and popular vegetable used in both Chinese and western cooking, either as a fresh or frozen product. It is nutritionally rich and a good source of many vitamins and minerals. Broccoli is potentially available as a year round crop. Australian broccoli is of a high quality, well regarded and in good demand during production season (May - October). The export market requires broccoli with a medium to large sized compact head of approximately 10 cm diameter and a stem length of 75 - 90 mm. The head should be uniformly green with no sign of yellowing. It is priority one vegetable for export to South East Asia.

2.2.1 Botany and Quality Characteristics

Broccoli is a member of the Cruciferae, in the family Brassicaceae. Its botanical name is *Brassica oleracea* var. *italica,* and is a cultivar of the same species as cauliflower. Broccoli is similar to cauliflower in its upright structure, leaf habit and head formation.

Broccoli is the term used to describe the annual green sprouting form of *B. oleracea* var. *italica* in America, Japan, the Netherlands, Australia and New Zealand. In Britain and Italy the term calabrese is used to describe the annual sprouting form of broccoli. Three growth stages suggested for broccoli (Gauss and Taylor, 1969a) are given in Table 1.

TABLE 1: Growth Stages of Broccoli

Growth Stage 1	Vegetative (Juveline) Stage
	0 - 6 true leaves; or 0 - 4 weeks
Growth Stage 2	Transitional Stage
	6 - 11 true leaves; or 4 - 6 weeks
Growth Stage 3	Reproductive Stage
	11 - 22 true leaves; or 6 - 9 weeks

Currently broccoli is sold as a fresh and frozen product world wide. Usually the head is consumed, but increasingly the thick stem is used in U.S.A.. Its future value as a vegetable will increase as continuity of supply of fresh product increases, and premium prices can be anticipated for high quality, pre - cooled (and ice pack) broccoli for local and export market. It has a potential for expansion as an export product to South East Asia.

2.2.2 Nutritional Value

Broccoli is nutritionally rich: a good source of vitamin A (155 g provides 68% daily requirement); excellent source of vitamin C (155 g provides more than twice the daily allowance); valuable amounts of iron and other minerals and is low in calories and high in fibre.

The composition of a 100 g edible portion of broccoli is given in Table 2.

TABLE 2: Nutrient Composition of Broccoli

Nutrient	Unit	In 100 g edible portion
Energy	J	80
Protien	g	3.6
Fat	g	0.3
Vitamin A	International unit	3800
Niacin	mg	0.6
Vitamin C	mg	110
Calcium	mg	78
Iron	mg	1
Magnesium	mg	39
Phosphorus	mg	74
Potassium	mg	360
Sodium	mg	40

(Adapted from the book, World Vegetables, 1983: as cited in source: Howard *et al,* 1962)

2.2.3 Hollow Stem in Broccoli

Hollow stem is a physiological disorder that ranges from vertical cracking to the development of open chambers in the pith tissue of broccoli stems. It occurs following initiation of the central inflorescence and is considered undesirable because it may reduce broccoli shelf life (Zink, 1968). The early signs of this disorder are the development of small elliptical cracks in the inner stem tissue. As plants approach maturity these cracks may enlarge and coalesce, causing the stem to become hollow. Besides detracting from the appearance of the head and hence overall quality of the produce, the presence of stem cavity at harvest may facilitate pathogenic activity. In addition hollow stem may exhibit discolouration which is undesirable for export markets, especially in South - East Asia where the consumers prefer the non - hollow, long stemmed broccoli.

Hollow stem in some cases is induced by boron (B) deficiency, which also produces symptoms such as stem browning, marginal leaf necrosis and floret discolouration (Shattuck and Shelp, 1987). B deficiency may be a consequence of the poor aeration of the soil and low pH that occurs when soils are flooded or waterlogged.

Boron (B) was first shown to be an essential micronutrient for plant growth more than six decades ago (Warington, 1923). Since that time, an extensive body of literature concerning the effects of B on the growth and yield of plants has been published. Since B is highly mobile in the soil and easily leached, the majority of information concerns the correction of B deficiencies affecting high-yielding crops in the more humid parts of the world (Gupta 1979). In nature, B toxicity is not as widespread as B deficiency. The range between B concentration that causes B deficiency and B toxicity symptoms is relatively narrow (Gupta *et al*, 1985; Keren and Bingham, 1985).

B is universally distributed in soils (Eaton and Wilcox, 1939). It is derived from certain boron-bearing rocks; sedimentary rocks contain more B than igneous rocks (Whitestone *et al*, 1942). However, B in rock is not very available to plants and most of the plant-available B comes from the decomposition of soil organic matter and from B adsorbed and precipitated onto the surfaces of soil particles (Russel, 1973; Bingham, 1973; Bowen, 1977). Less than 5% of the total soil B is available for crop uptake (Gupta, 1968). This explains the widespread occurence of B deficiency in many parts of the world.

Generally, soils that have developed in humid regions have low amounts of plant-available B because of leaching. Further, the plant-available B that is present in such soils is located in the top 15 cm in the organic matter fraction (Miljkovic *et al*, 1966; Wekhoven, 1964; Whitestone *et al*, 1942; Kanwar and Singh, 1961). Thus plants growing on regosols, sandy podzols, alluvial soils (in Lindenow), organic soils, and low humic gleys tend to develop B deficiencies because of very low soil reserves. There are a number of factors which can affect the availability of soil B to crops, including: the soil type and its various physical and chemical characteristics; plant species and genotypes; various other environmental factors such as temperature and climate; and the interaction of B with other nutrients (Gupta, 1993). Soil reaction, or soil pH, is an important factor affecting the availability of B in soil and plants. Generally, B becomes less available to plants with increasing soil pH (Gupta, 1993). A negative correlation has been observed between plant's B uptake and soil pH (Bennett and Mathias, 1973; Gupta, 1972b). A pH of 6.0 to 6.5 is optimum for B uptake along with the other favourable factors. Furthermore, the degree of B fixation is influenced by moisture, wetting and drying, temperature and soil texture (Eaton and Wil;cox, 1939; Parks and White, 1952; Bigger and Fireman, 1960; Bingham *et al*, 1971; Gupta, 1968; Singh, 1964).

Although the metabolic role of B is uncertain (Pilbeam and Kirkby, 1983), the evidence generally shows that that B is important in cell division and is apparently a necessary component of cell walls (Jackson and Chapman, 1975; Cohen and Lepper, 1977; Slack and Whittington, 1964), Symptoms of plant stress caused by B deficiency and toxicity have been well documented (Gupta *et al,* 1985). Broccoli plants grown in B deficient conditions exhibit low growth rates and a high incidence of pith damage or hollow stem (Shattuck *et al*, 1986, Hipp, 1974).

Hollow stem in broccoli has also been associated with increased row spacing in the field and increasing nitrogen (N) fertilisation (Zink, 1968; Cutcliffe, 1972). Cutcliffe and Gupta (1980) have reported that applied N increases the B concentration in cauliflower (*B. oleracea var. botrytis L.*), which is also affected by hollow stem. A balance must exist between B and N in Brassica crops and the addition of B alone, contrary to earlier studies, does not reduce the hollow stem incidence in broccoli (Gupta and Cutcliffe, 1972). It has been found that increasing N rate resulted in greater vegetative growth rate (Hipp, 1974). Tremblay (1989) found that nitrate - containing fertilisers increased broccoli yield by 4% but induced 13% more hollow stem. No N sources could be identified that would produce high broccoli yield without inducing high incidence of hollow stem. A seasonal effect also appears to influence the development of hollow stem in broccoli which has been observed to be higher during early summer when plant growth is usually more rapid than later in summer (Tremblay, 1989).

Different species and cultivars of vegetables respond differently to B deficiency because of differences in B requirement. In tomato genotypes known to respond differently to B supply (Brown and Ambler, 1973), physiological studies showed that B was absorbed into roots, but not translocated upwards at a rate sufficient to support normal plant growth (Wall and Andrus, 1962). Similar differences in broccoli cultivar susceptibility to hollow stem have been reported by Cutcliffe (1975) and Shattuck *et al* (1986).

Plant spacing has marked effects on crop yield and incidence of hollow stem in broccoli (Titley, Unpublished data; Cutcliffe, 1975; Griffith and Carling, 1991). Broccoli head weights and yields are highly sensitive to plant densities and rectangularity (Westcott and Callan, 1990). In one study, maximum yield of individual heads for fresh market was obtained at a spacing of 45 x 30 cm. using single plant transplant (Griffith and Carling, 1991). This study also found that row spacing also affects yield. Decreasing row spacing from 90 to 45 cm doubled the plant density and increased average yields by 32%. Raising two plants in a transplant plug also doubled the plant density, with an average increase in yield of 15%.

In studies of the effect of plant density on broccoli production, Salter *et al* (1984) observed that optimal yields of broccoli were obtained when the plants are grown in square (1:1) rather than rectangular (6:1) spatial arrangements at the same plant density. Chung (1985) found that changing from the traditional low plant density 2.8 plants m^{-2} to about 8 plants m^{-2} increased yield significantly without causing cultural or marketing problems.

Other environmental factors, such as climate and soil fertility may also play a role in hollow stem induction. Shattuck *et al* (1986) and Tremblay (1989) observed that the occurrence of hollow stem varies significantly between growing seasons and concluded that environmental conditions may play an important role in hollow stem formation.

It has been proposed that hollow stem may be related to changes in plant growth rates during the course of a field season, yet attempts to correlate the incidence of hollow stem with plant growth rate have given mixed results. Zink (1968) and Hipp (1974) both report that rapidly growing broccoli plants are more likely to develop hollow stem and Cutcliffe (1972, 1975) found that hollow stem occurs more frequently when plants are widely spaced and fertilised with high N. However, in the experiment carried out by Griffith and Carling (1991), the incidence of hollow stem decreased as plant density increased. The use of one plant per transplant plug exhibited a 17% higher incidence of hollow stem, increased head weight and head diameter compared with controls. Thus, the relationship between growth and hollow stem may depend, not on the rate of growth, but rather on the ultimate size of the inflorescence, which raises the possibility that hollow stem may have a physical origin in cracks created by radial strains that develop in the stem during flowering. According to this scenario, high density increases the competition for minerals and other factors, which results in slower growth, production of smaller heads and therefore a lower incidence of hollow stem.

No studies have been reported that looked at amount of water applied to broccoli crop and the correlation of this environmental factor with hollow stem occurrence.

2.3 LETTUCE: Quality and Quantity of Production

Lettuce is a pleasure food and the most important salad vegetable. It has a low nutrient density and little flavour, except that sometimes it is bitter. It is one of few horticultural food crops used exclusively as a fresh raw product. It is often minimally processed i.e. cut and / or shredded for salad mixes or harvested when immature and used in salad mixes which often contain other leafy vegetables, mainly Brassicas. Its chief merits are variety of textures and colours, a large surface volume ratio that serves admirably as a carrier of dressings of infinite variety, and a source of bulk for diet - conscious consumers. In Victoria, lettuce is available all year round and is mainly produced in the market gardens close to Melbourne with an increasing proportion of winter lettuce supplied from the Sunraysia district of Victoria and from Hay, in Southern N.S.W.

2.3.1 Botany and Quality Characteristics

Lettuce (*Lactuca sativa L*) is native to the Mediterranean and Near East and has been in cultivation at least 2,500 years. It is closely related to common wild or prickly lettuce (*L. serriola L*), which is somewhat different morphologically, but is reproductively completely compatible with the cultivated forms (Ryder and Whitaker 1976).

There are five distinct types of lettuce:

Crisphead or iceberg lettuce is the main lettuce type grown and is distinguished by firmness of head and crisp texture.

Butterhead lettuce has a soft head and the inner leaves feel oily or buttery.

Cos lettuce is distinguished by elongated head, stiff leaves and upright habit of growth.

Leaf lettuce has loose non-head forming leaves.

Stem lettuce has leaves with an enlarged stem and no head.

The important factors in quality for consumers are:

1. appearance, including size, colour and shape

2. condition and absence of defects

3. texture

4. flavour

5. nutritional value

Factors 2 and 5 will be reviewed further. Factors 1, 3 and 4 are often identified in product specifications although flavour is hard to measure.

2.3.2 Nutritional Value

Lettuce supplies relatively little nutrient value per unit weight. However, because per capita consumption is high, it is an important contributor of some dietary vitamins such as vitamins A, C, and niacin. It is also a useful source of some mineral elements such as phosphorus, calcium, iron and magnesium.

The concentrations of some nutrients and fiber in crisphead lettuce are given below in Table 3.

TABLE 3: Nutrient Composition of Lettuce

Nutrient	Unit	In 100 g edible portion
Energy	cal	11
Protien	g	0.8
Fat	g	0.1
Vitamin A	International unit	300
Niacin	mg	0.3
Vitamin C	mg	5
Calcium	mg	13
Iron	mg	1.5
Magnesium	mg	7
Phosphorus	mg	25

(Adapted from the book, World Vegetables, 1983; as cited in source: Howard *et al.* 1962)

2.3.3 Tipburn / Head rot in Lettuce

Tipburn of lettuce, a calcium (Ca) - related physiological disorder, is a serious limitation to the production of high - quality field and greenhouse crops. It involves a collapse and necrosis of the apex and margins of actively growing leaves (Collier and Tibbitts, 1982; Termohlen and Hoeven, 1966). The development of these small brown necrotic water - soaked areas provides ideal conditions for secondary bacterial soft rot infections, and often results in a slimy head (Lipton and Ryder, 1989). Besides Ca deficiency, various other events are also associated with tipburn, including the sudden acceleration of lettuce growth due to an increase in temperature, irrigation or rainfall, and / or nitrogen fertilisation.

Tipburn can occur even when there is an adequate supply of Ca to the roots. This is because Ca moves mainly by transpirational mass flow in xylem (Bell and Bidddulph, 1963; Clarkson, 1984). Most leaves of head forming lettuce cultivars are wholly or partly enclosed and are particularly susceptible to the disorder, as the inner leaves are restricted in their ability to transpire and thus can contain abnormally low levels of Ca. Tipburn is usually initiated after the head is well formed and close to market maturity (Ryder, 1979).

Extremely low tissue concentrations of Ca (0.2 to 0.3 mg g^{-1} dry weight) are associated with areas expressing tipburn injury compared with 0.4 - 0.5 mg g^{-1} dry weight in healthy lettuce leaf (Barta and Tibbitts, 1991). Ca concentrations of less than 0.4 mg g^{-1} dry weight in intervenal leaf areas appear to be critical for injury development and uninjured areas of tipburned leaf have been found to contain calcium concentrations of 0.4 - 0.5 mg g^{-1} dry weight Some reports have suggested that tipburn development is a manifestation of a localised Ca deficiency resulting from the chelation of Ca by organic acids and other metabolites, lowering the soluble Ca fraction within the leaf (Misaghi and Grogan, 1978; Thibodeau and Minotti, 1969).

It has also been found that leaves of field - grown plants are less susceptible to this injury as compared with those grown in controlled environmental conditions. Leaves of field - grown plants may have been free from injury because leaf enlargement and demand for Ca did not exceed the quantity of Ca that was being taken up by the roots and provided to the leaf tissues. Many other growing conditions such as soil temperatures, air movement, vapour pressure deficit and nutrient levels could also lead to the differences in Ca accumulation and tipburn development in field and controlled environments (Collier and Tibbitts, 1982). The occurrence of tipburn has been correlated with rapid growth rates (Collier and Huntington, 1983; Cox *et al*, 1976). Magnesium (Mg) is negatively correlated with tipburn as the higher concentration of Mg found in tipburned leaves compared with the uninjured leaves (Collier and Tibbitts, 1982).

Goto and Takakura (1992) observed that air supply to inner developing leaves could prevent lettuce tipburn without decreasing a rapid growth rate. In another experiment they also found that when air was supplied at a flow rate of 160 ml $minute^{-1}$, Ca accumulation in the inner leaves was increased 4.6 times over that in the control (no air supply). In the dark period, Ca accumulation increased in both inner and outer leaves when air was supplied. Thus air supply was shown to prevent tipburn by increasing Ca accumulation in the inner leaves, because it increased vapour pressure deficit in the air around the inner leaves, which encouraged transpiration from the leaves and consequently promoted Ca uptake from the root to inner leaves.

Many researchers have made attempts to solve the problem of tipburn in lettuce and identify the mechanism of tipburn development. Some methods include: selection of cultivars which are resistant to tipburn (Takagi *et al*, 1990); application of foliar sprays of Ca salts (Thibodeau and Minotti, 1969); and improvement of ion balance in nutrient solution (Ashkar and Ries, 1971; Son and Takakura, 1989). But Collier and Tibbitts (1982) indicated that a combination of causal factors are implicated in tipburn development and the above methods have not always been practical in preventing tipburn.

Tipburn occurs most frequently when lettuce grows rapidly and therefore, deceleration of growth rate during the later growing stages can be effective in reducing tipburn development. This is not a final and practical solution and it is necessary to find techniques to prevent this disorder without sacrificing a rapid growth rate.

2.3.4 Environmental Effects on Physical Characteristics

Another set of limitations to the production of lettuce suitable for export are head weight and quality. Singh and Alderfer (1966) found that head weight and quality of lettuce are decreased when a soil moisture potential greater than 100 kPa at 12.5 cm depth occurs during any period of growth. This study also found that with a higher moisture stress (700 - 900 kPa), the number of tipburned and burst heads increased. In addition Cox (1984) found that if irrigation was withheld until eight days after transplanting then lettuce yield was reduced up to 30% due to reduced survival during establishment. Thus irrigation timing and scheduling are very important to get a high yield and better quality of lettuce.

Various types of environmental stresses in the field can lead to problems of growth and development and thus of quality. Wurr *et al* (1992) found that lettuce showed high sensitivity to environmental variables at specific growth stages. Denser heads were associated with low temperature during the period up to and around hearting while less dense heads were primarily associated with high temperatures in the period up to hearting. Also, head weight at maturity is increased by high solar radiation in a specific period just before hearting and by low temperature in a longer period up to and around hearting (Wurr and Fellows, 1991).

After reviewing the literature, it is clear that many of the commercially desirable features of lettuce are related to production techniques and growing environment, of which irrigation is a key element.

2.4 GENERAL HYPOTHESES FOR FIELD TRIALS OF BROCCOLI AND LETTUCE

After reviewing the literature and observing existing cultivation practices and problems in East Gippsland, the following hypotheses were generated:

* Too much water leads to waterlogging and hence reduced Ca and B uptake in plants.
* Deficit water dries out the soil during the eight day irrigation cycle which also reduces mineral uptake and limits growth.

The alternating wet / dry cycles induced by the current irrigation practices produce a discontinuous growth cycle and exacerbate physiological disorders such as 'hollow stem' in broccoli and 'head rot' in lettuce. This thesis reports investigations designed to test this hypothesis by focussing on effect of irrigation (volume of water applied) on nutrient uptake and physiological disorders.

3. MATERIALS AND METHODS

3.1 FIELD TRIALS: Year 1 (1993 / 1994)

Field trials were carried out on grower's properties at Lindenow, in East Gippsland, Victoria, over the period October - May 1993 / 94 for broccoli and lettuce. Rainfall data for the duration of each trial was obtained for the nearby Bairnsdale airport (25 km from trial plots) from the Victoria state Bureau of Meteorology.

3.1.1 BROCCOLI

Nine sites (Table 4) on three different grower's properties were chosen to study the effects of current irrigation practices on the occurrence of hollow stem in broccoli. Three growing seasons studied at each site were spring (trial 1), summer (trial 2) and autumn (trial 3). Transplants of *B. oleracea* cultivar Marathon were grown in a nursery for all sites.

Marathon is the cultivar, most favoured by the growers but as it is more susceptible to hollow stem in summer, they grow Greenbelt over summer months. To study and compare the effect of different seasons on hollow stem occurrence, the same cultivar Marathon has been used throughout the 1993 / 94 trials.

Transplanting and normal grower practices of fertiliser application, irrigation, pest, disease and weed control were carried out by each grower. The dates of transplanting and harvesting, temperature at planting time, density and type of irrigator used at each site are given in Table 4.

TABLE 4: Broccoli Year 1 (1993 / 94) Trials 1, 2 and 3.

Site	Transplanting Date	Temperature t planting	Transplants Number	Density Plants/Ha	Irrigator	Harvest Date
Trial 1						
Site 1	7.10.93	20	2500	13000	Spray gun	20.12.93
Site 2	8.10.93	20	2500	12000	Arm type	24.12.93
Site 3	13.10.93	18	2500	13000	Arm type	30.12.93
Trial 2						
Site 4	1.12.93	30	2500	13000	Spray gun	5.2.94
Site 5	30.11.93	30	2500	12000	Spray gun	5.2.94
Site 6	30.11.93	30	3000	13000	Arm type	5.2.94
Trial 3						
Site 7	4.3.94	26	2500	13000	Spray gun	20.5.94
Site 8	4.3.94	26	2500	12000	Arm type	20.5.94
Site 9	4.3.94	26	2500	13000	Spray gun	20.5.94

A random sample of 15 plants was taken on the day of transplanting at each site and their fresh and dry weights were recorded. No further sampling occurred for the following four weeks, but continued every week after that until harvest.

Rainfall for trial one, i.e. at sites 1. 2 and 3, is presented in figure 1. The differences in measured rainfall are the result of different transplanting and harvesting dates.

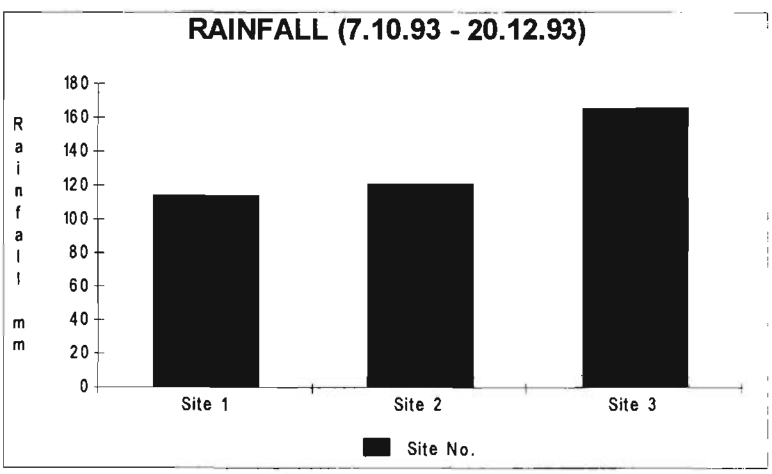

Figure 1: Total rainfall for trial 1 sites (October-December).

Rainfall for trials 2 and 3, i.e. sites 4, 5, 6, 7, 8 and 9, showed no appreciable difference between sites within each trial - see figures 2 and 3.

Plate 1

Photo 1: Spray gun irrigator and irrometer station (red top) in broccoli paddock

Photo 2: Irrigation being applied by Arm (boom) irrigator in lettuce transplants; either side of track used for irrigation movement.

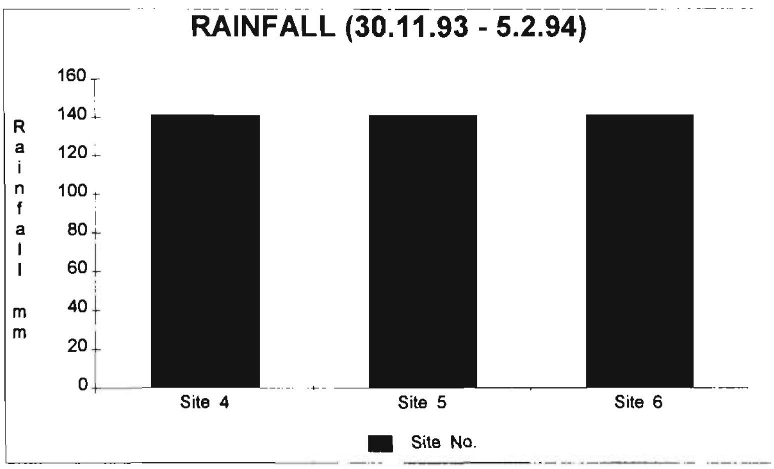

Figure 2: Total rainfall for trial 2 sites (December-February).

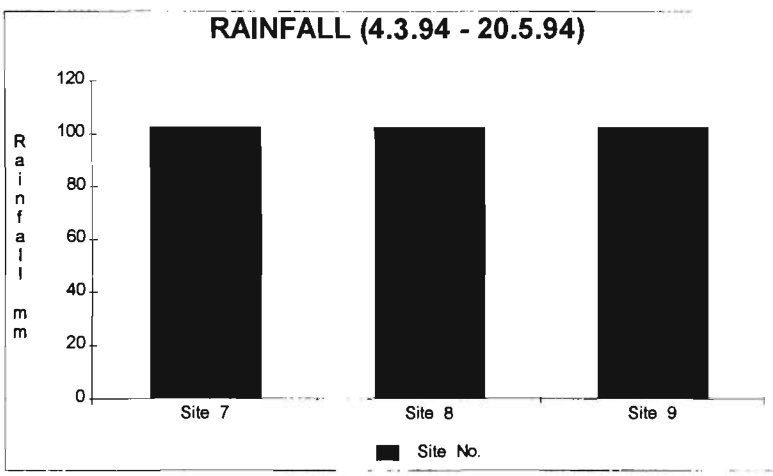

Figure 3: Total rainfall for trial 3 sites (March-May).

The irrigators used were overhead travelling irrigators:

Spray gun irrigator, the biggest and most powerful in the range of Southern Cross travelling irrigators, Model 200 can deliver up to 4×10^7 L of water per week, and it is capable of covering up to 1.3×10^4 m^2 in one unattended run of 600 metres. It uses 73 KL to 160 KL of water per hour (which can be controlled) for a run length of 600 metres. The area covered by the gun is approximately 22 metres on either side of the irrigator (Photo 1- Plate 1).

Arm (Boom) irrigator, is a low pressure lateral model, Upton 120, from Upton Irrigation Systems. The boom length is 60 metres and arms (booms) on either side are fitted with sprinklers, which can be controlled individually depending on the water requirements. It uses 82 KL to 109 KL gallons per hour (which can be controlled) for a run length of 400 metres (Photo 2 - Plate 1).

Two bags (50 Kg) of 'NPKS' NITROPHOSKA fertiliser per hectare was banded with transplants at sites 1, 3, 4, 6, 7 and 9. Composition of the fertiliser is given in Table 5.

TABLE 5: 'NPKS' Nitrophoska Fertiliser used at sites 1, 3, 4, 6, 7, and 9.

Component Analysis	w / w %
Nitrogen (N) as ammonium	7
Nitrogen (N) as nitrate	5
Nitrogen (N) total	12
Phosphorus (P) as water soluble	3.9
Phosphorus (P) as citrate soluble	1.3
Phosphorus (P) total	5.2
Potassium (K) chloride form	7.1
Potassium (K) sulfate form	7
Potassium (K) total	14.1
Magnesium (Mg) as magnesium sulfate	1.2
Calcium (Ca) as dicalcium phosphate	5
Sulfur (S) as sulfates	4
Iron (Fe) as iron oxide	0.16
Copper (Cu) as copper oxide	0.0004
Zinc (Zn) as zinc oxide	0.01
Boron (B)	0.02
Molybdenum (Mo)	0..0005

Two bags (50 Kg) of 'NPKS' PIVOT BLUE (composition shown in Table 6) per hectare was band ed with the transplants at sites 2, 5 and 8.

TABLE 6: 'NPKS' Pivot Blue Fertiliser Composition used at sites 2, 5 and 8

Component Analysis	w / w %
Nitrogen (N) as ammonium	8
Nitrogen (N) as nitrate	3.8
Nitrogen (N) total	11.8
Phosphorus (P) as water soluble	3.1
Phosphorus (P) as citrate soluble	0.7
Phosphorus (P) total	3.8
Potassium (K) nitrate	11
Potassium (K) sulfate form	3.3
Potassium (K) total	14.3
Magnesium (Mg)	2
Sulfur (S) as sulfates	10.9
Copper (Cu) as copper oxide	0.0004
Zinc (Zn)	0.01
Manganese (Mn)	0.1
Boron (B)	0.05
Molybdenum (Mo)	0.005

No side dressing was applied at any site. Tissue analysis was performed only on the samples taken from the spring (trial 1) and summer (trial 2) seasons.

At site 8 an 'EnviroSCAN, soil water monitoring system, was installed by Aquafield Irrigation Systems. EnviroSCAN is a soil moisture monitor which measures the dielectric constant of soil, and consequently its water content. EnviroSCAN uses sensor arrays within PVC access tubes to display time and soil water for decision making in irrigation scheduling. Two probes (A and B) were installed in the experimental area having sensors at the depths of 10, 20, 30, 50 and 70 cm. The sensors are energised by means of a solar panel and a storage battery. The data are sampled at a frequency (every five days in this study) which can be set to vary from every 7 days to as little as every 2 minutes between readings, depending on the configuration of the probe. The data are then stored in EnviroSCAN's custom - built logging system. The logged data are downloaded to a computer and software display which enables fast display of continuous data recorded at multiple depth levels to generate soil water dynamics, which can be used as decision parameters in irrigation scheduling.

3.1.2 LETTUCE

Only one trial of lettuce in autumn (March - May) season was carried out at site 10. Transplants of *Lactuca sativa* cultivar Greenway were transplanted into 1 m

Plate 2

Photo 3: Lettuce paddock showing three rows of lettuce in each bed and irrometer station (red top).

Photo 4: Lettuce showing tipburn and head rot.

wide raised beds in three offset rows (Photo 3 - Plate 2) on 26.3.94. Four beds, 55 metres long were used for experimental measurements and sampling. A random sample of 10 plants was taken fortnightly until harvest and fresh and dry weights were recorded. Irrigation was done by Spray gun irrigator. The crop was harvested on 4.6.94. Rainfall recorded over the trial period (26.3.94 - 4.6.94) was estimated to 76 mm.

3.2 FIELD TRIALS: Year 2 (1995)

Field trials were carried out only for broccoli at sites 11 and 12 in Lindenow, East Gippsland, Victoria over the period January - April 1995. Two irrigation methods: overhead fixed sprinklers and drip irrigation were applied at site 11 and at site 12 a travelling spray gun type irrigator was used. The irrigation methods were assessed by broccoli yield, quality and incidence of hollow stem occurrence.

3.2.1 BROCCOLI: SITE 11

Transplants of *Brassica oleracea* cultivar Greenbelt raised by growers were planted on 23. 1. 95. The day was mild with maximum temperature of 25^0 C and a rainfall of about 19 mm was recorded two days before. The experimental plot was divided into four blocks having two different systems i.e. drip and overhead fixed sprinklers in two replicates as presented below:

1)	Drip Irrigation - 1	25 metres by 7 metres
2)	Drip Irrigation - 2	25 metres by 13 metres
3)	Overhead fixed Sprinklers	27 metres by 7 metres
4)	Overhead fixed Sprinklers	45 metres by 13 metres

The density was 10,000 plants per hectare and two bags of 'NPKS' NITROPHOSKA fertiliser (composition given in Table 5) were incorporated at the time of transplanting. No side dressing was used.

Fifteen plant samples were collected on 24. 1. 95 and their fresh and dry weights were recorded. Further plant sampling was undertaken every week after four weeks until maturity. The crop was harvested on 27. 3. 95.

Plate 3

Photo 5: Broccoli paddock (site 11) showing Fixed Overhead Sprinklers in function in background and turned off (drip irrigation area) in foreground.

Photo 6: Broccoli paddock (site 11) showing dripper lines for drip irrigation and cans on supports to measure water volume applied.

a) Drip Irrigation

Typhoon light (13 mL) dripper lines (Photo 6 - Plate 3) were used in both plots. These thin - walled dripper lines are unique single chamber polyethylene tubes with injection - moulded emitters welded to the inner wall of the tube. The drippers were 0.40 m apart and each dripper had six racks for better filtration. The typhoon dripper's total filtering area (0.55 mm by 0.72 mm) is eight times larger than the passage area. The flow rate was 1.75 L hr^{-1} at 10 (m) pressure. The whole system was connected to a tensiometer, fixed at a depth of 30 cm, in the experimental plot, which operated automatically when the tensiometer reading reached 200 kPa and continued until tensiometer again reads 0..

b) Overhead fixed Sprinklers

The CROPWELL (tm) AG15 double jet (3.5 by 2.5) sprinklers (Photo 5 - Plate 3) were installed in both plots. The distance between the risers in a row was 9 metres and each sprinkler was 0.75 metre above the ground. The distance between the two rows of sprinklers was 13 metres and the precipitation rate was 11 mm hr^{-1} at 350 kPa pressure.

These were half - circle sprinklers and spray area was directed in order to minimise impact on drip irrigated treatments.

3.2.2 BROCCOLI: SITE 12

Transplants of *Brassica oleracea* cultivar Greenbelt raised by the grower were planted on 24. 1. 95 in 12 rows, each 60 metres long. 12,000 plants were transplanted per hectare. A 'Spray gun' travelling irrigator was used. The crop was harvested on 2. 4. 95. Plants were sampled during growth as for site 11.

Rainfall for the 1995 trial at sites 11 and 12 is given in figure 4.

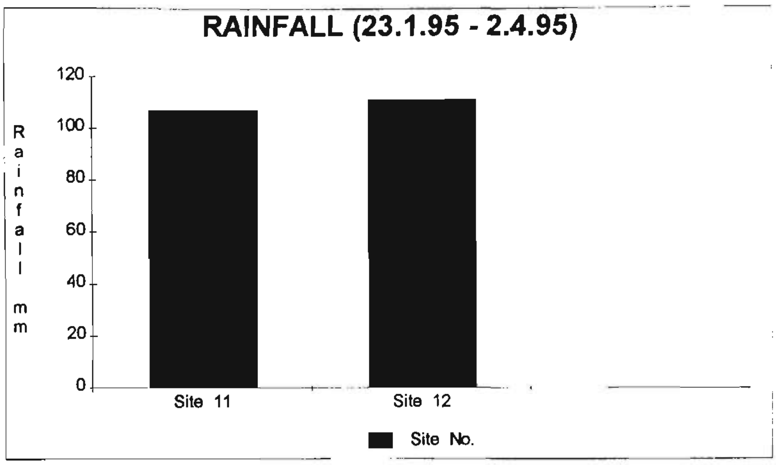

Figure 4: Total rainfall trial 1995 sites (January-March).

3.3 Soil Analysis

Soil properties play an important role in irrigation scheduling, plant growth and crop - water requirements. Therefore, soil samples in year 1 and 2 trials were taken to assess the properties listed below:

3.3.1 Soil Profile

Soil samples in triplicate were taken at a depth of 10 cm from each experimental block. The core used for sampling had a diameter of 10 cm and height of 10 cm. The pressure plate equipment at State Chemistry Laboratory, Werribee was used to determine the soil moisture content. The soil moisture characteristic curves of soil samples were determined at 10, 33, 100, 500, 1000 and 1500 kPa and soil profiles were drawn. From these curves soil type and amount of water available to plants in the field soil could be identified. (Loveday, 1974). According to Mclyntre (1974b) intact soil samples should be used from the range 0-300 kPa (McIntyre 1974b), whilst ground soil material is best for the values higher than 300 kPa. But at the State Chemistry Laboratory the ground material is used even for low potential (0-300 kPa) because it is convenient, cheaper and time saving.

Preparation of Sample: Samples were prepared by grinding air-dry aggregates (45^0 C for three days) until the material would pass through a 2.0 mm sieve. Samples taken from thoroughly ground material were used on pressure plates within small rubber retaining rings. These rings were 5 cm in diameter and 1 cm high. Samples are best wetted while on the pressure plate to be used for the

Plate 4

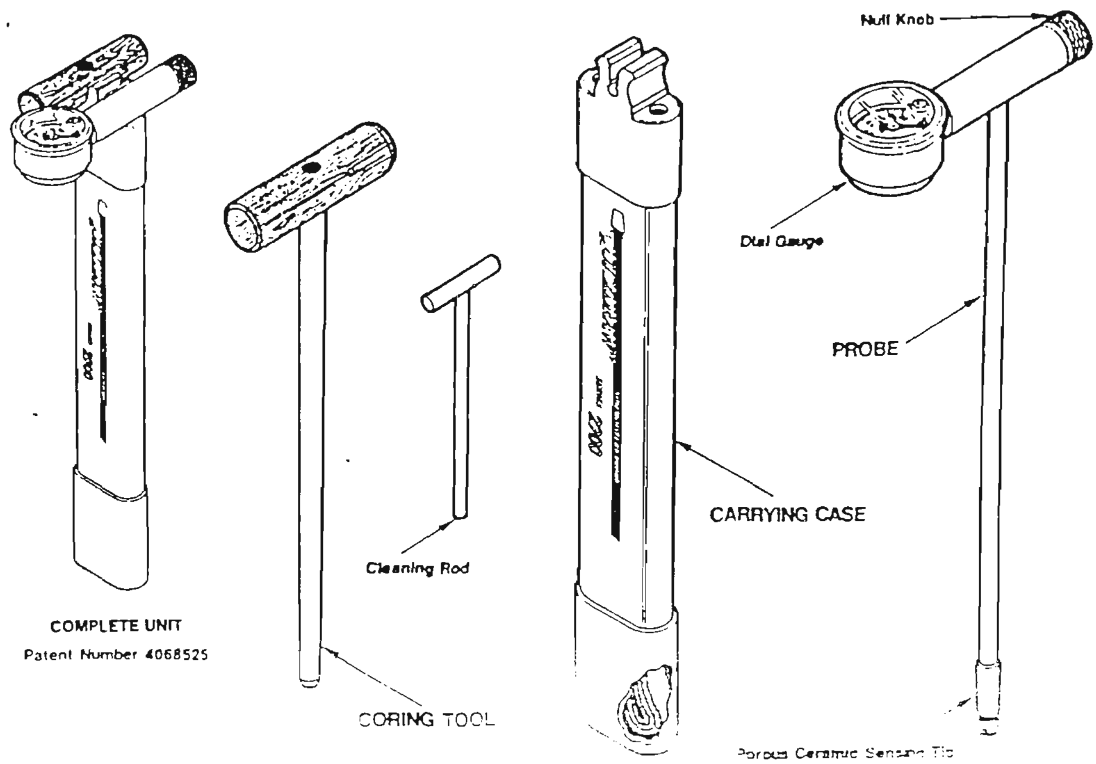

Figure a: Portable tensiometer showing its parts (adapted from instruction manual).

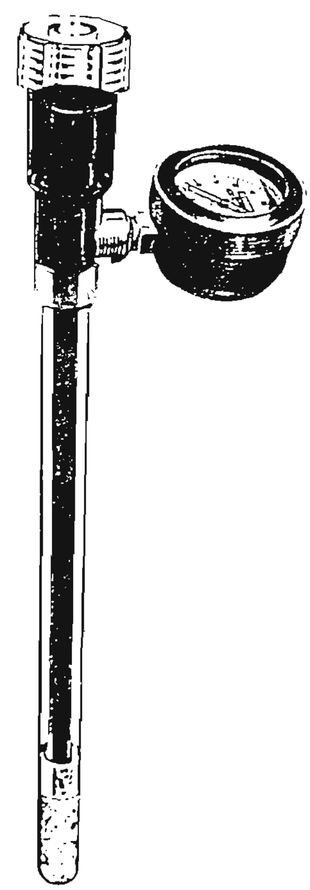

Figure b: Irrometer for fixed station (adapted from instruction manual).

measurement. This was achieved by flooding the pressure plate (with spooned sample in retaining rings) with water to a depth of about 1 mm, thus wetting the samples by capillary uplift. Once the upper surfaces of the samples were visibly wet then the depth of water was increased slowly until it almost reached the top of the samples. These were then left for approximately 16 hours to ensure complete wetting before the excess water was removed from the plate using a syringe. The plates containing samples were placed in closed chamber and measurements were made by applying desired level of pressure gradually.

The moisture retention curves relates the amount of water retained in soil to the energy state (potential) of that water (Childs, 1940).

Moisture Characteristics in Plant Studies: A complete draining moisture characteristic covers the range of soil moisture from saturation at atmospheric pressure (zero suction) to oven dry condition. However, it is rarely necessary to obtain such a complete curve and in most plant - water - soil studies, the measurements are taken up to 1500 kPa. The draining characteristic, determined by measuring the moisture retained at a number of suctions in the range from 0 - 1500 kPa should cover most edaphic requirements. The most important part is probably in the range from 0 - 100 kPa for most soils (Gardner, 1971) and 0 - 300 kPa for heavy clay soils.

3.3.2 Field Soil Moisture content

Four soil samples were each taken at the depths of 30 cm and 60 cm before irrigation and every alternate day during one complete irrigation cycle in year 1 (1993/94) broccoli trials at sites 1 - 9. Fresh and oven dried (105^0 C) weights were recorded. The average water content (% weight / oven dry weight) was determined and results were used to produce graphs.

3.3.3 Soil Moisture Tension

Tensiometer: Four readings were taken at 30 cm and 60 cm with portable tensiometers (Figure a - Plate 4), before irrigation and every alternate day until the next irrigation in year 1 (1993 /94) broccoli trials. Results (similar readings out of four measurements - matching with irrometers) were used to produce a drying profile of soil through irrigation cycle.

Tensiometers measure the soil suction which is a direct measure of the availability of soil water for plant growth, and the standard unit is "Pa" but tensiometers used

Plate 5

Photo 7: Cans placed in between the rows of broccoli paddock (site 1) to collect irrigation water

Photo 8: Cans mounted on sticks in broccoli paddock (site 11) to collect irrigation water.

in this experiment had a gauge in centibars. Common design consists of four basic parts (Figure a - Plate 4) including: dial gauge, null knob, probe and porous ceramic sensing tip. The gauge on the probe is calibrated in hundredths of a bar (or centibars) of vacuum and is graduated from 0 - 100. In wet soil, the vacuum gauge displays 0 - 5 centibars. As the soil dries out, the gauge reading increases, to a maximum of about 90 centibars. When the soil is rewet after irrigation or rain, the gauge reading falls.

Irrometer: Two fixed stations of irrometers (Figure b - Plate 4) were installed in each paddock at depths of 30 cm and 60 cm at each station. These were monitored several times a week and readings were recorded before irrigation, on irrigation and during the complete irrigation cycle.

The irrometer is a tensiometer brand and type which operates on the same principle as the standard tensiometer. It consists of a sealed water filled tube equipped with a special vacuum gauge and with a porous tip that is installed in the ground at desired root zone depths. Irrometers require frequent maintenance and are often unreliable. In this series of trials, the irrometers were used as backup to the portable tensiometers.

3.4 Irrigation

Between forty and fifty 500 ml cans were placed randomly in the experimental plot and were marked with an identifying number. After the irrigation was complete, the amount of water collected in each can was measured and recorded to assess the uniformity and range of water quantity delivered during the irrigation. Two raingauges were placed in the plot randomly near two different cans. The water collected in the cans was converted into mm using the raingauge readings. The amount of water delivered for every irrigation was measured after four weeks until harvest. Twenty of these cans were randomly selected and marked in each plot and three plants around each of these cans were tagged. These plants were used for photosynthesis measurements, then harvested and assessed for yield and other quality measurements (broccoli and lettuce) at maturity.

Cans for monitoring irrigation water were placed in between the lettuce and broccoli rows in year I, trials 1 and 2 (Photo 7 - Plate 5). These cans were fixed on sticks (Photo 8 - Plate 5) in year 1, trial 3 and year 2 at both sites to minimise the leaf shading effect, when plants grew taller.

3.5 Yield and Quality measurements

3.5.1 BROCCOLI

The sixty heads from the tagged plants (section 3.4) were harvested in each trial in the morning. The heads were weighed for their fresh market weights after the heads trimmed the extra leaves and the stem to a length of about 10 cm. The stem diameter (S.D.) was measured at 4.5 cm from the last branching. Head diameter (H.D.) was recorded and bud diameter (B.D.) was measured from the buds in second row.

The subjective assessment of quality of heads was made by considering several attributes which included colour, texture, size and any defects or rot etc. These characteristics are not independent of one another and are closely associated with the overall appearance and perception of produce. Maturity at harvest and hollow stem occurrence were assessed having following ratings:

Maturity at Harvest

1. Completely immature
2. Small flower head
3. Not fully mature
4. Uneven and small buds
5. Optimum
6. Buds unequal
7. Loose buds
8. Yellowing
9. Overmature
10. Flowering

Hollow Stem (H. S.)

1. None (0%)
2. Initiation (0% - 25%)
3. Nearly half of diameter of stem affected (26% - 50%)
4. Getting close to full stem affected (51% - 75%)
5. Hollowness (pithiness) affected whole stem (76% - 100%)

Heads were then kept in cool room at around 2^0 C for fifteen days, followed by three days at room temperature in the laboratory, and assessed for the market value (M. V.) and any breakdown (Bd) using the following ratings:

Market Value (M. V.)

1. Non - marketable
2. Unequal and loose buds
3. Buds getting yellow
4. Initiation of browning of buds
5. Optimum

Breakdown (Bd)

1. No breakdown
2. Very few buds getting brown
3. Initiation of bacterial rot
4. Rot getting worse
5. Rot (too bad) covering most of the head

3.5.2 LETTUCE

The forty heads from the tagged plants (sec. 3.4) were harvested on 4. 6. 94 in the morning. these heads were weighed for their fresh market weights after trimming the outer loose leaves. The head diameter (H. D.) was recorded. Firmness, maturity and head rot (H. ROT) were assessed using the following ratings:

Firmness

1. Soft and loose leaves
2. Moderate
3. Firm

Maturity

1. Immature
2. Optimum
3. Overmature

Head Rot (H. ROT)

1. Bad rot with slimy head
2. Rot progressing
3. Rot initiated
4. A few burnt tips
5. Optimum

Heads were kept in the cool room at around 2^0 C for fifteen days, followed by three days at room temperature and were assessed for the market value (M. V.) and breakdown (Bd) using the following ratings.

Market Value (M. V.)

1. Non - marketable
2. Few rotten leaves
3. Browning of the mid rib of leaves
4. Leaves turning yellow
5. Optimum

Breakdown (Bd)

1. No rot
2. Leaves turning brown
3. Slimy head

3.6 Plant Analysis

3.6.1 Plant growth

Plant growth was measured by removing 15 plants from each plot every week from 4 weeks after transplanting until maturity. The fresh weights of the plants (after removing roots), leaf number and dry weights were recorded and results for average fresh weight were plotted against dry weight. Average percentage dry matter was calculated by the following formula:

$$\textbf{\% Dry matter} = \frac{\textbf{Average dry weight of plants x 100}}{\textbf{Average fresh weight of plants}}$$

3.6.2 Photosynthesis

see chapter 6

3.6.3 Nutrient Analysis

Fifteen samples from the tagged, harvested broccoli heads, after yield and quality assessment, were washed with decon and distilled water to remove any traces of soil or minerals. Samples were dried in the oven at 70^0 C for three days and analysed for potassium (K), calcium (Ca), boron (B) and nitrogen (N).

Potassium and Calcium: K and Ca concentrations in harvested heads of broccoli were determined using the method of Piper (1944) as follows:

a) **Ashing:** A dry ashing procedure was used for the preparation of a solution of the ash from the broccoli plant material (Piper, 1944) as follows:

Procedure for Ashing:

1. A flat-shaped silica crucible was oven dried for approximately 30 minutes at 105^0 C.
2. The crucible was cooled in a desiccator and weighed to 0.0001 g.
3. Approximately 1.5 g oven dried (70^0 C) plant material was weighed into the crucible and charred very slowly by placing the crucible on a hot plate for about 1 hour or longer. A watchglass was placed over the material to avoid any loss.
4. When the sample was sufficiently charred, the crucible was placed in a muffle furnace and left overnight at 420^0 C. The temperature of the muffle furnace was raised slowly and maintained at 420^0 C for 24 hours.

5. The crucible and its contents were then placed in a desiccator and when cool were weighed to obtain the weight of crude ash.
6. The crucible was covered with a watchglass and the ash was then moistened with 1- 2 drops of distilled water and 3 mL 5N HCl was cautiously pipetted under the lip of the watchglass, so as to avoid any loss by effervescence.
7. The crucible, still covered was placed in a boiling water bath and the ash solution digested for 30 minutes.
8. The cover was removed and rinsed, 2 drops of concentrated HNO_3 were added. The solution was evaporated to dryness.
9. The dried salts were moistened with 2 ml 5 N HCl and 10 mL deionised water was added. The sample solution was warmed on a water bath for about 10 minutes to dissolve all the salts.
10. The solution was transferred from the crucible to a 250 mL volumetric flask with hot water using a rubber tipped stirrer and was diluted to the volume mark with deionised water.
12. The solution was then transferred to a 250 mL polythene bottle and a crystal of a thymol was added for the preservation of the solution.

This solution was used to determine K and Ca on atomic absorption spectrophotometer.

Potassium

K in the ashen solution was determined as follows:

Stock Solution: 0.2742 g KCl (A.R.) was dissolved in 25 mL of Milli Q water to prepare **1000 mg L^{-1} of K.**

Intermediate Solutions

A) A 10 mL of stock solution was diluted to 100 mL with deionised water to give a concentration of **100 mg L^{-1} of K.**

B) A 5 mL of solution A was diluted to 100 mL with deionised water to give a concentration of **5 mg L^{-1} of K.**

Ionisation suppressant

K is partially ionised in the air / acetylene flame and ionisation can be suppressed by the addition of caesium chloride (CsCl). 1.267 g of CsCl was dissolved in 100 mL of deionised water to give a concentration of 10% as Cs.

Working Standard solutions for K as prepared from the stock solution are given in Table 7.

TABLE 7: Working Standard Solutions for K

Concentration of K mg/L	Volume of 5 mg K/L mL	Volume of 10% Cs mL	Total volume mL
0.00	0	10	100
0.25	5	10	100
0.50	10	10	100
0.75	15	10	100
1.00	20	10	100
1.25	25	10	100

A 5 mL of unknown solution + 5 mL of 10% Cs was diluted to 50 mL and was aspirated to the flame and the absorbency of unknown solution was estimated using the atomic absorption spectrophotometer.

The concentration of K in the broccoli head was calculated using the following formula:

$$\text{mgkg}^{-1} \text{ of K} = \frac{\text{mgL}^{-1} \text{ in solution x ash volume x dilution (L)}}{\text{Oven dry weight of plant material (kg)}}$$

Calcium

Ca stock solution was available as 1000 mg L^{-1} of Ca in the store and used to prepare intermediate solutions..

Intermediate solutions:

A) **100 mg Ca L^{-1}:** 10 mL of stock solution was diluted to 100 mL with deionised water.

B) **25 mg Ca L^{-1}:** 25 mL of solution A was diluted to 100 mL with deionised water.

Releasing Agents

Interferences which have the potential to depress the absorbance of Ca can be eliminated by introduction of a releasing agent such as strontium (Sr) or lanthanum (La). 10% Sr solution was used to depress the interferences. 76.1 g of $SrCl_2.6H_2O$ was dissolved in 250 mL of milli Q water.

Working standards solutions as prepared from Ca stock solution are given in Table 8.

TABLE 8: Working Standard solutions for Ca

Ca Concentration mg/L	Volume of 25 mg/L Ca mL	Volume of 10% Sr mL	Total volume mL
0	0	10	100
1	5	10	100
2	10	10	100
3	15	10	100
4	20	10	100
5	25	10	100

A 5 mL of aliquot of unknown concentration was added to 5 mL of the 10% Sr solution and diluted to 50 mL. This solution was aspirated to the flame and absorbance readings were taken on the atomic absorption spectrophotometer.

The concentration of Ca was calculated by the following formula:

$$\text{mgkg}^{-1} \text{ of Ca} = \frac{\text{mgL}^{-1} \text{ in solution x ash volume x dilution (L)}}{\text{Oven dry weight of plant material (kg)}}$$

Boron

Gaines and Mitchell's (1979) method was used to estimate B in plant material.

Sample Preparation: A 0.5 g of oven dried sample was weighed in to a crucible. A 1.5 mL of $Ca(OH)_2$ saturated solution was added to the material before ashing, to prevent the loss of boric acid. This sample was then heated in muffle furnace for 14 hours at 550^0 C, cooled and weighed. After wetting the ash with 2 - 3 drops of distilled water, 4 mL of 0.36 N H_2SO_4 was pipetted into the crucible. The solution was kept standing at room temperature for 1 hour, with occasional stirring to break the ash. The solution was centrifuged in small sorval tubes at 2,000 rpm for about 10 minutes.

Colour Development: Each 0.6 mL sample of supernatant filtrate was pipetted into a microcuvette and 0.75 mL of working solution (see below) was added. These were mixed thoroughly and kept for one hour to develop the colour. The absorbance of the solution was measured at 420 nm using a colorimeter and concentration of the sample was determined from a standard curve constructed by plotting absorbance verses concentration of standards in mgkg^{-1}.

Calculations:

$$\text{mgkg}^{-1} \text{ of B} = \frac{\text{mgL}^{-1} \text{ in solution} \times \text{final volume (L)}}{\text{Oven dry weight of sample (kg)}}$$

Preparation of Reagents for B analysis

1. **Buffer - masking solution:** 280 g ammonium acetate, 20 g potassium acetate, 20 g tetra - sodium salt of EDTA and 8 g nitrilotriacetic acid were dissolved in 400 mL of deionised water and 125 mL of acetic acid was slowly added with stirring. The solution was heated to dissolve the contents and then filtered through Whatman No. 4 filter paper to remove any undissolved residue.

2. **Azomethine H solution:** 0.9 g azomethine H and 2 g ascorbic acid were dissolved in water with gentle heating and diluted to 100 mL volume. The solution thus prepared could be stored for 14 days if stored in a brown bottle under refrigeration.

3. **Working Solution:** 20 mL azomethine H solution was added to 80 mL buffer - masking reagent when required.

4. **B Stock Solution:** 100 mgL^{-1} B solution was prepared by dissolving 0.5716 g boric acid in deionised water and diluted to 1 L.

5. **Diluted sulphuric acid (0.36N H_2SO_4):** 10 mL concentrated H_2SO_4 acid was diluted to 1 L with deionised water.

B standards were prepared from the stock solution as given in Table 9.

TABLE 9: Boron Standards

B Concentration	B Stock Solution	0.36 N Sulphuric acid	Total volume
mg/L	mL	mL	mL
1	1	99	100
2	2	98	100
3	3	97	100
4	4	96	100
5	5	95	100

Nitrogen

N was estimated in each sample using Kjeldahl method. Kjeldahl nitrogen is the sum of ammonium and those organic compounds which can be converted to ammonium under Kjeldahl reaction conditions.

Reagent and Solutions for N analysis

1. **Sodium hydroxide solution:** 400 g NaOH was dissolved in 1 L of water.

2. **Reaction mixture:** 5 g selenium, 5 g copper sulfate, 250 g sodium sulfate (anhydrous) were mixed together in a mortar and stored under dry conditions.

3. **Phenolphthalein Solution:** 1 g phenolphthalein was dissolved in 100 mL ethanol; 100 mL water was then added.

4. **Concentrated sulfuric acid:** Analytical grade.

5. **Ethanol:** Analytical grade.

Digestion: 1 g oven dry sample (head) was placed in Kjeldahl flask and treated with I g of reaction mixture and 10 ml of ethanol. After shaking, 10 ml of conc. sulphuric acid was added and the mixture heated to boiling until a dark green colour was obtained. Boiling was then continued for 30 minutes to remove nitrates and nitrites.

Distillation: The digestion contents diluted with 280 ml of distilled water were transferred to a 1 litre flask. A few drops of phenolphthalein solution were then added together with 40 - 45 ml of sodium hydroxide to colour the content wine red.

The flask was then attached to the distillation apparatus and approximately 200 ml of liquid distilled over. The ammonium content in the distillate was then determined on Aqua - tec in mg L^{-1}. Aqua - tec (Tecator supplier) is an auto analyser which can be used to determine a range of chemical concentrations including the concentration of nitrogen in a sample solution after digestion.

Calculations: N in the sample was calculated by the following formula:

$$\text{mg g}^{-1} \text{ of N} = \frac{\text{mg N L}^{-1} \times \text{distillate (L)}}{\text{Oven dry weight of plant sample (g)}}$$

3.7 Statistical Analysis

Genstat 5, a command - based statistical package was used to analyse the data for yield and quality measurements, nutrient content, hollow stem and irrigation. Ordinal regression models for yield measurements and ordinal logistic regression (proportional - odds) models for the five point hollow stem (H. S.) ratings as a function of site or water delivered were used in trial 2 (summer 1993 / 94). The five point scale for hollow stem was the same as outlined earlier in section 3.5.

In trials 1 (spring 1993) and 3 (autumn 1994) and in year 1995 at sites 11 and 12, these ordinal logistic regression models for five point hollow stem ratings as a function of site or water delivered during an irrigation could not be fitted due to numerical problems (low number of heads affected by hollow stem in these trials), so the five point scale for rating hollow stem was collapsed to a three point scale as follows:

1. None 0% (1 on five point scale)
2. Initiation or nearly half of diameter of stem affected 0% - 50% (2 or 3 on the five point scale).
3. Getting close to full stem affected or covers whole stem 51% - 100% (4 or 5 on the five point scale).

When this was done, the ordinal logistic regression models could be fitted. These models use the logit link function.

4. RESULTS

4.1 FIELD TRIALS: Year 1 (1993/94)

4.1.1 BROCCOLI

TRIAL 1 (Spring) October - December 1993.

Trial 1 was carried on three grower's properties (sites 1, 2 and 3) and travelling irrigators were used .

SITE 1

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this site was a **loamy sand** (visual examination) and moisture characteristic curve has a water content percentage (g/g) values between 42% and 18% over a range of water potentials (Figure 5).

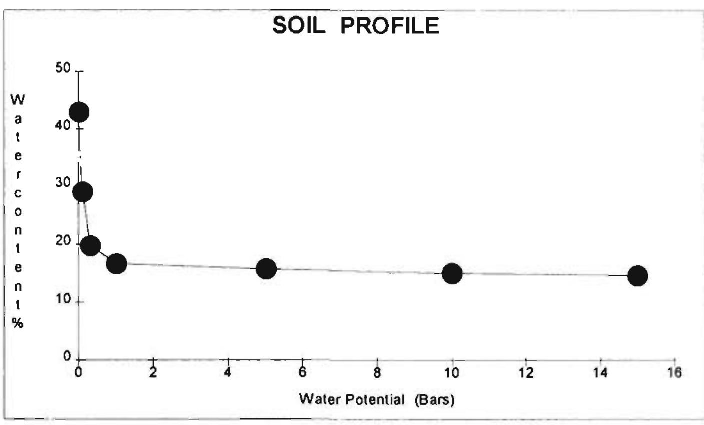

Figure 5: Moisture characteristic curve at different water potentials for site 1.

4.3.2 Field Soil Moisture Content

The percentage field soil moisture content values at 30 cm and 60 cm depths are given in the appendix (Table 1) and are shown in figure 6. The grower at this site watered in small water volumes compared to the other two growers and there was not much difference in water content at 30 and 60 cm depths (Figure 6).

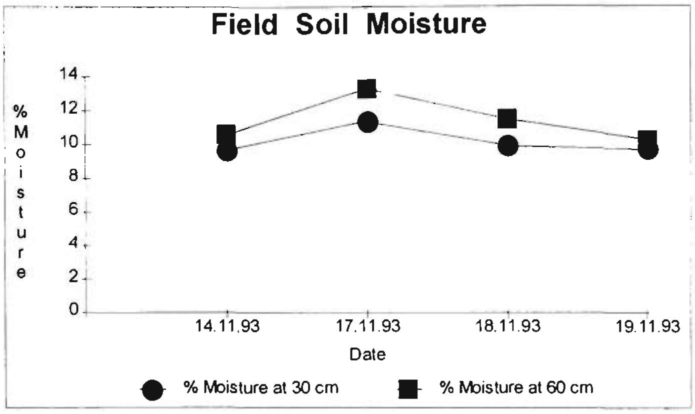

Figure 6: Field soil moisture content during an irrigation cycle at site 1.

4.3.3 Soil Moisture Tension (Irrometer/Tensiometer)

The soil moisture tension values at 30 cm and 60 cm depths are given in the appendix (Table 2) and plotted in figure 7. The field was irrigated on 14. 11. 93 when shallow tensiometer (30 cm) reading was 38 centibars.

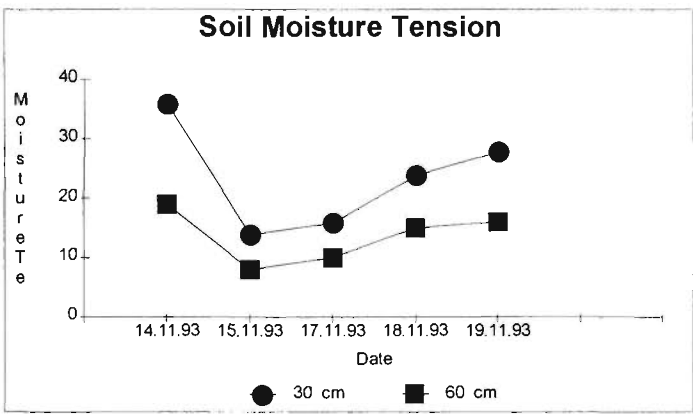

Figure 7: Irrometer readings for soil moisture tension (centibars) for an irrigation cycle at site 1.

4.4 & 4.5 Irrigation, Yield and Quality Measurements

The assessment of harvested broccoli heads for various quality attributes (sec. 3.5.1), overall yield measurements, and total water applied during crop growth at each of 20 locations over two irrigations (sec. 3.4) are given in Table 10. The amount of water delivered throughout the crop during an irrigation was very uneven. The position of the irrigator would account for some of this variation and other factors such as wind velocity and direction would have an influence. Plants in rows closest to the irrigator line (usually 1 - 4) received only a small amount of water compared to those planted in more distant rows (e.g. cans 1, 9 and 15 were placed in between rows 1 and 2 and received less water compared to cans 18 and 20 placed in row 20, see Table 10). Uniformity in water distribution with the spray gun irrigator was found only in distant rows (8 to 30) and plants in these rows were harvested one week earlier than those in the rows closest to the irrigator. The lower water values in cans 6, 9 and 17 (Table 10) are because these cans were knocked over during one irrigation. The water collected during irrigation varied with some cans receiving twice the amount as other cans (Table 10). In the sixty harvested broccoli heads taken out for measurements only four were affected with hollow stem disorder (Table 10) and none had a severe rating.

Legend:	**for Table 10**
H.Wt.	Fresh weight of harvested broccoli head.
H.D.	Head diameter of harvested broccoli head.
S.D.	Stem diameter of harvested broccoli head.
B.D.	Bud diameter of harvested broccoli head.
H.S.	Hollow stem rating in harvested head.
M.V.	Market value of broccoli head after taking out from cool room and 3 days at ambient temperature.
Bd.	Breakdown (any rot) in broccoli heads after taking out from cool room and 3 days at ambient temperature.
C (1-20)	Can numbers representing location in the field.
P (1-3)	Plants 1, 2 and 3 tagged around each can.
*	Head sample taken for nutrient analysis.
**	Cans knocked over during irrigation - These readings were not used for statistical analysis.

TABLE 10: Yield Measurements & Irrigation at site 1, Trial 1 (Oct. - Dec. 1993).

SAMPLE	H.Wt.	H.D.	S.D.	B.D.	H.S	MATURITY	M.V	Bd	WATER
	g	mm	mm	mm					mm
C1P1	177.7	108	33	30	1	5	5	1	36.9
P2	234.4	112	33	33	1	5	5	1	
P3	223.4	110	35	30	1	5 *			
C2P1	220.4	108	37	37	1	5	5	1	38.5
P2	317.8	105	35	30	1	5	5	1	
P3	347.5	130	38	36	1	8	2	3	
C3P1	56.6	50	25	13	1	1	1	1	38.3
P2	175.9	95	35	30	1	5	4	1	
P3	168.9	92	33	34	1	5 *			
C4P1	186	106	33	34	1	6	4	2	42.2
P2	250.2	115	38	30	1	5	5	1	
P3	116.2	90	28	25	1	5	5	1	
C5P1	298.5	120	38	35	1	5	5	1	30.3
P2	394.5	135	39	34	1	6	4	1	
P3	498.8	155	40	38	1	7	2	2	
C6P1	195.7	110	34	33	1	5	5	1	21.2**
P2	250.6	120	30	34	1	5	5	1	
P3	216.7	115	34	35	1	5	5	1	
C7P1	164.7	96	32	35	1	5 *			40.9
P2	297.6	118	36	43	1	7	5	1	
P3	213.5	105	30	34	1	5	5	1	
C8P1	314	120	39	40	1	6	4	2	43
P2	193.3	100	35	38	1	5	5	1	
P3	162.6	90	30	36	1	5	5	1	
C9P1	83	69	29	26	1	2 *			16.5**
P2	56.2	58	24	23	1	1	1	1	
P3	75.7	65	25	25	1	1	1	1	
C10P1	160.2	96	33	32	1	4	4	1	31.5
P2	169.8	106	34	28	1	4	4	1	
P3	99.7	67	29	22	1	3	1	1	
C11P1	99	70	31	26	1	3	1	1	41.2
P2	202.9	95	30	24	1	5	5	1	
P3	291.6	110	39	35	1	5 *			
C12P1	206.7	115	32	37	1	5	4	2	35.7
P2	175.9	108	39	36	1	5	5	1	
P3	226.2	120	35	32	1	5	4	1	
C13P1	112.9	70	28	25	1	3	1	1	37.4
P2	234.8	116	33	29	1	5	5	1	
P3	315.6	136	35	34	1	6	4	1	
C14P1	259.1	130	33	39	1	5 *			31.9
P2	171.5	99	36	34	1	5	5	1	
P3	248.9	135	34	43	1	6	5	1	
C15P1	210.4	110	38	35	1	5	5	1	30.3
P2	188.8	109	34	35	1	5	5	1	
P3	332.8	140	40	43	1	7	2	3	
C16P1	412.2	170	38	45	2	10 *			58.7
P2	175.6	100	35	36	1	5	5	1	
P3	148.9	97	37	26	1	5	5	1	
C17P1	245.7	125	38	35	1	5	5	1	26.3**
P2	227.6	122	37	38	1	5	5	1	
P3	298.5	135	40	38	1	6	5	1	
C18P1	671.3	190	49	56	3	10	2	3	68.8
P2	482.5	150	45	40	2	9	2	3	
P3	399.5	135	40	40	2	8 *			
C19P1	215	115	35	32	1	5	5	1	45.6
P2	210.4	112	35	34	1	5	5	1	
P3	188.4	108	33	32	1	5 *			
C20P1	430.4	160	40	38	1	8	5	1	53.4
P2	275.6	119	35	35	1	5	5	1	
P3	310.5	135	36	33	1	6 *			

Legend: see previous page.

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter (of fifteen plants) are given in the appendix (Table 3) and average fresh and dry weights are plotted in figure 8.

The average dry matter of 18.5% at transplanting and 12.3% at harvest (Table 3 in the appendix) indicates that water is the main component of broccoli. Percentage dry matter decreased with plant maturity.

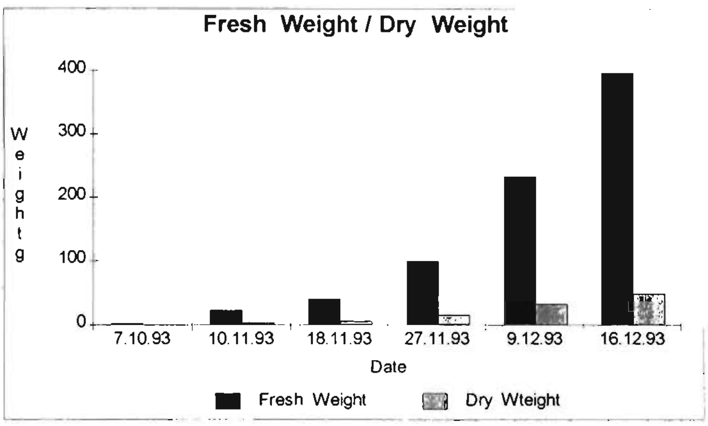

Figure 8: The average fresh and dry weights of broccoli plants for site 1.

4.6.3 Nutrient Analysis

The results of the tissue analysis are given in the appendix (Table 4).

Graphs of parameters which are known to significantly affect hollow stem rating, head weight and nutrient uptake are plotted in figures 9 - 13. Statistical analysis of all data is outlined on page 56. Hollow stem rating increased with increasing amount of water delivered to plants (Figure 9).

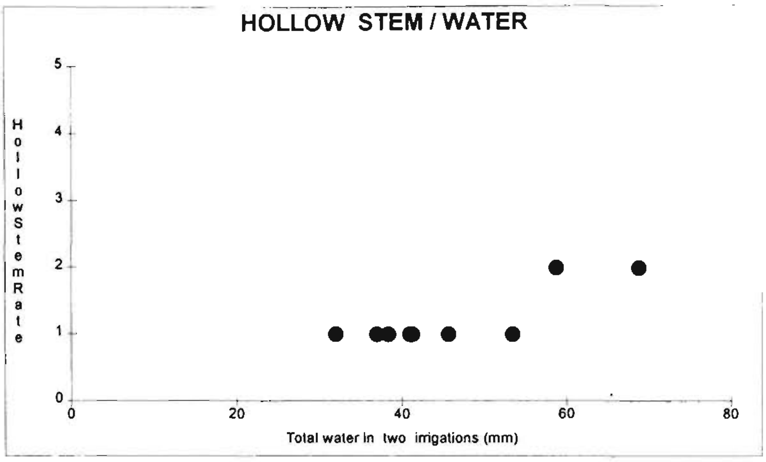

Figure 9: Hollow stem rating as affected by irrigation water.

Concentration of boron (B) decreased with increasing water application (Figure 10).

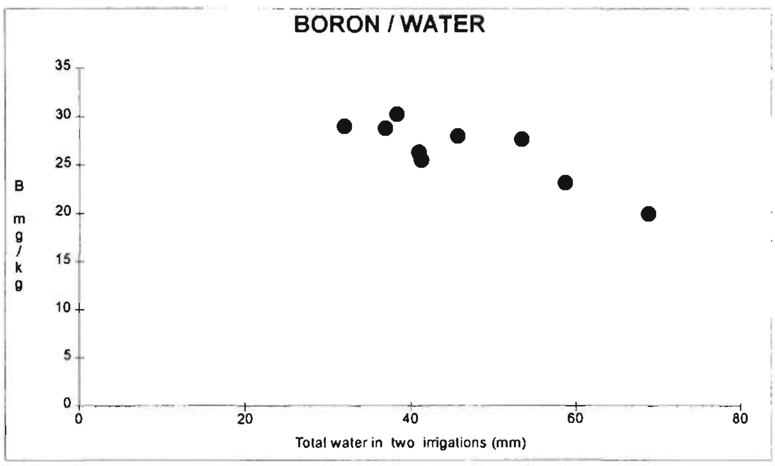

Figure 10: Concentration of B as affected by irrigation water.

Concentration of B was positively related to hollow stem rating; with greater B concentration there was less severe hollow stem rating (Figure 11).

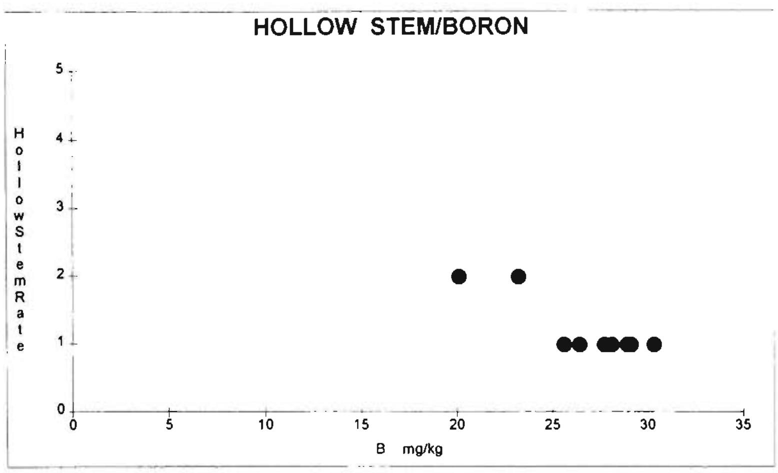

Figure 11: Hollow stem rating as affected by B concentration.

A high concentration of tissue N is likely to be associated with a high hollow stem rating (Figure 12).

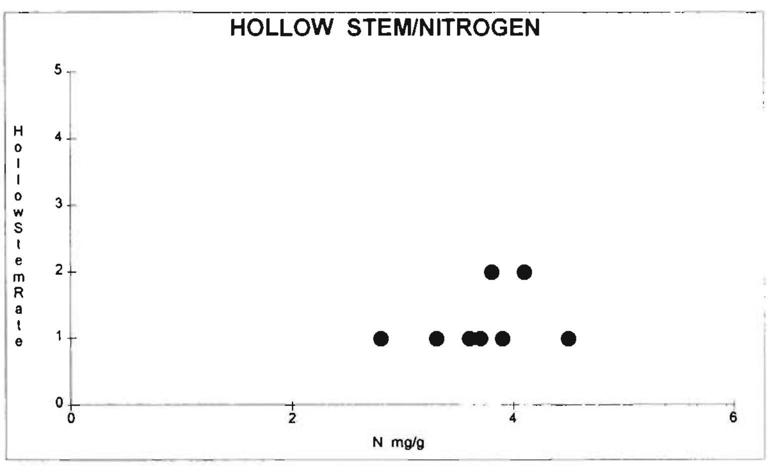

Figure 12: Hollow stem rating as affected by N concentration.

In general, broccoli head weight increased with increasing amount of water applied by irrigation (Figure 13).

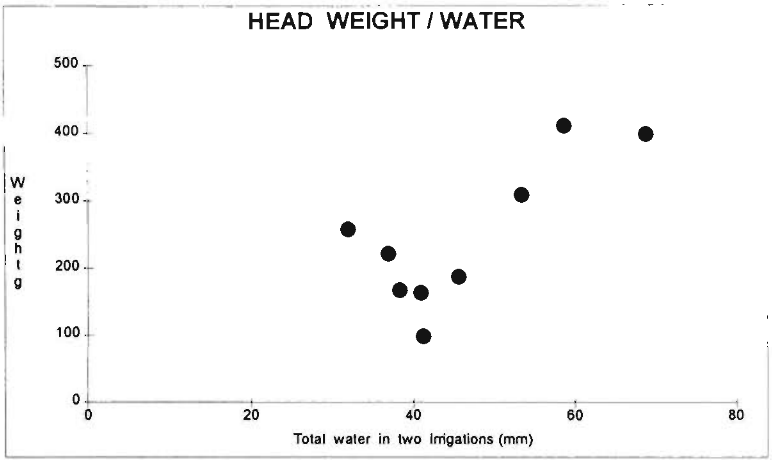

Figure 13: Head weight as affected by irrigation water.

SITE 2

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this site was a **clay loam** (visual examination) and moisture characteristic curve has a water content percentage (g/g) values between 49.5% and 16.8% over a range of water potentials (Figure 14).

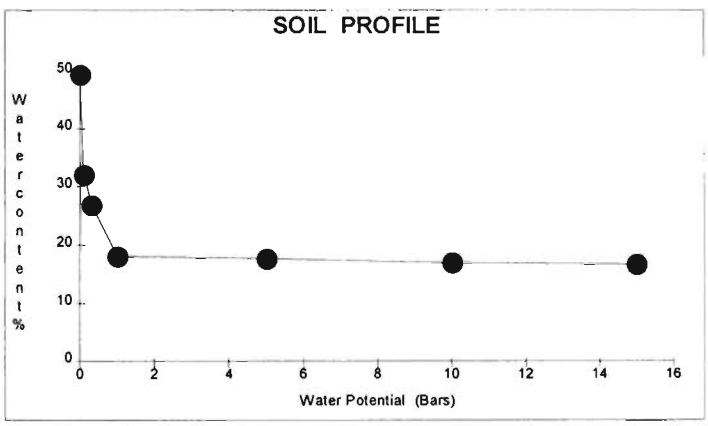

Figure 14: Moisture characteristic curve at different water potentials for site 2.

4.3.2 Field Soil Moisture Content

The percentage field soil moisture content values at 30 cm and 60 cm depths are given in the appendix (Table 5) and is shown in figure 15.

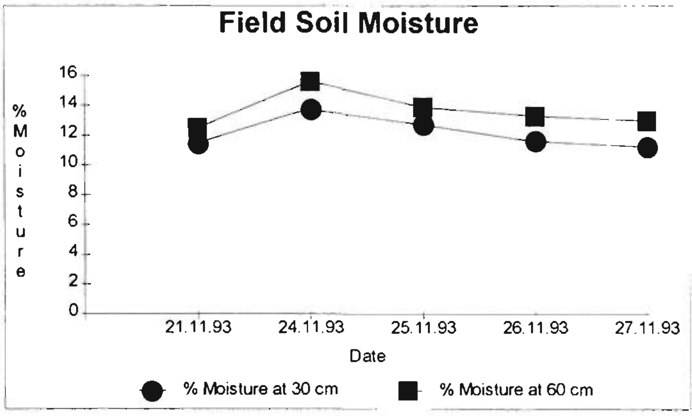

Figure 15: Field soil moisture content during an irrigation cycle at site 2.

4.3.3 Soil Moisture Tension (Irrometer/Tensiometer)

The soil moisture tension values at 30 cm and 60 cm depths are given in the appendix (Table 6) and plotted in figure 16. The field was irrigated on 21. 11. 93 when the irrometer reading was at 55 centibars at 30 cm depth.

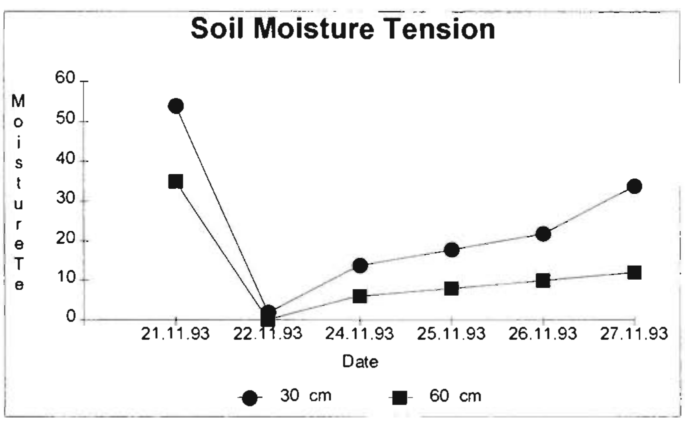

Figure 16: Irrometer readings for soil moisture tension (centibars) for an irrigation cycle at site 2.

4.4 & 4.5 Irrigation, Yield and quality measurements

The assessment for various quality attributes (sec. 3.5.1), yield measurements, and total water applied over two irrigations until harvest (sec. 3.4) are given in Table 11. The water distribution using an arm type irrigator was very uneven (some plants such as those represented by can 5, receiving more than twice as much water as others e.g. cans 1 and 12 - Table 11) and the total output of water over the two irrigations was greater at this site than site 1. The variation in water distribution was found along as well as across the rows. In general the plant frames were bigger compared with those at site one. Thirteen out of sixty harvested heads (22%) had hollow stem disorder, with only three having severe (4-5) rating.

TABLE 11: Yield Measurements & Irrigation at site 2, Trial 1 (Oct. - Dec. 1993).

SAMPLE	H.Wt.	H.D.	S.D.	B.D.	MATURITY	H.S.	M.V.	Bd	WATER
	g	mm	mm	mm					mm
C1P1	288.7	125	35	39	6	1	4	1	60.7
P2	194.5	106	35	37	4	1	5	1	
P3	244.9	118	34	34	5	1	5	1	
C2P1	130.6	80	35	28	3	1	1	1	101.7
P2	250.6	110	37	33	5	3	*		
P3	270.9	115	38	34	5	1	5	1	
C3P1	197.2	103	36	35	5	1	*		81.5
P2	228.8	116	36	31	5	1	5	1	
P3	223.4	108	39	32	5	1	5	1	
C4P1	204.6	105	35	32	5	1	5	1	80.4
P2	302	125	43	33	5	2	5	1	
P3	247.7	102	36	41	5	1	5	1	
C5P1	283.8	110	38	35	5	4	5	1	131.4
P2	224.7	105	45	40	5	5	4	2	
P3	307.8	125	45	40	6	5	*		
C6P1	251.9	100	40	32	5	1	5	1	84.6
P2	251.1	105	41	38	5	1	5	1	
P3	244.8	103	38	35	5	1	5	1	
C7P1	133.32	80	32	25	3	1	1	1	66.6
P2	257.9	120	37	30	5	1	5	1	
P3	296.3	120	39	35	5	1	*		
C8P1	267.7	110	40	35	5	1	5	1	67.9
P2	175.2	103	37	33	4	1	4	2	
P3	284.6	115	38	35	5	1	5	1	
C9P1	149.98	92	30	25	3	1	1	1	82.4
P2	156.8	95	33	28	4	1	5	1	
P3	138.1	81	35	31	3	1	*		
C10P1	160.6	110	35	40	4	1	4	2	95
P2	209.5	115	39	30	5	1	5	1	
P3	224	120	37	38	5	2	5	1	
C11P1	181.1	95	35	30	5	1	5	1	99.5
P2	228.5	105	35	36	5	1	5	1	
P3	262.9	110	40	38	5	3	*		
C12P1	254	120	41	32	5	1	5	1	61
P2	296.3	118	40	38	6	2	*		
P3	210	110	35	32	5	1	5	1	
C13P1	149.3	92	35	28	4	1	5	1	86
P2	112.5	69	32	28	2	1	1	1	
P3	118.4	68	36	20	2	1	1	1	
C14P1	127.7	80	38	32	3	1	1	3	79.6
P2	212.2	105	38	35	5	1	5	1	
P3	212.6	105	38	33	5	1	4	2	
C15P1	252.2	110	34	35	5	1	5	1	87
P2	295.4	115	37	32	6	1	*		
P3	285.8	112	37	30	5	1	5	1	
C16P1	270.7	120	45	36	5	1	5	1	70.7
P2	176.5	100	39	35	5	2	5	1	
P3	133.7	70	39	20	4	1	5	1	
C17P1	257.9	120	37	30	5	1	5	1	83.6
P2	328.5	125	40	38	6	1	*		
P3	280.9	115	38	35	5	1	5	1	
C18P1	181.4	102	35	30	5	1	5	1	87.8
P2	112.5	85	30	25	3	1	1	1	
P3	202.3	108	36	32	5	1	5	1	
C19P1	284.1	118	40	35	5	1	5	1	76.6
P2	291.7	125	39	30	6	2	*		
P3	277.7	120	36	37	5	2	4	3	
C20P1	270.5	115	35	32	5	1	5	1	95.4
P2	257.8	110	40	34	5	2	5	1	
P3	321.3	130	40	35	6	2	*		

Legend: As Table 10 on page 42.

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter for each sampling during the trial are given in the appendix (Table 7) and fresh and dry weights are presented in figure 17.

The plant fresh weight increased two fold on every sampling and percentage dry matter was 18.2% at transplanting and 13% at harvest (Table 7 of the appendix). These results are similar to those for plants harvested at site 1.

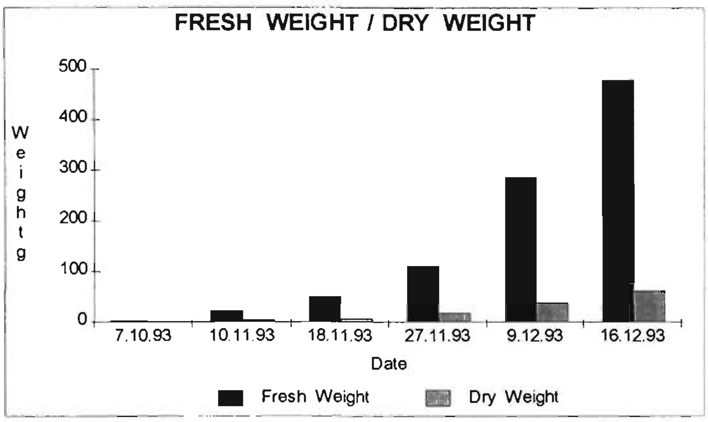

Figure 17: The average fresh and dry weights of broccoli plants for site 2.

4.6.3 Nutrient Analysis

The results of the tissue analysis are given in Table 8 in the appendix.

Graphs of parameters which are known to significantly affect hollow stem rating, head weight or nutrient uptake are plotted in figures 18 - 21. A high rating of hollow stem occurred at higher water application rates (Figure 18).

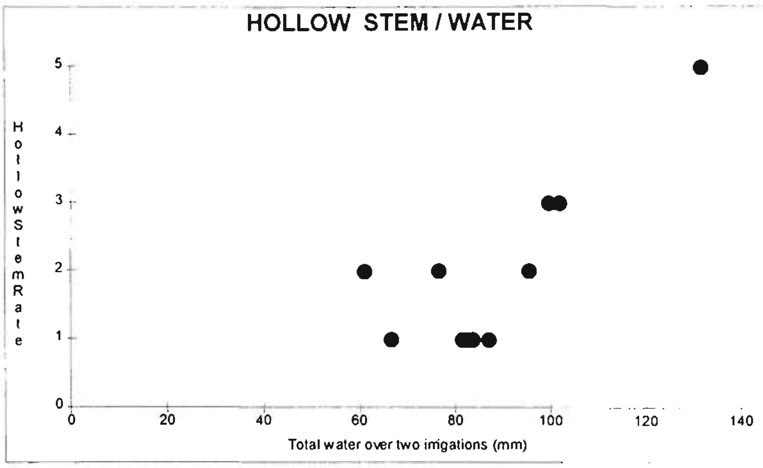

Figure 18: Hollow stem rating as affected by irrigation water.

B concentration in tissue decreased with greater water application. This is probably as a result of some water logging conditions during plant growth (Figure 19).

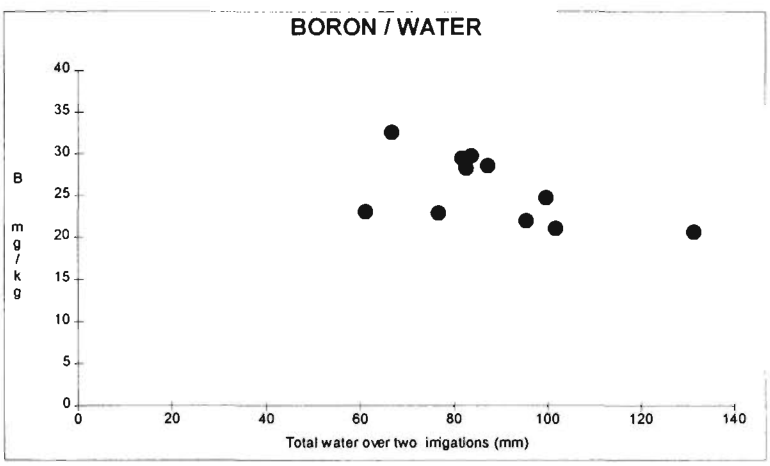

Figure 19: B concentration as affected by irrigation water.

The occurrence of higher hollow stem rating is related to lower B concentration (Figure 20).

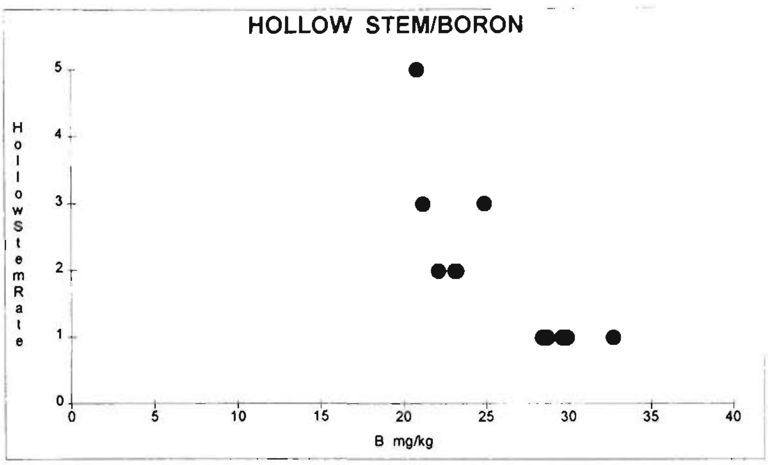

Figure 20: Hollow stem rating as affected by B concentration.

High hollow stem ratings were found in heads with higher N concentration levels (Figure 21).

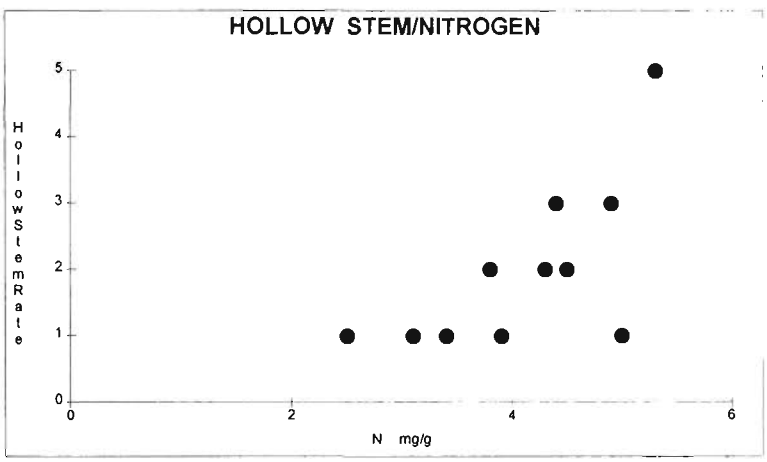

Figure 21: Hollow stem rating as affected by N concentration.

SITE 3

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at was a **clay loam** (visual examination) and its moisture characteristic curve has a water content percentage (g/g) values between 63.1% and 25.4% over a range of water potentials.

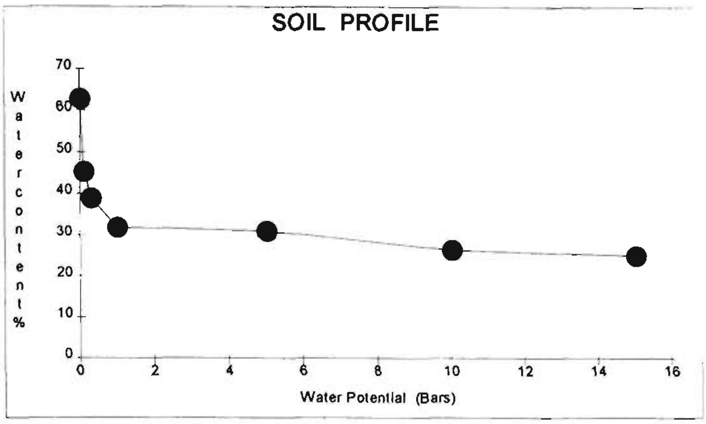

Figure 22: Moisture characteristic curve at different water potentials for site 3.

4.3.2 Field Soil Moisture Content

The percentage field soil moisture content values at 30 cm and 60 cm depths are given in the appendix (Table 9) and are shown in figure 23. The grower at this property applied a greater water volume and the irrigation cycle went for more days than at sites 1 and 2.

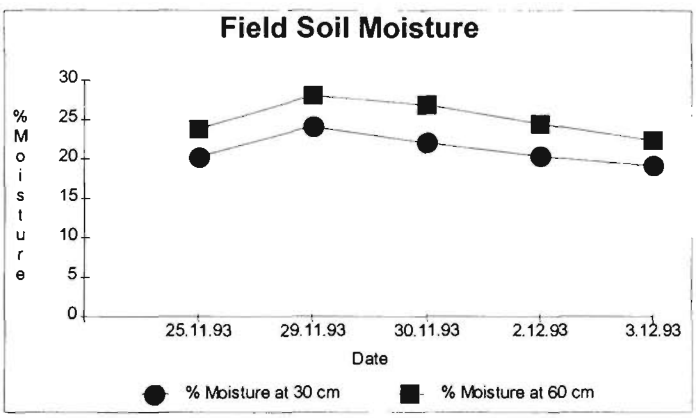

Figure 23: Field soil moisture content during an irrigation cycle at site 3.

4.3.3 Soil Moisture Tension (Irrometer / Tensiometer)

The soil moisture tension values at 30 cm and 60 cm depths are given in the appendix (Table 10) and plotted in figure 24. This grower irrigated on 26. 11. 93 at 78 centibars which shows that the soil was very dry and the next irrigation was also initiated on a very high reading (90 centibars) on the tensiometer gauge.

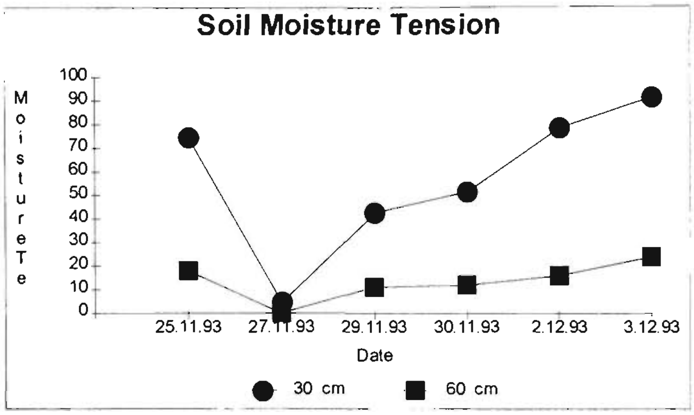

Figure 24: Irrometer readings for soil moisture tension (centibars) for an irrigation cycle at site 3.

4.4 & 4.5 Irrigation, Yield and Quality measurements

The quality assessment for various attributes (sec. 3.5.1), yield measurements and water delivered in one irrigation during crop growth (sec. 3.4) are given in Table 12. As with site 2, the water distribution with an arm type irrigator was very uneven (variation of two fold) e.g. cans 1, 7 and 8 received twice the water volume compared with water collected in cans 9, 10 and 20 (Table 12). The water volume delivered (with one irrigation) at this site was greater than that delivered by the spray-gun irrigator used at site 1 (over two irrigations). The variation in water distribution was found along as well as across the rows. The grower irrigated only once and applied more water than at sites 1 and 2. As a result, some of this water may not have reached its target. Much of the water applied would have been in excess of crop requirements and was probably wasted, creating adverse conditions such as water logging. Fifty seven out of the sixty (95%) broccoli heads had hollow stem and nearly 50% were severely affected (rating 4-5). The average plant frame was much bigger (up to three times) than for samples collected at sites 1 and 2 (Tables 3, 7, and 11 in the appendix).

TABLE 12: Yield Measurements & Irrigation at site 3, Trial 1 (Oct.-Dec. 1993).

SAMPLE	H.Wt.	H.D.	B.D.	S.D.	MATURITY	H.S.	M.V.	Bd	WATER
	g	mm	mm	mm					mm
C1P1	175.6	90	32	38	5	5	5	1	89.5
P2	199	95	29	36	4	4	5	1	
P3	202.9	110	32	42	5	5 *			
C2P1	166.2	76	25	42	5	4	5	1	83.5
P2	184.5	78	35	43	5	4 *			
P3	207.5	94	33	34	5	3	5	1	
C3P1	193.8	95	33	35	4	2	5	1	67.7
P2	174.8	90	30	38	4	2	5	1	
P3	193.6	92	32	35	4	2	5	1	
C4P1	153	80	28	40	5	3	4	1	80.7
P2	156	88	32	39	5	5	5	1	
P3	310.8	114	36	46	6	5	4	1	
C5P1	286.6	115	35	42	5	4	2	1	88.4
P2	178.8	98	32	40	5	4 *			
P3	123.1	85	28	35	3	3	2	1	
C6P1	227.5	90	32	35	5	2 *			71.7
P2	311.4	104	44	42	6	2	5	1	
P3	207.5	89	31	36	5	2	5	1	
C7P1	192.8	89	34	32	5	4	5	1	96.6
P2	259	99	38	41	6	5	5	1	
P3	294.7	125	42	47	6	5	5	1	
C8P1	240.8	105	38	40	5	5	5	1	94.8
P2	260.8	106	35	41	5	5 *			
P3	365.5	130	46	45	6	5	5	1	
C9P1	251.9	110	35	40	5	2	4	1	51.6
P2	254.1	115	32	38	5	2 *			
P3	296.1	118	38	43	5	2	4	1	
C10P1	135.2	75	25	30	3	1 *			44.5
P2	142.1	60	20	28	3	1	1	1	
P3	101.2	55	18	25	2	1	1	1	
C11P1	169.6	85	28	44	5	5 *			80.7
P2	142.9	76	30	32	3	4	3	1	
P3	224.6	94	34	36	5	5	5	1	
C12P1	212.9	102	38	35	5	2	5	1	53.7
P2	234.2	108	40	40	5	2	5	1	
P3	315.6	118	43	45	6	4 *			
C13P1	327.8	130	35	42	6	5	4	1	90.5
P2	411.5	140	35	54	6	5	3	1	
P3	470.1	145	47	49	6	5	3	1	
C14P1	201.2	95	35	36	5	3	5	1	72.7
P2	121.9	72	28	38	3	2	4	1	
P3	241.4	105	35	38	5	3	5	1	
C15P1	293.9	110	38	48	5	5	5	1	60.9
P2	240.6	105	35	40	5	4 *			
P3	177.5	95	33	33	5	3	5	1	
C16P1	216.8	105	35	40	5	3	5	1	61.6
P2	219.8	108	34	42	5	2	5	1	
P3	270.2	115	32	48	5	3 *			
C17P1	324.6	115	40	37	7	3	3	1	65
P2	162.9	89	29	30	4	4	4	1	
P3	145.5	84	25	36	4	2	4	1	
C18P1	198.2	102	35	42	5	2	5	1	67.9
P2	174.2	100	30	42	5	2 *			
P3	150.4	95	28	40	5	2	5	1	
C19P1	269	112	41	43	5	4	5	1	63.2
P2	193.7	100	36	40	5	3	5	1	
P3	330.4	120	40	45	5	4 *			
C20P1	200.9	105	35	40	5	2	5	1	45.2
P2	187.5	100	34	38	5	2	5	1	
P3	182.5	100	32	36	5	2	5	1	

Legend: As Table 10 on page 42

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 11) and fresh and dry weights are plotted in figure 25.

The average final fresh weight of samples taken at this site was greater than for samples taken at the other sites and the dry matter was only 9.2% (Table 11 of the appendix). The plant frames were large when compared to plants at other two sites but there was very little difference between the head weights at the three sites.

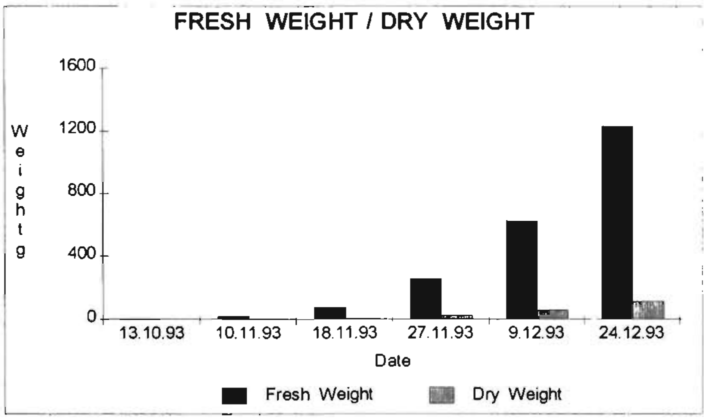

Figure 25: The average fresh and dry weights of broccoli plants for site 3.

4.6.3 Nutrient analysis

The results of tissue analysis are given in Table 12 in the appendix.

Graphs of parameters which are known to significantly affect hollow stem rating, head weight and nutrient uptake are presented in figures 26 - 30. The hollow stem rating increased with increasing amount of water applied (Figure 26).

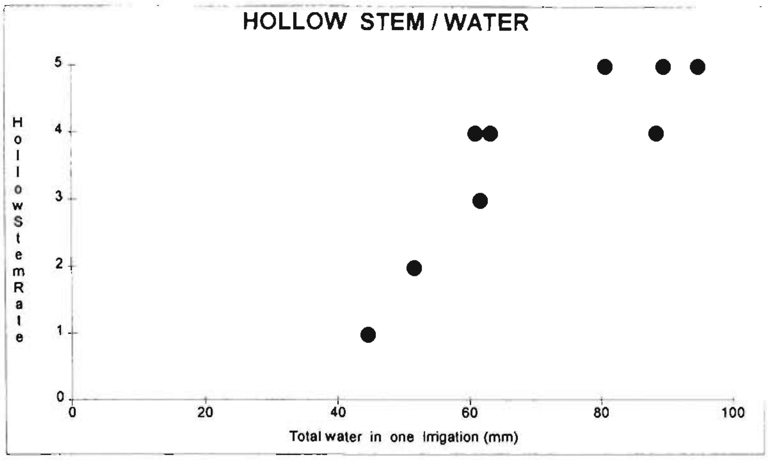

Figure 26: Hollow stem rating as affected by irrigation water.

B concentration in tissue was found to decrease with increasing amount of water applied (Figure 27).

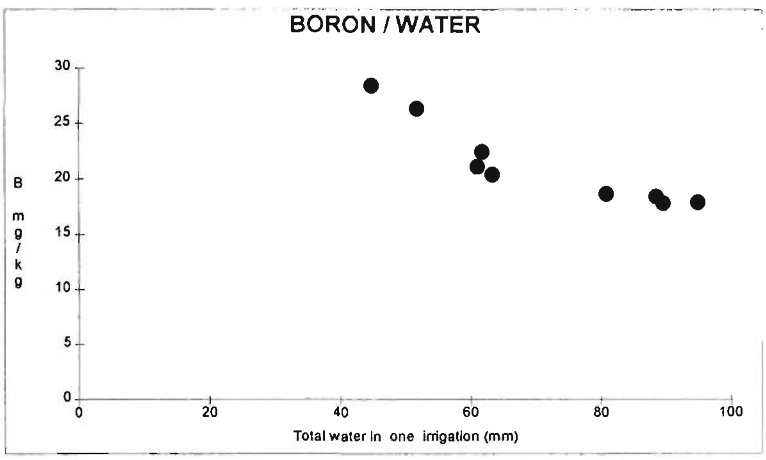

Figure 27: B concentration as affected by irrigation water.

Plants with lower B concentrations showed more severe hollow stem (Figure 28).

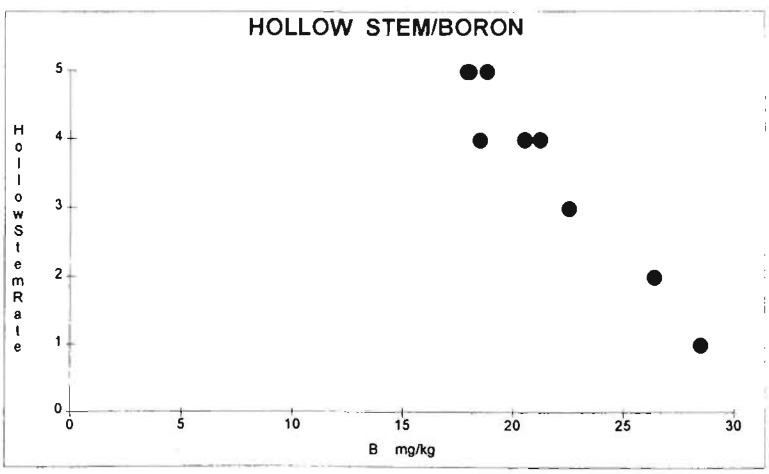

Figure 28: Hollow stem rating as affected by B concentration.

Plants with higher tissue N concentration showed higher hollow stem rating (Figure 29).

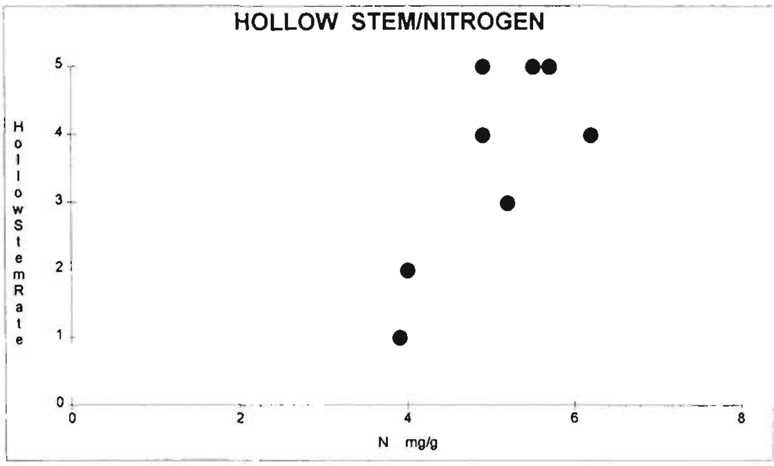

Figure 29: Hollow stem rating as affected by N concentration.

The head weight of broccoli increased with increasing water applied up to 70 mm, but showed significantly lower weights at irrigation levels in the range 80-95 mm (Figure 26).

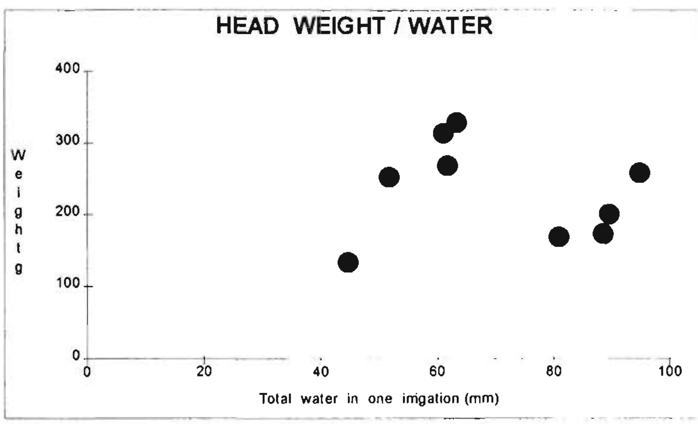

Figure 30: Broccoli head weight as affected by irrigation water.

4.7 Statistical analyses of yield parameters and irrigation application across the three sites for trial 1 (spring crops).

a) Yield and Quality measurements

Moderately high correlations at the three sites between fresh weight, head diameter, stem diameter, bud diameter and maturity were found (Table 13).

TABLE 13: Correlation matrix between Yield and Quality parameters across the three sites - Trial 1.

F. Wt.	1.000						
H.D.	0.900	1.000					
S.D.	0.702	0.711	1.000				
B.D.	0.651	0.610	0.453	1.000			
H.S.	0.220	0.048	0.115	0.543	1.000		
Maturity	0.838	0.850	0.638	0.658	0.179	1.000	
M.V.	0.152	0.317	0.303	0.306	0.077	0.396	1.000
Bd	0.350	0.325	0.278	0.212	-0.051	0.357	-0.331
	F. Wt.	H.D.	S.D.	B.D.	H.S.	Maturity	Bd

The per plant yield measurements, fresh weight, head diameter, stem diameter and bud diameter were regressed on sites (1 and 2) against amount of water applied and hollow stem ratings. Results for sites 1 and 2 were regressed and compared with results for site 3. These results are summarised in Table 14.

TABLE 14: Yield Analysis for Trial 1

Yield measurement	Significance (p-values) of......				
	Site 1	Site 2	Water	ollow ste	R (%)
F. Wt.	< 0.001	0.040	0.588	0.001	10.8
H.D.	< 0.001	0.002	0.906	0.001	12.5
S.d.	< 0.001	< 0.001	0.983	< 0.001	23.4
B.D.	0.706	0.280	0.932	< 0.001	32.7

Legend: for Table 13 and 14.

F.Wt. Fresh weight of harvested broccoli head.

H.D. Head diameter of harvested broccoli head.

S.D. Stem diameter of harvested broccoli head.

B.D. Bud diameter of harvested broccoli head.

M.V. Market value

H.S. Hollow stem rate

Bd Breakdown

p-values probability values.

R^2% percentage regression.

Water does not appear to have had a significant effect on the yield variables and the R^2 values are disappointingly low.

There was a significant difference between the sites in hollow stem rating ($p < 0.0001$) with a significantly higher probability of greater hollow stem ratings at site 3, compared to the other two sites. The probability of a high hollow stem rating increased with the amount of water applied to the plant ($p < 0.0001$). There were no significant differences in the market value ratings attributable to site or water.

b) Nutrient analysis

At all three sites a moderately strong negative correlation was found between B and N, and moderate negative correlations between water applied and concentration of B, and of Ca, water and nitrogen, were also found (Table 15).

TABLE 15: Correlation matrix between Water and nutrients across the three sites - Trial 1.

Water applied	1.000				
Boron	-0.502	1.000			
Nitrogen	0.548	-0.765	1.000		
Potassium	0.349	-0.138	0.453	1.000	
Calcium	-0.509	0.084	0.009	-0.240	1.000
	Water applied	Boron	Nitrogen	Potassium	Calcium

There were site differences in amount of water applied, hollow stem, B, N, and Ca.

The single-variable models which best fitted the hollow stem ratings are presented in Table 16.

TABLE 16: Effect of a Number of Variables on Hollow Stem Ratings for Trial 1

Variable Name	Regression Deviance (df)	Residual Deviance (df)	p - value for added variable
Boron	45.39 (1)	9.91 (23)	< 0.0001
Nitrogen	25.19 (1)	30.11 (23)	< 0.0001
Site	18.87 (2)	36.42 (22)	< 0.0001
Water	8.9 (1)	46.4 (23)	0.0029

The probability of a high hollow stem rating decreased with higher level of B, but increased with higher level of N, and to a lesser extent, water. Models with two or more variables could not be fitted due to numerical problems associated with the small number of plants with hollow stem at site 1 (and their low but identical hollow stem ratings).

TRIAL 2 (Summer) December 1993 - February 1994.

Trial 2 was carried out on three seperate properties of the three same growers (trial 1) but in different paddocks (sites 4, 5 and 6).

SITE 4

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this was **loamy sand** (visual examination) and its moisture characteristic curve has a water content percentage (g/g) values between 40.1% and 16.3% over a range of water potentials.

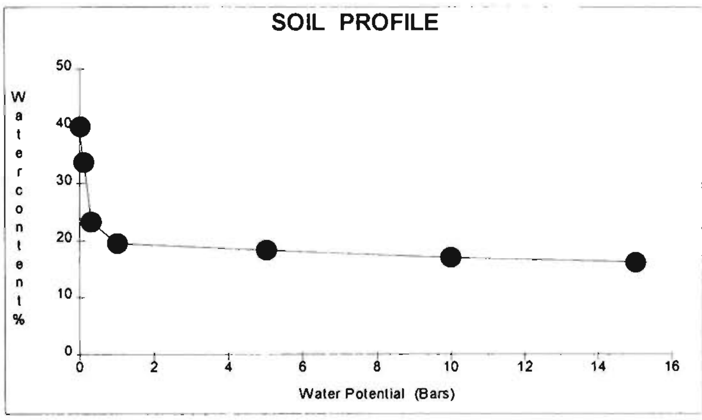

Figure 31: Moisture retention curve at different water potentials for site 4.

4.3.2 Field Soil Moisture Content

The percentage field soil moisture content values at 30 cm and 60 cm depths over an irrigation cycle are given in the appendix (Table 13) and are shown in figure 32.

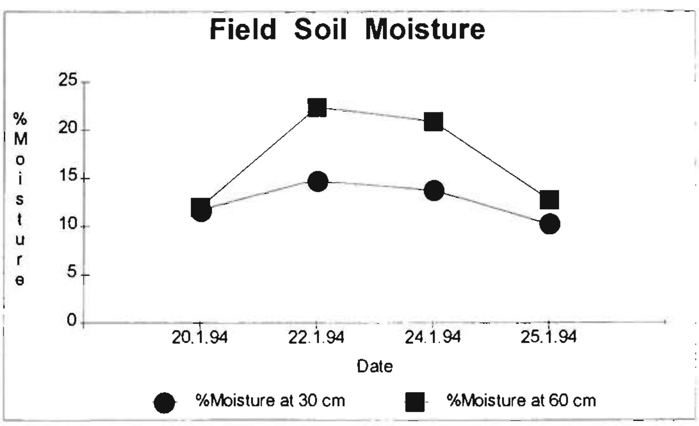

Figure 32: Field soil moisture content during an irrigation cycle at site 4.

4.3.3 Soil Moisture Tension (Irrometer/Tensiometer)

The soil moisture tension values at 30 cm and 60 cm depths are given in the appendix (Table 14) and plotted in figure 33. The weather was very hot and the irrometer readings indicate that the paddock should have been irrigated more frequently or with greater water volume (depending on weather conditions) at low tensiometer readings. Irrigation was commenced on 21. 1. 94 and cycle completed on 25. 1.94.

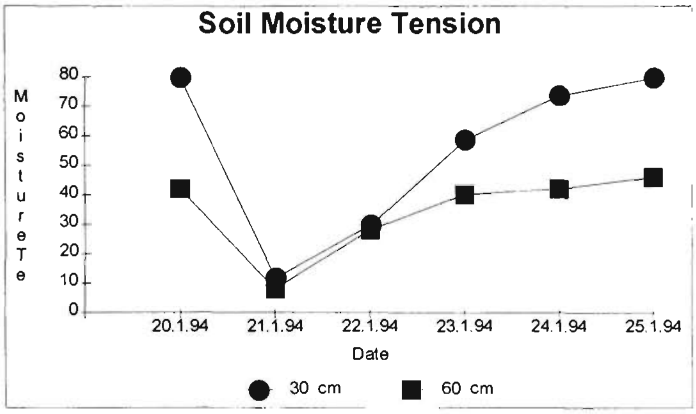

Figure 33 : Irrometer readings for soil moisture tension (centibars) for an irrigation cycle at site 4.

4.4 & 4.5 Irrigation, Yield and Quality measurements

The quality assessment for various attributes (sec. 3.5.1), yield measurements and total water delivered over three irrigations (sec. 3.4) are given in Table 17. As in trial 1, the water distributed over an irrigation was very uneven. At some collection sites (e.g. cans 8 and 11) water collected was more than twice the amount collected at others (e.g. cans 5 and 7 - see Table 17). The lower volume of water recorded for cans 6 and 12 is because these cans were knocked over during one irrigation. This grower watered more frequently but applied less water at each irrigation compared to the other two growers. In sixty harvested broccoli heads, twenty-three (33%) were affected with hollow stem disorder, but severe occurrence (rating 4-5) was found in only three heads (Table 17).

TABLE 17: Yield Measurements & Irrigation at site 4, Trial 2 (Dec. '93-Feb. '94).

SAMPLE	H.Wt.	H.D.	S.D.	B.D.	H.S.	MATURITY	M.V.	Bd	WATER
	g	mm	mm	mm					mm
C1P1	166.3	90	32	32	1	5	5	1	67.2
P2	235	105	40	47	1	5	4	1	
P3	294.5	120	48	40	2	6	*		
C2P1	218.4	130	32	33	5	6	*		72.5
P2	220.4	120	33	41	2	7	3	2	
P3	251.6	125	42	44	3	5	5	1	
C3P1	246.2	115	37	40	2	5	*		56.8
P2	162.6	105	29	34	1	5	4	1	
P3	198.3	80	32	30	1	5	4	1	
C4P1	173.3	110	32	37	1	5	2	2	45.4
P2	156.9	105	34	40	1	5	5	1	
P3	149.5	80	34	30	1	4	*		
C5P1	237.1	110	40	43	3	6	4	1	96.6
P2	268.4	125	39	41	4	5	*		
P3	259.1	135	37	43	4	5	4	1	
C6P1	142.1	90	32	38	2	4	4	2	34.85**
P2	154.1	90	32	30	1	5	2	3	
P3	209.3	115	37	40	2	5	5	1	
C7P1	192.1	110	32	34	5	5	*		97.2
P2	168.5	110	31	32	1	5	5	1	
P3	195.9	110	35	38	1	5	4	1	
C8P1	258.9	125	39	40	1	5	*		39.2
P2	145.8	95	33	38	2	5	3	1	
P3	256.4	125	41	42	3	5	5	1	
C9P1	253.3	120	41	41	1	5	*		40.2
P2	171.7	105	30	31	1	5	4	1	
P3	149.5	100	30	35	1	5	5	1	
C10P1	178.7	110	29	32	1	6	3	2	72.5
P2	210.4	100	32	38	2	7	4	1	
P3	174.5	100	38	40	2	4	4	1	
C11P1	115.8	90	30	30	1	4	*		38.8
P2	137.5	90	35	34	1	4	5	1	
P3	132.4	90	30	30	1	4	4	1	
C12P1	191.8	110	30	33	3	5	5	1	22.5**
P2	184.7	110	29	35	3	5	*		
P3	161.9	115	30	32	1	6	3	1	
C13P1	231.6	125	30	42	1	5	4	1	49.13
P2	211	115	32	37	1	6	*		
P3	236.8	110	38	35	2	5	5	1	
C14P1	183.3	95	35	39	1	5	5	1	40.2
P2	156	100	27	40	1	5	4	2	
P3	159.9	110	35	35	1	5	*		
C15P1	138	100	29	35	1	4	3	1	47.1
P2	176.3	100	34	39	1	5	5	1	
P3	163.5	110	31	40	1	5	5	1	
C16P1	190	110	35	39	1	5	*		43.5
P2	246.2	155	38	35	1	7	2	4	
P3	240.6	160	40	55	1	10	1	5	
C17P1	180.9	105	40	37	1	5	*		47.4
P2	201.1	110	34	39	2	5	5	1	
P3	166.6	100	33	34	1	6	4	1	
C18P1	182.8	120	30	33	1	5	1	1	47.3
P2	269.9	140	42	42	2	9	1	2	
P3	250.9	130	41	41	1	9	1	5	
C19P1	159.8	100	32	32	1	6	3	1	63.8
P2	167.9	95	36	34	1	5	4	1	
P3	205.6	120	34	34	2	8	*		
C20P1	174.5	100	33	40	1	5	5	1	49.2
P2	215.6	110	37	37	2	5	*		
P3	259.5	115	42	42	3	6	4	2	

Legend: As Table 10 on page 42

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 15) and average fresh and dry weights over time are plotted below (Figure 34).

The plant growth was faster than in trial 1 and average plant size was also larger throughout growth period. The percentage dry matter decreased from 20.2% at the first sampling to 9.1% at harvest (see Table 15 in the appendix). The percentage of dry matter was less than at harvest in trial 1, site 1 on the property of the same grower.

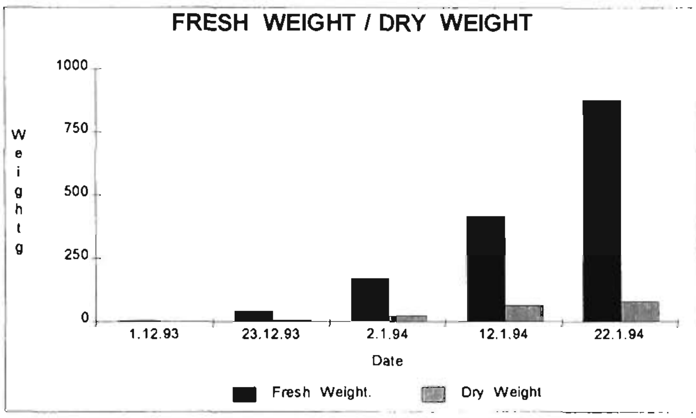

Figure 34: The average fresh weight and dry weight of broccoli plants for site 4.

4.6.3 Nutrient Analysis

The results of tissue analysis are given in the appendix (Table 16).

The graphs for parameters which are known to significantly affect hollow stem rating, nutrient uptake and head weight are given in figures 35-39. The fresh weight of broccoli heads increased with an increase in amount of water delivered (up to 70 mm), then dropped significantly at 100 mm (Figure 35).

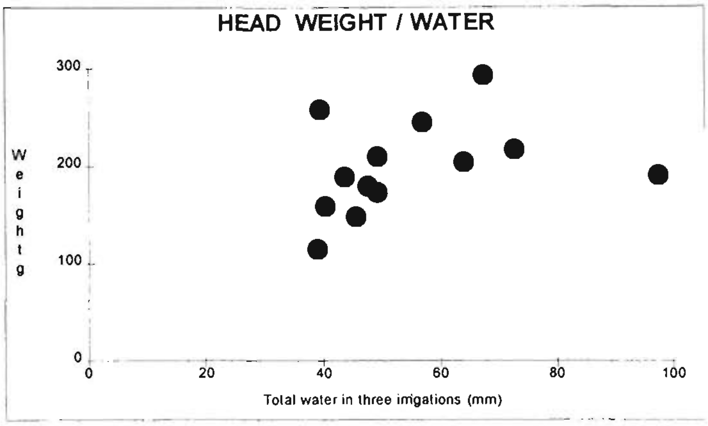

Figure 35: Head weight as affected by irrigation water.

Hollow stem rating was lower with less water application and as water volume increased hollow stem rating also increased (Figure 36).

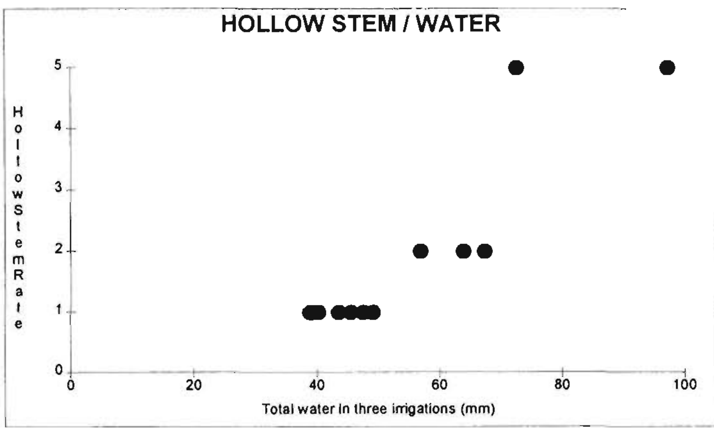

Figure 36: Hollow stem rating as affected by irrigation water.

The level of B in the plant tissue decreased with an increase in the amount of water delivered during an irrigation (Figure 37).

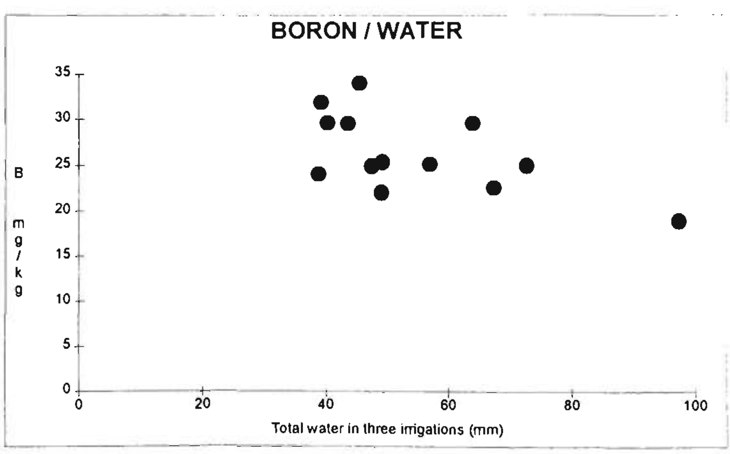

Figure 37: B concentration as affected by irrigation water.

With decreasing B content, hollow stem rating increased (Figure 38).

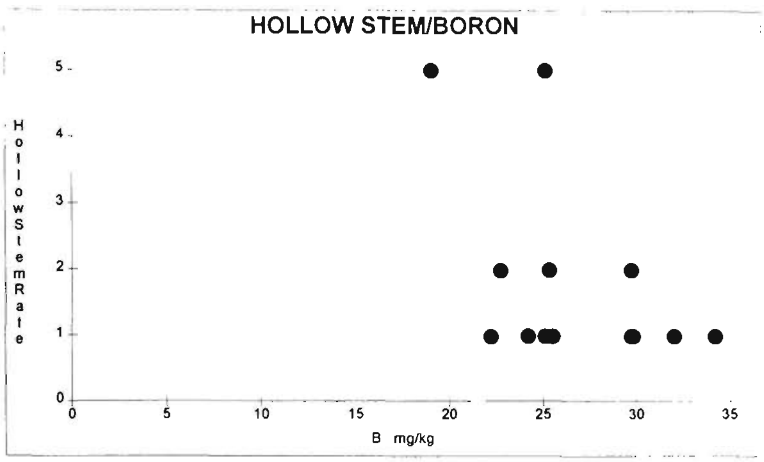

Figure 38: Hollow stem rating as affected by B concentration.

SITE 5

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this site was **loamy** (visual examination) and its moisture characteristic curve has water content percentage (g/g) values between 50.1% and 12.6% over a range of water potentials (Figure 39).

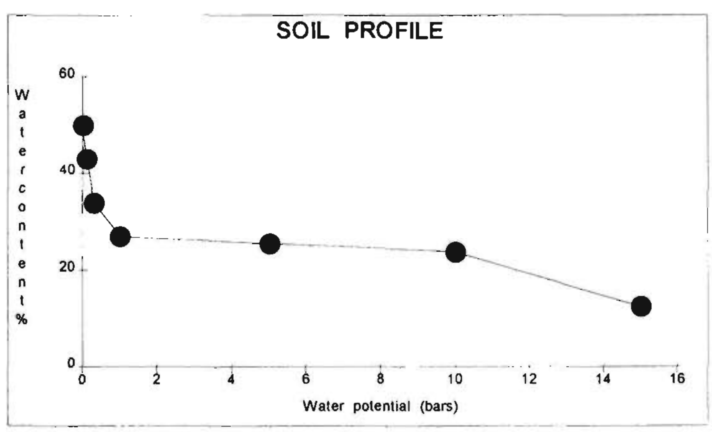

Figure 39: Moisture characteristic curve at different water potentials for site 5.

4.3.2 Field Soil Moisture Content

The percentage field soil moisture content values at 30 cm and 60 cm depths over an irrigation cycle are given in the appendix (Table 17) and average values are shown in figure 40. There was not much difference in the soil moisture contents at 30 and 60 cm depths (Figure 40).

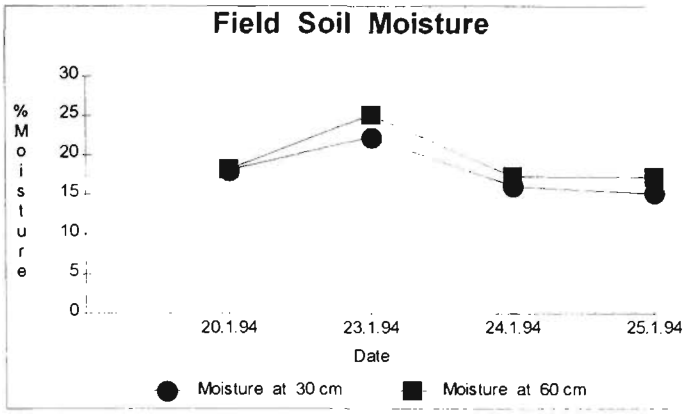

Figure 40: Field soil moisture content during an irrigation cycle at site 5.

4.3.3 Soil Moisture Tension (Irrometer/Tensiometer)

The soil moisture tension values at 30 cm and 60 cm depths are given in the appendix (Table 18) and plotted in figure 41. The irrigation was initiated at 64 centibars on 20. 1 .94 which is quite high for broccoli grown in summer (Henderson and Webber, 1991).

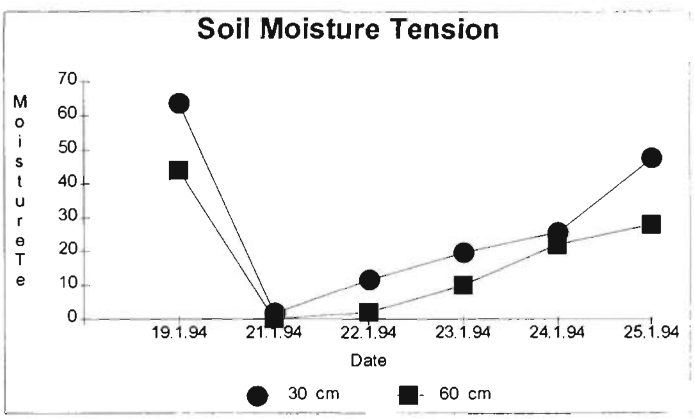

Figure 41: Irrometer readings for soil moisture tension (centibars) for an irrigation cycle at site 5.

4.4 & 4.5 Irrigation, Yield and Quality measurements

The quality assessment for various attributes (sec. 3.5.1), yield measurements and total water delivered during three irrigations (sec. 3.3) are given in Table 18. As at this site in trial 1, some plants received more than twice the volume of water (e.g. cans 13 and 15) compared to others (e.g. cans 5, 17 and 18). Hollow stem was found in 39 out of the 60 harvested heads (66%). Seventeen plants had a high hollow stem rating (4-5) compared to site 4 with only three plants with a rating 4-5 (Tables 17 and 18).

TABLE 18: Yield Measurements & Irrigation at site 5, Trial 2 (Dec. '93-Feb. '94).

SAMPLE	H.Wt.	H.D.	S.D.	B.D.	H.S.	MATURITY	M.V.	Bd	WATER
	g	mm	mm	mm					mm
C1P1	150.6	90	33	35	3	4	4	1	87.6
P2	129.3	85	35	35	4	4	*	*	
P3	101.4	80	30	30	3	2	1	5	
C2P1	150.6	95	34	38	1	4	*	*	43.8
P2	157.1	90	26	40	2	4	5	1	
P3	225.8	140	29	47	2	6	4	1	
C3P1	364.7	160	40	46	2	7	4	1	62.6
P2	363.7	160	41	47	2	8	*	*	
P3	227.7	130	31	35	3	5	4	2	
C4P1	134	100	28	33	1	5	5	1	42.6
P2	235.9	130	28	32	1	5	5	1	
P3	229.9	120	42	37	1	5	5	1	
C5P1	315.8	150	38	40	1	5	*	*	39.1
P2	105.4	80	25	30	1	5	4	2	
P3	222.8	130	31	36	1	5	4	1	
C6P1	204.6	130	32	40	1	5	5	1	52.2
P2	230.9	130	33	36	2	5	*	*	
P3	187	120	31	35	1	5	5	1	
C7P1	143	75	35	32	4	3	1	4	72.6
P2	325.7	135	37	44	2	6	2	3	
P3	131.4	75	38	34	4	3	1	3	
C8P1	314.1	140	35	50	1	5	5	1	54.2
P2	204.3	110	30	58	1	5	4	2	
P3	217.3	115	38	37	1	5	5	1	
C9P1	188.7	110	34	36	4	5	*	*	69
P2	232.4	120	34	37	3	5	3	1	
P3	171.1	120	30	34	4	5	5	1	
C10P1	284.2	130	42	42	2	5	*	*	54.2
P2	372.4	145	37	39	3	5	5	1	
P3	405.5	160	50	52	2	9	1	4	
C11P1	371.6	160	33	45	3	8	2	1	57.3
P2	348.7	150	33	44	2	5	4	1	
P3	440.8	170	40	45	3	9	3	2	
C12P1	256.9	120	30	30	5	5	*	*	73.8
P2	167	100	28	30	4	5	5	1	
P3	155.9	95	32	35	2	5	5	1	
C13P1	198.7	110	30	32	4	5	2	3	91.9
P2	227.6	135	32	41	4	6	1	5	
P3	166.8	100	30	30	5	5	5	1	
C14P1	257.4	145	29	38	4	5	2	1	85.5
P2	192.3	105	30	35	3	5	5	1	
P3	414.4	170	37	43	4	8	*	*	
C15P1	277.3	125	34	40	2	5	5	1	96.9
P2	208.4	110	30	35	2	5	3	2	
P3	352.2	150	42	44	5	6	*	*	
C16P1	211.3	125	32	41	1	5	4	1	64.9
P2	336.2	145	35	47	4	5	*	*	
P3	239.6	120	32	38	4	5	4	1	
C17P1	110.3	80	32	28	1	3	1	4	41.6
P2	55.3	65	22	25	1	2	1	3	
P3	70.1	70	27	22	1	1	1	1	
C18P1	526.7	190	45	48	1	10	1	5	40.5
P2	206.9	120	32	37	1	5	4	1	
P3	486.2	170	45	50	2	8	*	*	
C19P1	209.1	110	32	35	1	5	5	1	45.2
P2	114.6	90	28	32	1	4	4	1	
P3	177.8	110	31	37	1	5	*	*	
C20P1	373.2	155	41	45	3	8	1	3	79.3
P2	388.4	150	46	50	5	6	2	1	
P3	370.3	160	40	43	4	7	*	*	

Legend: As Table 10 on page 42

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 19) and average fresh and dry weights are presented in figure 42.

The average fresh weight of plants was higher on this property compared to samples from trial 1 but percentage dry matter was low (8.6) at harvest.

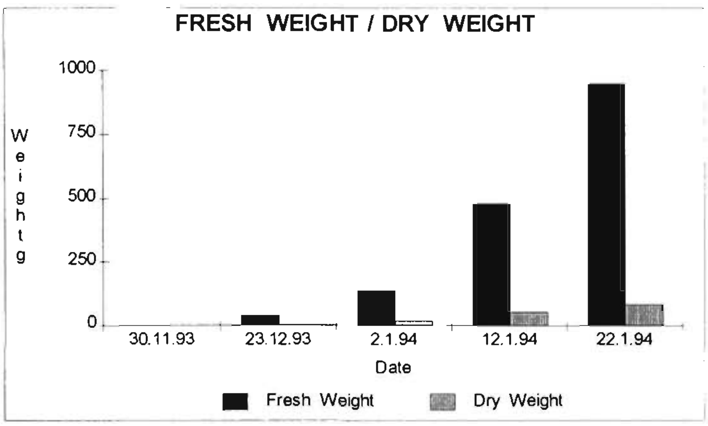

Figure 42: The average fresh weight and dry weight of broccoli plants for site 5.

4.6.3 Nutrient analysis

The results of tissue analysis are given in the appendix (Table 20).

Graphs for parameters which significantly affected head weight, hollow stem and nutrient uptake are shown in figures 43 - 46. Broccoli head weight increased on average with increasing water application but after 70 mm the effect decreased and a mix of of high and low weight heads were collected (Figure 43).

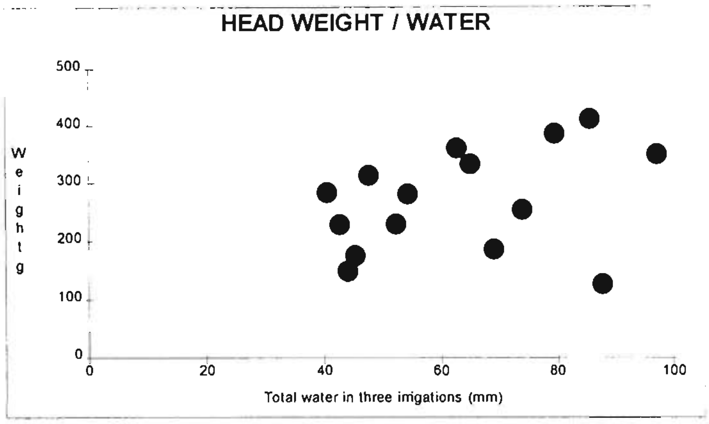

Figure 43: Broccoli head weight as affected by irrigation water.

Hollow stem rating increased with increasing volume of water applied (Figure 44).

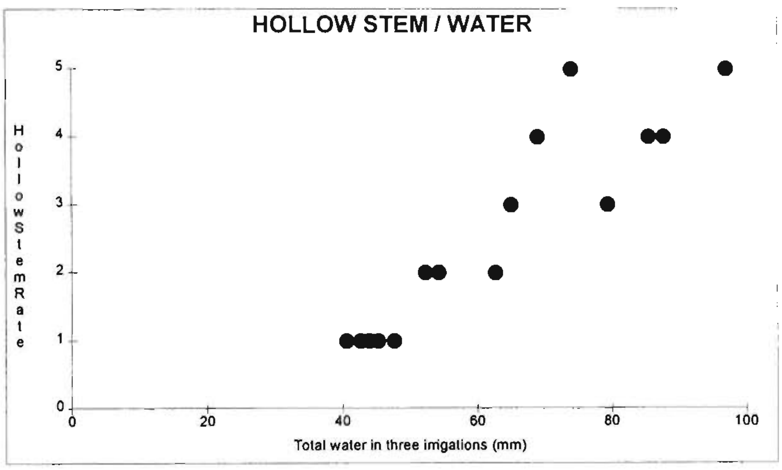

Figure 44: Hollow stem rating as affected by irrigation water.

With increasing water application B concentration decreased (Figure 45).

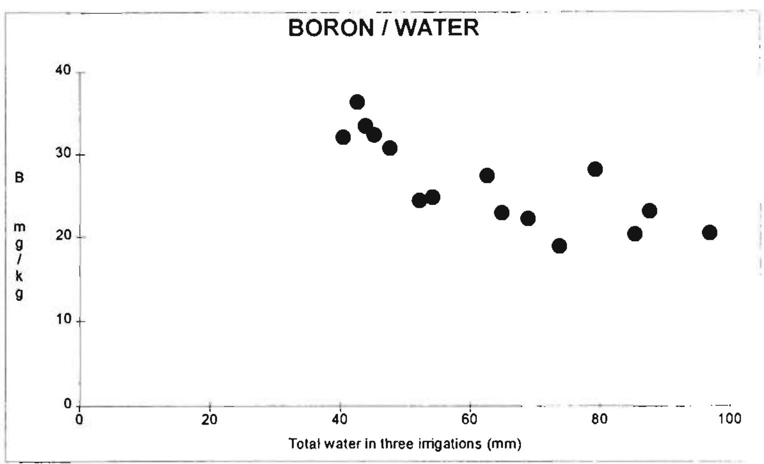

Figure 45: B concentration as affected by irrigation water.

With decreasing B concentration, the hollow stem rating increased (Figure 46).

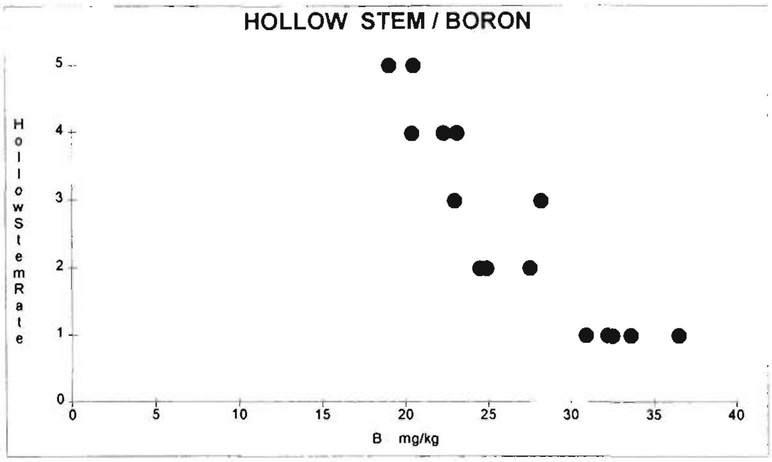

Figure 46: Hollow stem rating as affected by B concentration.

SITE 6

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this site was **clay loam** (visual examination) and its moisture characteristic curve has a water content percentage (g/g) values between 66.5% and 25.6% over a range of water potentials (Figure 47).

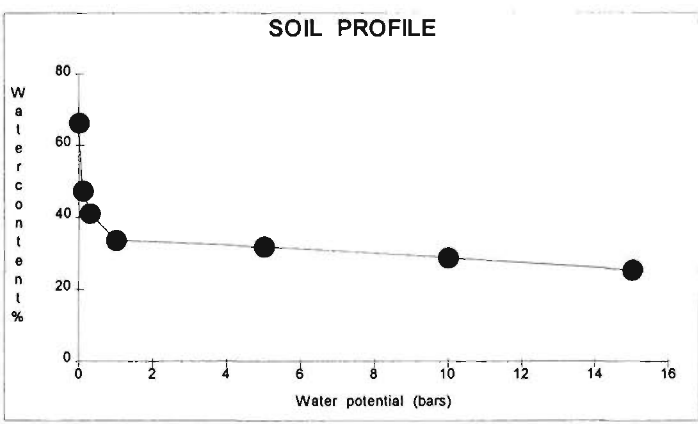

Figure 47: Moisture characteristic curve at different water potentials for site 6.

4.3.2 Field Soil Moisture Content

The percentage field soil moisture content values at 30 cm and 60 cm depths are given in the appendix (Table 21) and averages are shown in figure 48. The percentage soil moisture content increased after irrigation and decreased as water was taken up by plants through the cycle.

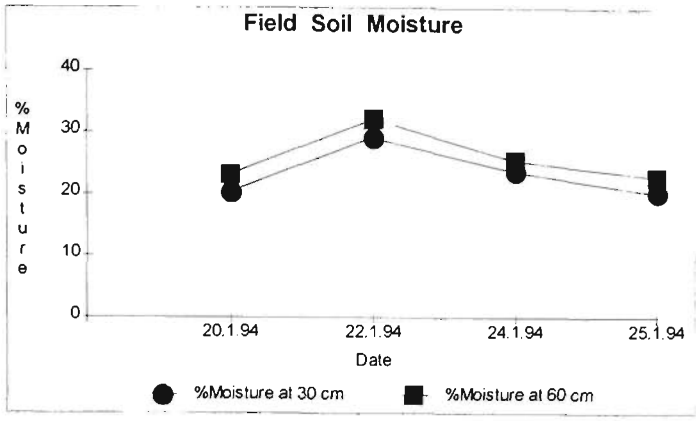

Figure 48: Field soil moisture content during an irrigation cycle at site 6.

4.6.3 Soil Moisture Tension (Irrometer/Tensiometer)

The soil moisture tensions at 30 and 60 cm depths are given in the appendix (Table 22) and plotted in figure 49. Irrigation was initiated at 89 centibars on 21. 1. 94 which is very high for hot summer days (Henderson and Webber, 1991).

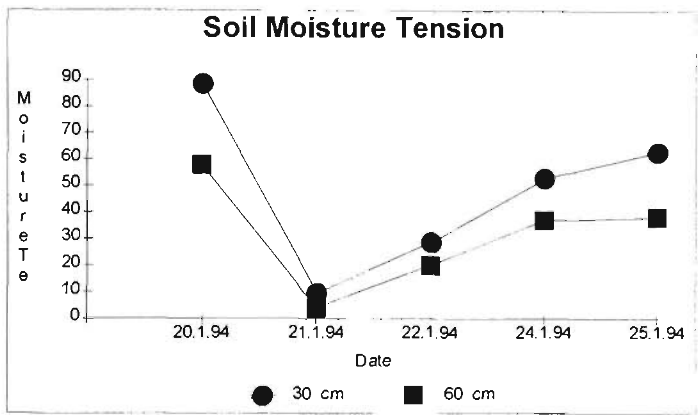

Figure 49: Irrometer readings for soil moisture tension (centibars) over an irrigation cycle at site 6.

4.4 & 4.5 Irrigation, Yield and Quality measurements

The quality assessment of harvested heads for various attributes (sec. 3.5.1), yield measurements and total water applied over three irrigations (sec. 3.4) are given in Table 19. The amount of water delivered across the crop during each irrigation was very uneven. Some plants (around cans 1 and 20) received approximately three times as much water as others (around cans 2, and 19 - see Table 19). Cans 4, 5 and 15 were knocked over twice during two irrigations and as a result low water measurements were recorded. The harvested heads from plants receiving low volumes of water did not show a major difference in fresh weight when compared to plants receiving more water. The general plant frame was bigger at this site than for plants at the other two sites. Fifty six out of sixty harvested heads (93%) had hollow stem with thirty six of these having a high rating (4 -5). As in trial 1, hollow stem disorder was more severe at this site compared to sites 4 and 5 (Tables 17, 18 and 19).

TABLE 19: Yield Measurements & Irrigation at Site 6, Trial 2 (Dec.'93 - Feb. 94).

SAMPLE	H.Wt	H.D.	S.D.	B.D.	H.S.	MATURITY	M.V.	Bd	WATER
	g	mm	mm	mm					mm
C1P1	275.1	120	51	47	4	5	5	1	208.1
P2	249.4	115	47	35	5	5	*	*	
P3	162.9	95	46	33	2	5	4	1	
C2P1	372.5	145	45	47	4	8	3	1	69.2
P2	181.1	105	40	40	1	6	*	*	
P3	337.2	140	45	52	5	7	1	4	
C3P1	254.9	110	51	45	5	5	*	*	160.5
P2	253	110	48	40	4	5	4	1	
P3	214.6	110	44	39	2	5	3	1	
C4P1	137.8	80	55	33	4	5	3	2	17.4**
P2	178.4	100	37	39	2	5	*	*	
P3	280.9	125	50	48	4	5	5	1	
C5P1	422.9	150	50	51	4	5	4	2	41.2**
P2	342.8	95	45	40	4	5	5	1	
P3	418.8	145	48	55	4	6	3	1	
C6P1	237.1	105	52	40	3	5	3	2	162.6
P2	315.9	150	54	51	5	7	1	4	
P3	252.6	110	51	40	5	5	*	*	
C7P1	244.7	110	52	42	1	5	*	*	79.6
P2	182.5	110	50	40	3	4	3	2	
P3	218.6	110	56	38	3	5	4	1	
C8P1	192.2	85	42	35	3	4	4	1	164.2
P2	342.2	110	56	49	4	5	4	2	
P3	264.1	120	42	37	3	5	4	1	
C9P1	243	110	50	35	5	5	5	1	146.9
P2	242.8	95	47	42	5	5	*	*	
P3	209.1	95	46	42	3	5	5	1	
C10P1	304.1	130	47	52	4	7	1	3	79.6
P2	203.7	100	54	40	1	5	*	*	
P3	304.3	120	47	44	4	5	3	1	
C11P1	174.2	100	47	37	2	5	*	*	98.8
P2	220.8	100	46	44	3	5	1	5	
P3	258.9	110	50	39	3	5	4	1	
C12P1	356.1	130	44	44	3	6	2	1	120.2
P2	140.3	90	36	32	4	4	4	1	
P3	161	100	37	32	4	5	*	*	
C13P1	413.9	150	47	55	5	6	3	1	78.5
P2	359.3	140	50	60	5	3	1	2	
P3	372.1	130	55	51	5	5	4	1	
C14P1	240.8	125	43	42	5	3	1	2	94.5
P2	290.2	110	41	39	4	4	4	1	
P3	218.1	105	40	38	5	4	4	1	
C15P1	193.6	110	46	44	4	5	3	1	44.2**
P2	176.2	90	42	34	3	5	4	1	
P3	191	100	42	40	4	5	3	2	
C16P1	315	115	57	46	4	5	5	1	142.2
P2	257.5	110	51	40	4	5	4	1	
P3	198	100	48	42	3	5	*	*	
C17P1	228.7	100	54	45	5	5	4	1	165.7
P2	239.3	95	56	50	3	4	4	1	
P3	141.9	90	37	32	5	4	2	3	
C18P1	165.8	85	50	34	3	4	*	*	77.7
P2	266	120	46	38	3	5	5	1	
P3	346	135	51	46	4	5	5	1	
C19P1	351.6	120	50	40	5	5	4	1	52.9
P2	226.8	120	47	35	1	5	*	*	
P3	214.7	95	52	34	4	5	5	1	
C20P1	427	160	44	55	4	10	1	5	177.5
P2	228	110	41	43	2	5	*	*	
P3	240.7	100	57	45	3	5	5	1	

Legend: As Table 10 on page 42

4.6 Plant Analysis

4.6.1 Plant Growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 23) and fresh and dry weights are presented in figure 50.

The average fresh weight increased three fold in each sampling and percentage dry matter was 18.9% at transplanting and decreased to 9.2% at harvest. At this property there was no difference in plant growth between the two trials.

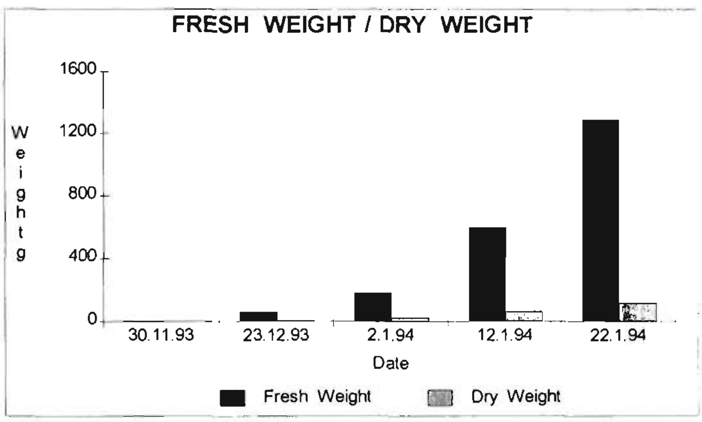

Figure 50: The average fresh weight and dry weight of broccoli plants for site 6.

4.6.3 Nutrient analysis

The results of tissue analysis are given in the appendix (Table 24).

Graphs for parameters which are known to significantly affect hollow stem, nutrient uptake and head weight are presented in figures 51-54.

Broccoli head weight did not increase much with the increasing amount of water applied (Figure 51), as found at other sites. Water volume applied at this site was greater than at the other two sites, probably too high to show the head weight response measured at sites 4 and 5, where up to 70 mm and 80 mm respectively weight was positively affected by water volume and after this value showed a decrease. At site 6 all plants except those around can 19 received 70 mm or more water.

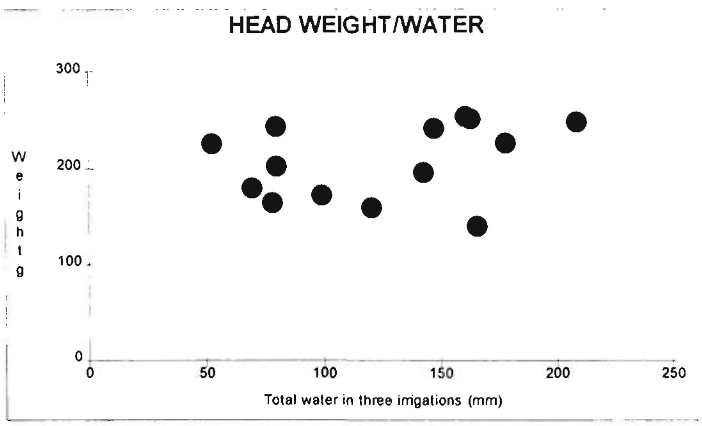

Figure 51: Broccoli head weight as affected by irrigation water.

With increasing water application, the hollow stem rating increased (Figure 52).

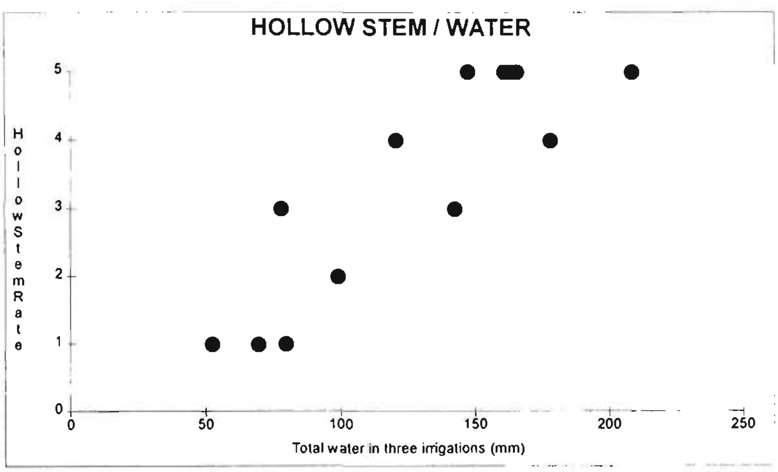

Figure 52: Hollow stem rating as affected by irrigation water.

B concentration decreased with increasing amount of water applied (Figure 53).

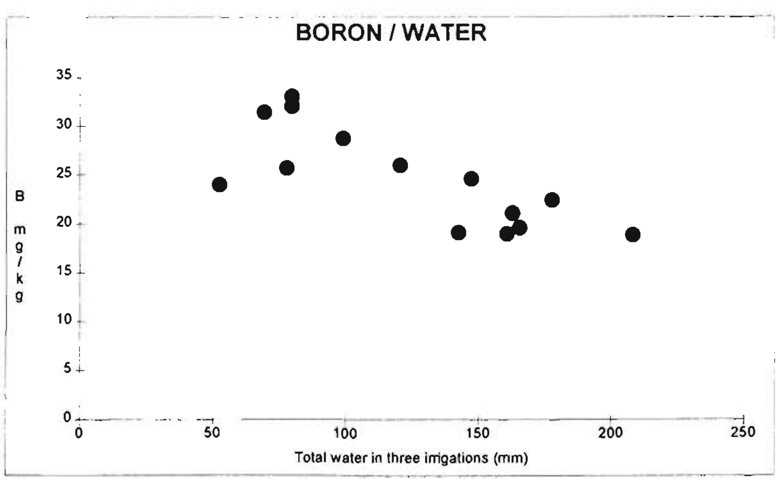

Figure 53: B concentration as affected by irrigation water.

With lower B level in plant tissue hollow stem rating increased (Figure 54).

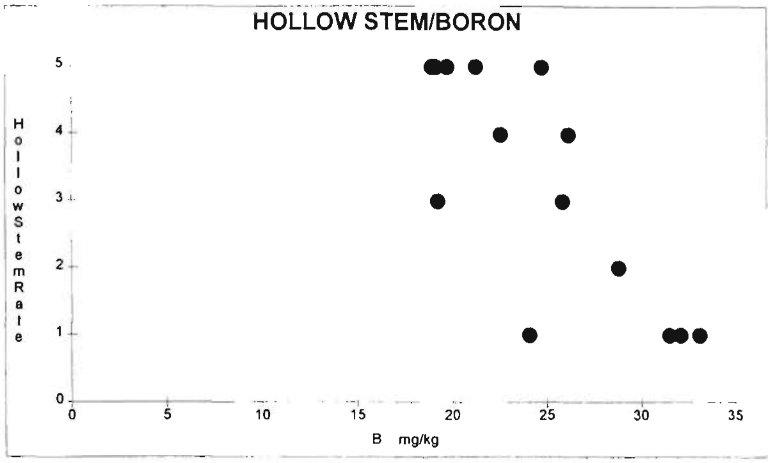

Figure 54: Hollow stem rating as affected by B concentration.

4.7 Statistical analyses of yield parameters and irrigation application across the three sites for trial 2 (summer crops)

a) Yield Measurements

Moderately high correlations between yield and quality parameters (as expected) were found (Table 20) across the three sites.

TABLE 20: Correlation matrix between the Yield and Quality parameters across the three sites - Trial 2.

F. Wt.	1.000						
H.D.	0.838	1.000					
S.D.	0.561	0.253	1.000				
B.D.	0.761	0.668	0.572	1.000			
H.S.	0.420	0.172	0.600	0.359	1.000		
Maturity	0.595	0.714	0.196	0.481	-0.027	1.000	
M.V.	-0.161	-0.228	-0.065	-0.161	-0.150	-0.244	
Bd	0.132	0.205	0.060	0.167	0.062	0.034	1.000
	F. Wt.	H.D.	S.D.	B.D.	H.S.	Maturity	Bd

Legend: As Table 14 page 59

The per plant yield measurements, fresh head weight, head diameter, stem diameter and bud diameter were regressed on sites (4 and 5) against water delivered and hollow stem ratings. Results for sites 4 and 5 were regressed and compared with results for site 6. The results are summarised in Table 21.

TABLE 21: Yield Analysis for Trial 2

Yield measurement	Significance (p-values) of...				
	Site 4	Site 5	Water	Hollow stem	R (%)
F. Wt.	0.3	0.627	0.91	< 0.001	15.7
H.D.	0.861	0.32	0.135	0.005	8.3
S.D.	< 0.001	< 0.001	0.388	0.227	60.7
B.D.	0.008	0.19	0.349	0.074	9.7

Legend: As Table 14 on page 59.

The effect of water on fresh head weight was significant at the 10% level, but water was not significantly correlated with other yield variables. Hollow stem was significantly correlated with fresh head weight, head diameter and bud diameter, but not stem diameter.

There were site differences as follows:

* head fresh weight at site 4 was significantly less than fresh weight at site 6 (Tables 17 and 19).
* head diameter at site 5 was significantly greater than head diameter at site 6 (Tables 18 and 19).
* stem diameters at sites 4 and 5 were significantly less than stem diameter at site 6 (Tables 17, 18, and 19).
* bud diameters at sites 4 and 5 were significantly less than bud diameter at site 6 (Tables 15, 16, and 17).

b) Nutrient analysis

The correlation matrix between different nutrients, water, head weight and hollow stem is given below (Table 22) across the three sites.

TABLE:22 Correlation matrix between different Nutrients, Water applied, Fresh weight and Hollow stem across the three sites.

N	1.000						
K	-0.004	1.000					
Ca	-0.145	0.177	1.000				
B	0.381	-0.271	0.068	1.000			
Water applied	-0.323	-0.362	-0.304	-0.467	1.000		
F. Wt.	-0.348	0.116	0.144	-0.024	0.000	1.000	
H.S.	-0.434	0.127	-0.117	-0.667	0.625	0.214	1.000
	N	K	Ca	B	Water applied	F.Wt.	H.S.

The reduction in the residual deviance as we successively include the added covariates is significant at the 5% level except at the last step when I attempt to include potassium (K) as shown in Table 23. It is concluded that the covariates boron, water and site significantly affect the cumulative probabilities of the ordered hollow stem ratings.

TABLE 23: Effect of a number of variables on Hollow Stem Ratings for Trial 2

Variable Name	Regression Deviance (df)	Residual Deviance (df)	p - value for added variable
B	23.9 (1)	97.4 (35)	< 0.0001
B + Water	34.9 (2)	86.3 (34)	0.0009
B + Water + Site	43.6 (4)	77.6 (32)	0.0129
B + Water + Site + K	45.9 (5)	75.4 (31)	0.133

Legend:

B Boron tissue concentration

p - value probability values for different variables

K Potassium tissue concentration

Generally speaking, as the water volume reading increased and the boron concentration measurement decreased, the probability of a high hollow stem rating increased.

The different "constants" for each site are such that for a fixed combination of water and boron at each site, the probability of a low hollow stem rating is highest at site 6 and lowest at site 5. For example, if plants had water measurements of 72 mm and boron measurements of 25 ppm at each site, then the probabilities of various hollow stem ratings are given below in Table 24.

TABLE 24: Model probabilities of Hollow Stem Rating at three sites with fixed Water and Boron

Site	p [1]	p [2]	p [j > 2]
4	0.51	0.38	0.11
5	0.19	0.47	0.34
6	0.05	0.26	0.69

Legend

p [1] probability of a rating of 1 for hollow stem occurrence.

p [2] probability of a rating of 2 for hollow stem occurrence.

p [j>2] probability of a rating of more than 2 for hollow stem occurrence.

TRIAL 3 (Autumn) March - May 1994

This trial was carried with the same growers but in different paddocks (sites 7, 8 and 9) than those used in trials 1 and 2

SITE 7

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this site was **loam** and its moisture characteristic curve has water content percentage (g/g) values between 42.2% and 6.8% over a range of water potentials (Figure 55).

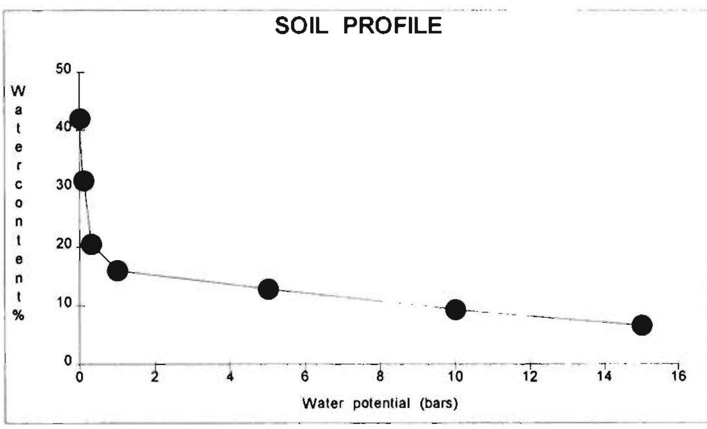

Figure 55: Moisture characteristic curve at different water potentials for site 7.

4.3.2 Field Soil Moisture Content

The percentage field soil moisture contents at 30 cm and 60 cm depths are given in the appendix (Table 25) and average values are shown in figure 56.

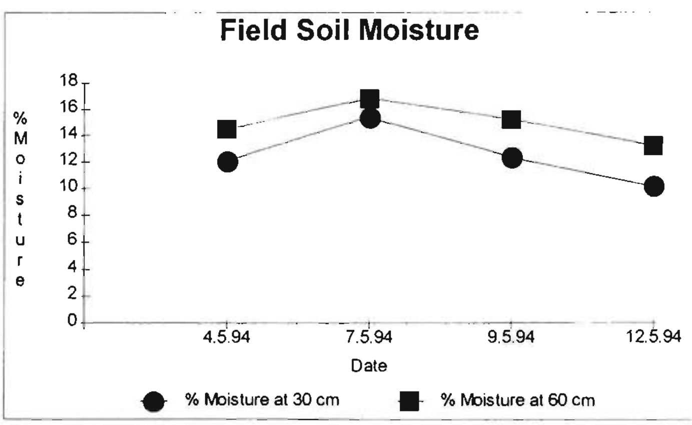

Figure 56: Field soil moisture content during an irrigation cycle at site 7.

4.3.2 Soil Moisture Tension (Irrometer/Tensiometer)

The soil moisture tension values at 30 and 60 cm depths are given in the appendix (Table 26) and plotted in figure 57. The irrigation was initiated on 7. 5. 94 at 38 centibars as registered at the shallow depth on the irrometer (30 cm).

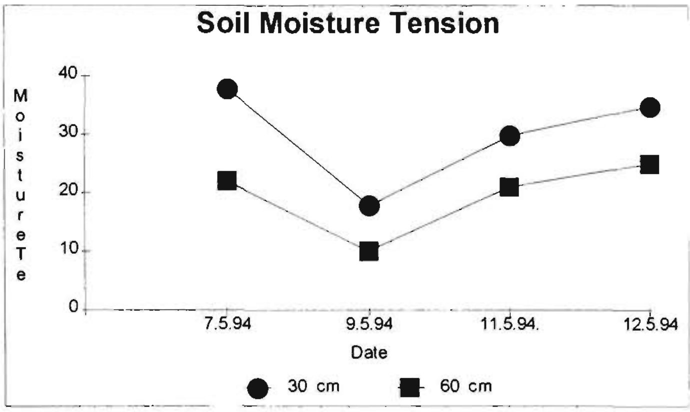

Figure 57: Irrometer readings for soil moisture tension (centibars) for an irrigation cycle at site 7.

4.4 & 4.5 Irrigation, Yield and Quality measurements

The quality assessment of harvested broccoli heads for various attributes (sec. 3.5.1), yield measurements and water delivered during two irrigations (sec. 3.4) are given in Table 25. The water distribution was quite uneven. Some plants (cans 3, 14 and 16) received more than twice as much water as others (cans 8, 10, 15, 17 and 18). Only five out of sixty heads (8%) had hollow stem. These were plants which received the highest water volume and had hollow stem ratings ranging between 2-3. Only a few heads were overmature, these heads have some loose and uneven buds (Table 25).

TABLE 25: Yield Measurements & Irrigation at site 7, Trial 3 (Mar.-May 1994).

SAMPLE	H.Wt.	B.D.	S.D.	H.D.	H.S.	MATURITY	M.V.	Bd	WATER
	g	mm	mm	mm					mm
C1P1	296.8	47	40	130	1	6 *			37.91
P2	378.5	47	37	150	1	6	5	1	
P3	404.2	42	39	150	1	7	4	1	
C2P1	374.9	47	37	150	1	5 *			38.1
P2	361.7	42	35	150	1	5	4	1	
P3	352.7	40	37	140	1	5	5	1	
C3P1	356.3	45	40	150	1	5	5		53.3
P2	455.1	45	42	150	2	5 *			
P3	233.3	40	33	127	1	5	5	1	
C4P1	353.1	45	39	140	1	5 *			40.6
P2	225.7	40	34	110	1	5	5	1	
P3	216.2	35	30	112	1	5	5	1	
C5P1	397.6	45	39	142	1	7	4	2	35.7
P2	399.2	47	37	161	1	5	5	1	
P3	226.3	40	35	135	1	6	5	1	
C6P1	290.8	44	38	128	1	5 *			37.4
P2	286.5	43	35	150	1	5	4	2	
P3	267.7	40	34	130	1	5	5	1	
C7P1	211.7	44	32	120	1	5 *			44.2
P2	267.3	40	35	135	1	5	5	1	
P3	282.4	38	35	125	1	5	5	1	
C8P1	205.2	39	35	120	1	6 *			45.9
P2	269.3	40	35	122	1	5	5	1	
P3	172.1	40	32	110	1	4	5	1	
C8P1	236.3	35	32	115	1	5 *			20.4
P2	287.5	40	36	130	1	5	5	1	
P3	299.9	42	36	150	1	6	5	1	
C10P1	362.7	42	42	130	1	7 *			28.5
P2	421.7	45	37	165	1	6	5	1	
P3	420.5	54	40	160	1	6	5	1	
C11P1	257.4	40	36	130	1	5 *			31.6
P2	187.5	47	32	110	1	5	5	1	
P3	178.5	38	37	100	1	4	5	1	
C12P1	372.3	45	40	140	1	5	5	1	42.5
P2	180.7	42	31	110	1	4	5	1	
P3	340.8	47	42	140	1	5	5	1	
C13P1	240.6	45	33	130	1	6	4	1	34
P2	218.7	40	33	120	1	5	5	1	
P3	142.8	37	31	115	1	4	4	2	
C14P1	513.1	45	39	180	3	7	2	3	59.2
P2	307.6	40	35	140	1	7	4	2	
P3	490	45	40	160	1	7	4	1	
C15P1	209	40	35	120	1	5 *			26.2
P2	262.3	43	37	115	1	5	5	1	
P3	367.9	40	40	135	1	6	5	1	
C16P1	360.3	47	42	140	2	6 *			66.2
P2	509.5	48	42	160	2	6	5	1	
P3	380	47	42	140	1	7	2	3	
C17P1	384.1	47	37	140	1	6 *			27.6
P2	392.6	41	42	150	1	5	5	1	
P3	322.5	48	37	140	1	5	5	1	
C18P1	331.7	43	38	140	1	5	5	1	27.2
P2	424.9	50	37	160	1	6	5	1	
P3	306.2	42	37	140	1	5	5	1	
C19P1	377.1	43	39	140	1	5 *			36.7
P2	317.5	38	36	130	1	5	5	1	
P3	349.4	40	37	140	1	5	5	1	
C20P1	335	40	38	120	2	6 *			48.1
P2	224.4	45	35	110	1	5	5	1	
P3	425.3	52	41	145	1	6	3	1	

Legend: As Table 10 on page 42

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 27) and average fresh and dry weights are presented in figure 58.

The average fresh weight increased roughly one and a half times between each sampling. Percentage dry matter was 22.2% at transplanting and decreased to 11.2% at harvest.

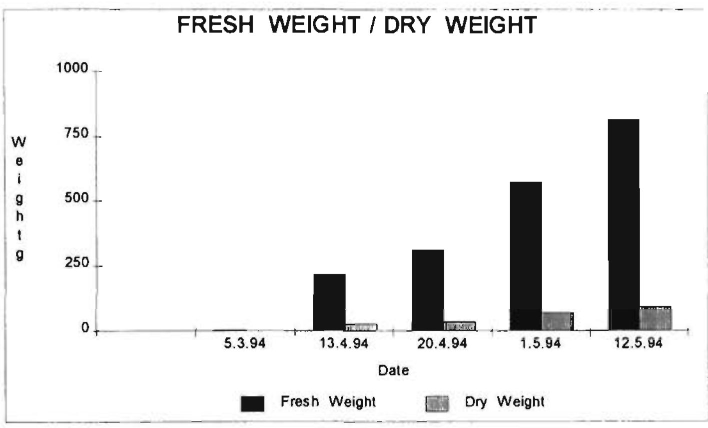

Figure 58: The average fresh weight and dry weight of broccoli plants for site 7.

SITE 8

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this site can was **loam** (visual examination) and its moisture characteristic curve has a water content percentage (g/g) values between 49.8% and 8.1% over a range of water potentials (Figure 59).

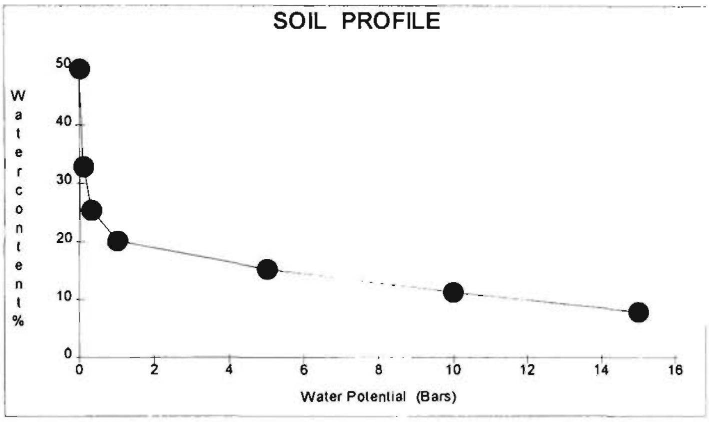

Figure 59: Moisture retention curve at different water potentials for site 8.

4.3.2 Field Soil Moisture Content

The percentage field soil moisture content values at 30 cm and 60 cm depths are given in the appendix (Table 28) and averages are shown in figure 60.

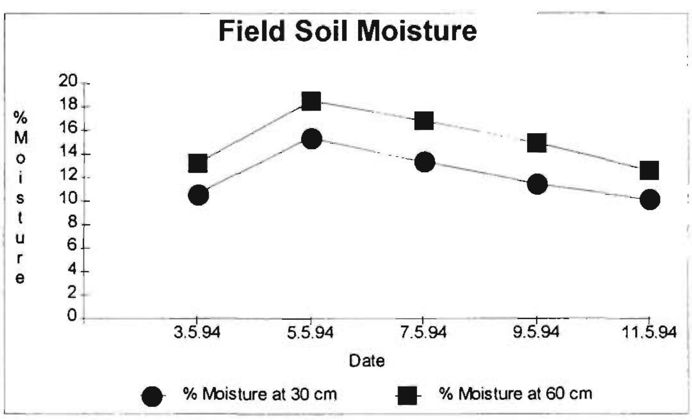

Figure 60: Field soil moisture content during an irrigation cycle at site 8.

4.3.3 Soil Moisture Tension (Irrometer/Tensiometer)

The soil moisture tension values at 30 cm and 60 cm depths are given in the appendix (Table 29) and plotted in figure 61. The irrigation was initiated on 3.5.94 at 80 centibars, a value which indicated that plants were undergoing drought conditions before they were irrigated.

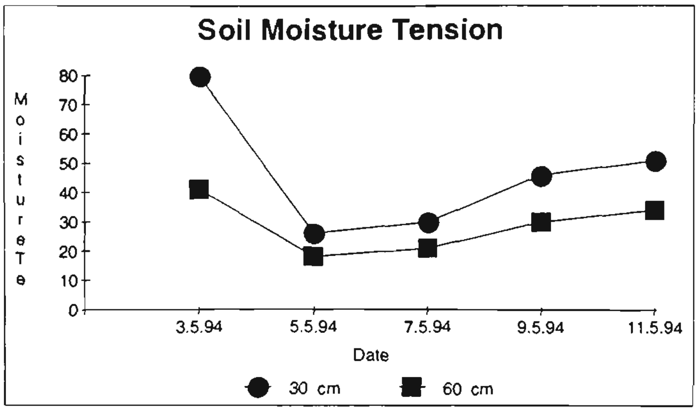

Figure 61: Irrometer readings for soil moisture tension (centibars) for an irrigation cycle at site 8.

EnviroSCAN monitoring of Soil Moisture content and Irrigation

The results with enviroSCAN also showed that the water distribution over a paddock is quite uneven with travelling irrigators as shown in figures 62 and 63 below. As stated in material and methods chapter 3, two probes A and B were installed having sensors at 10, 20, 30, 50 and 70 cm depths.

In figures 62 and 63 it is very clear that at probe B the soil water content of soil was higher (between 84 - 112 mm) compared with the soil at probe A (between 58 - 80 mm) between the periods 26. 4. 94 to 1. 6. 94. Probe B was installed between broccoli rows 6 - 7 next to the irrigator line and probe A was installed away from the irrigator between rows 30 - 31.

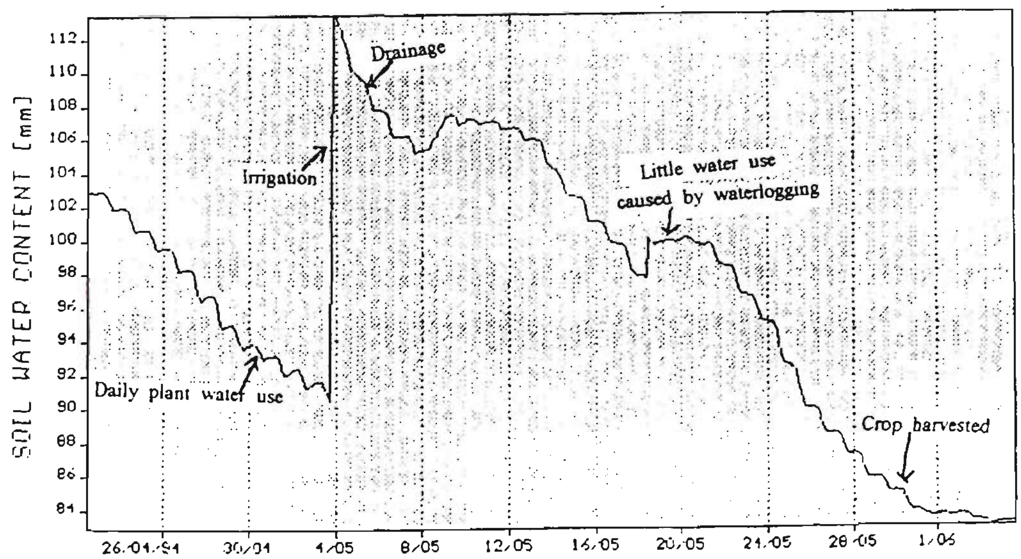

Figure 62: Soil water content for probe B at site 8 over a 5 week period with two irrigations. Water content is sum of sensors at 10 + 20 + 30 + 50 + 70 cm depths.

As figure 58 illustrates the irrigation on 4. 5. 94 was heavy and some of the water has drained into the ground water but in another irrigation on 19. 5. 94 the plants were waterlogged due to the heavy irrigation and little water usage occurred.

Similarly, figure 63 shows that plants were waterlogged during the irrigation made on 19. 5. 94 and soil water content on 25. 5. 94 due to the irrigation in the next paddock.

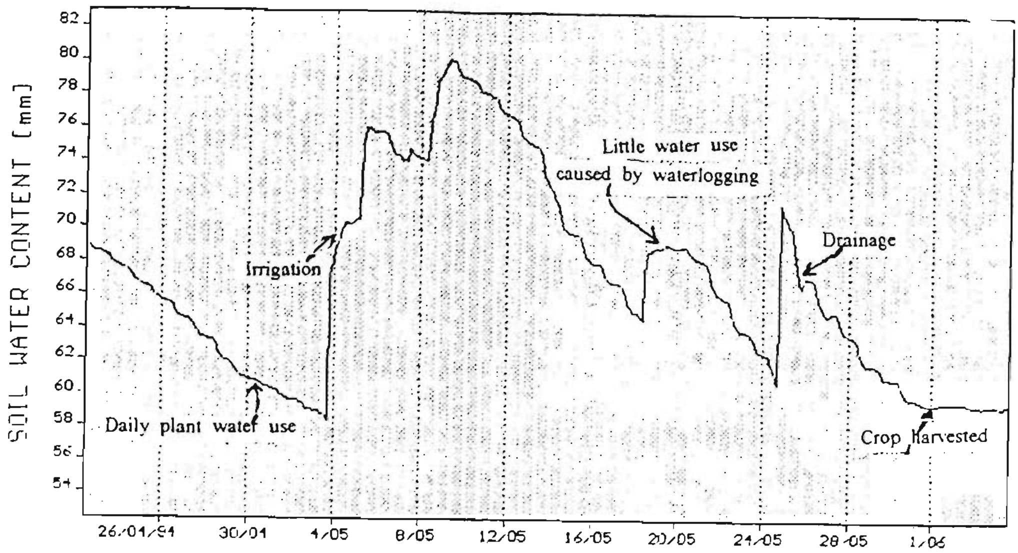

Figure 63: Soil water content for probe A at site 8 over a 5 week period with two irrigations. Water content is sum of sensors at 10 + 20 + 30 + 50 + 70 cm depths.

4.4 & 4.5 Irrigation, Yield and Quality measurements

The assessment of harvested broccoli heads for various quality attributes (sec. 3.5.1), yield measurements and water delivered during one irrigation (sec. 3.4) are given in Table 26. The water delivered was very uneven (e.g. cans 7, 8, and 9 received less than half the water as compared to can 14). Eight out of sixty harvested heads (13%) had a hollow stem rating 2 - 4 and the highest rating (3 or 4) occurred in plants which received greater volume of water. The overall plant frame was bigger for site 8 plants than for site 7 plants but smaller than for site 9 plants. The growth was slow because of mild weather and the occurrence of hollow stem was also low compared to hollow stem in plants in the summer trial at this site.

TABLE 26: Yield Measurements & Irrigation at site 8, Trial 3 (Mar.-May 1994).

SAMPLE	H.Wt.	H.D.	S.D.	B.D.	MATURITY	H.S.	M.V.	Bd	WATER
	g	mm	mm	mm					mm
C1P1	267.7	110	30	44	5	1 *			20.4
P2	226.6	110	40	41	5	1	5	1	
P3	241.9	130	30	38	5	1	5	1	
C2P1	274.2	120	30	32	5	2 *			20.1
P2	448.4	150	37	45	7	1	4	2	
P3	283.8	125	37	37	6	1	5	1	
C3P1	337.1	130	40	40	5	1	4	2	24.5
P2	204.6	110	32	38	5	1	5	1	
P3	193.1	105	30	33	5	1	5	1	
C4P1	173.2	100	30	32	4	1	5	1	25.2
P2	293.3	130	37	35	5	1	5	1	
P3	184	110	30	37	5	2 *			
C5P1	324.4	140	38	45	5	1	5	1	19.1
P2	214.8	110	31	38	5	1	5	1	
P3	250.6	120	32	35	5	1	5	2	
C6P1	315	130	35	40	6	1	5	1	21.1
P2	393.3	140	38	40	7	1	5	1	
P3	340.2	132	35	40	5	1	5	2	
C7P1	371.8	140	35	37	6	1	4	2	17
P2	450.5	170	35	42	7	1	4	2	
P3	650	200	42	50	8	1	4	1	
C8P1	272.6	130	32	38	5	1 *			16.7
P2	360.6	140	35	42	5	1	5	1	
P3	326	135	35	43	5	1	5	1	
C9P1	571.8	180	43	50	7	1	4	1	17
P2	329	140	35	45	6	1	5	1	
P3	458.2	170	37	41	7	1	4	1	
C10P1	494.1	160	42	48	5	1	5	1	18.7
P2	364.2	135	37	40	5	1 *			
P3	450.9	160	35	40	6	1	5	1	
C11P1	385.6	150	38	45	5	1	5	1	25.2
P2	336	130	40	42	5	2 *			
P3	484.9	160	42	43	5	1	5	1	
C12P1	515.7	160	39	47	6	1	4	2	22.1
P2	472.2	140	38	40	5	1	5	1	
P3	499.2	160	37	42	8	1	4	2	
C13P1	455.8	180	35	45	5	2 *			25
P2	350.8	150	35	45	5	1	5	1	
P3	391	140	35	40	6	1	4	1	
C14P1	564.2	170	40	46	8	4	4	1	38.7
P2	339.6	144	40	42	5	3	5	2	
P3	364.7	120	37	40	5	4 *			
C15P1	375	148	35	47	5	1	4	2	19.4
P2	279.8	120	35	38	5	1 *			
P3	433.6	160	40	47	5	1	5	1	
C16P1	344.4	125	35	48	5	1 *			18.2
P2	320.7	130	35	40	5	1	5	1	
P3	288.8	100	29	32	5	3	5	1	
C17P1	173	100	30	38	5	1	5	1	19.4
P2	238.4	120	30	40	5	1 *			
P3	277.8	140	38	45	6	1	5	1	
C18P1	506.8	180	40	50	6	1	5	1	18.7
P2	389.9	150	32	40	5	1	5	1	
P3	414.4	148	37	44	5	1	5	1	
C19P1	460.4	160	38	45	5	1	5	1	20.8
P2	551.3	180	42	48	6	1	5	1	
P3	490.8	170	36	45	6	1	5	1	
C20P1	348.6	145	35	42	5	1	5	1	19.8
P2	364.1	150	35	42	5	1	4	1	
P3	562.9	175	42	50	6	1	5	1	

Legend: As Table 10 on page 42

PLANT ANALYSIS

a) Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 30) and average fresh and dry weights are presented in figure 64.

The average fresh weight increased by roughly 1.5 times in the intervals between the first few samplings and by twice at the harvest. The percentage of dry matter was 19.1% at transplanting and had decreased to 10.2% at harvest.

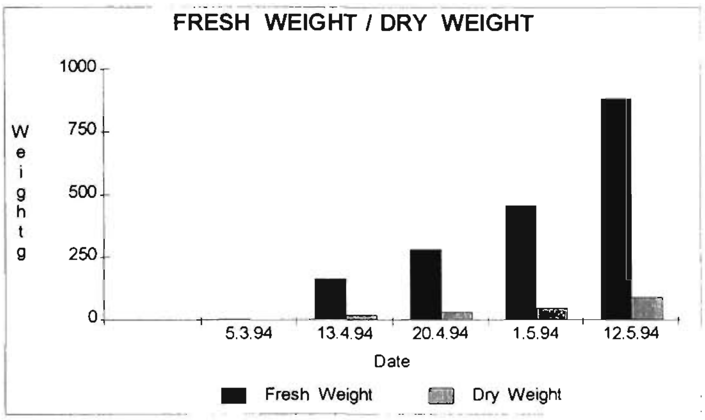

Figure 64: The average fresh weight and dry weight of broccoli plants for site 8.

SITE 9

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this site can was a **clay loam** (visual examination) and its moisture characteristic curve has a water content percentage (g/g) values between 52.5% to 9.4% over a range of water potentials (Figure 65).

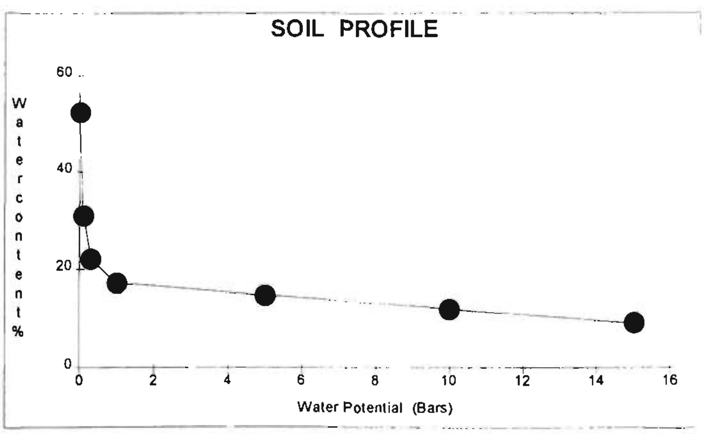

Figure 65: Moisture characteristic curve at different water potentials at site 9.

4.3.2 Field Soil Moisture Content

The percentage field soil moisture content values at 30 cm and 60 cm depths are given in the appendix (Table 31) and averages are shown in figure 66.

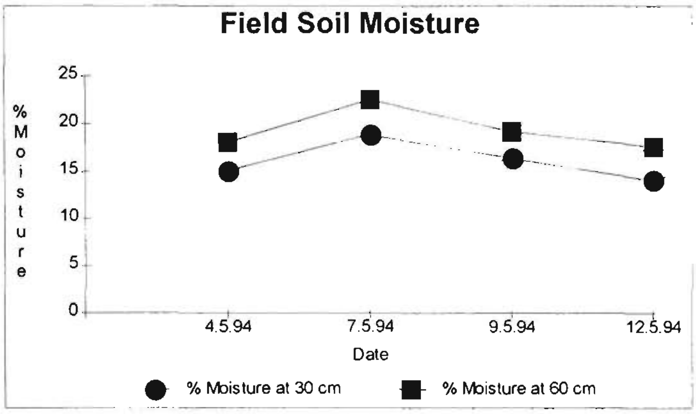

Figure 66: Field soil moisture content during an irrigation cycle at site 9.

4.3.3 Soil Moisture Tension (Irrometer/Tensiometer)

The percentage field soil moisture content values at 30 cm and 60 cm depths are given in the appendix (Table 32) and is shown in figure 67 . The irrigation was initiated on 4. 5. 94.

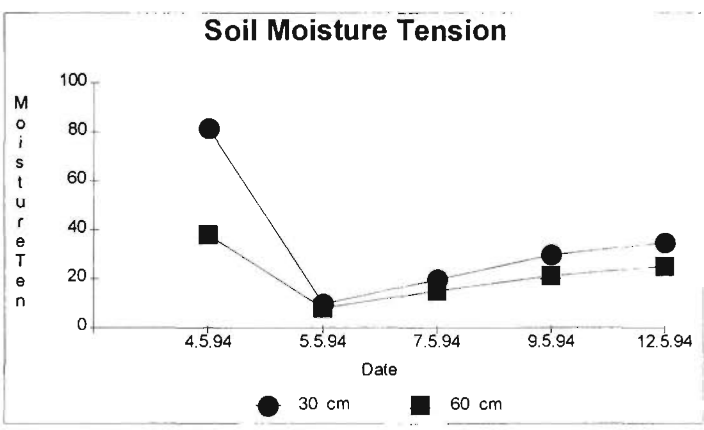

Figure 67: Irrometer readings for soil moisture tension (centibar) for an irrigation cycle at site 9.

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4.4 & 4.5 Irrigation, Yield and Quality measurements

The quality assessment of harvested broccoli heads for various attributes (sec. 3.5.1), yield measurements and amount of water delivered during one irrigation (sec. 3.3) are given in Table 27. Some plants (e.g. those around cans 4, 6 and 7) received approximately twice the water volume compared with others (e.g. cans 8, 14, 15 16 and 17). Ten harvested out of sixty heads (17%) had hollow stem with highest hollow stem occurring with greater volumes of water applied.

TABLE 27: Yield Measurements & Irrigation at site 9, Trial 3 (Mar. - May 1994).

SAMPLE	H.Wt.	H.D.	B.D.	S.D.	MATURITY	H.S.	M.V.	Bd.	WATER
	g	mm	mm	mm					mm
C1P1	227.4	101	33	34	4	1	5	1	18.4
P2	338.1	128	34	40	5	1	5	1	
P3	311	140	35	34	5	1 *			
C2P1	301.5	125	34	35	5	1	5	1	27.2
P2	288.2	98	32	32	5	1	5	1	
P3	207.9	82	29	30	5	1 *			
C3P1	280.5	120	32	36	5	1	5	1	18.1
P2	256.2	115	30	33	5	1	5	1	
P3	400.7	141	35	37	5	1 *			
C4P1	499.4	150	43	40	6	2 *			33.6
P2	346.7	132	34	36	5	3	5	1	
P3	459.7	149	40	42	5	4	5	1	
C5P1	248.2	102	30	32	5	1	5	1	18.9
P2	316.9	128	32	34	5	1	5	1	
P3	274.7	121	31	33	5	1 *			
C6P1	298.8	110	32	33	5	1	5	1	28.4
P2	412.3	145	34	38	5	3 *			
P3	275.9	122	31	36	5	1	5	1	
C7P1	361.2	140	33	37	5	1	5	1	29.9
P2	386.3	150	44	41	6	1	5	1	
P3	347.4	135	41	39	5	2 *			
C8P1	375.4	140	35	40	5	1	5	1	16.7
P2	364.6	135	34	39	6	1	5	1	
P3	394.9	145	36	38	5	1	5	1	
C9P1	401.9	170	39	35	5	1	5	1	19.8
P2	428.8	158	35	36	7	1	4	1	
P3	467.6	160	39	42	5	2 *			
C10P1	424.4	163	36	40	6	2 *			24.2
P2	414.6	160	34	33	6	1	5	1	
P3	381.9	153	36	38	6	1	5	1	
C11P1	462.5	165	44	41	6	1	4	1	21.1
P2	288.6	112	31	33	5	1	5	1	
P3	335.4	125	35	35	5	1 *			
C12P1	357.8	140	35	40	5	2 *			18.7
P2	454.8	158	41	39	6	1	5	1	
P3	419	152	38	42	5	1	5	1	
C13P1	439.2	146	34	39	5	3 *			23.8
P2	312.1	131	36	35	6	2	5	1	
P3	366.5	130	38	35	6	1	5	1	
C14P1	237.2	98	29	34	5	1	5	1	16
P2	207.8	90	34	33	4	1	5	1	
P3	232.1	100	30	32	4	1	5	1	
C15P1	389	142	34	37	6	1	5	1	16.7
P2	298.4	126	32	34	5	1	5	1	
P3	321.7	129	36	33	5	1 *			
C16P1	213.1	88	32	36	4	1	4	1	15.3
P2	227.9	109	32	34	5	1	5	1	
P3	238.3	102	28	34	6	1 *			
C17P1	250.9	122	31	34	5	1	5	1	15.7
P2	224	98	29	35	5	1	5	1	
P3	234.7	103	30	34	5	1	5	1	
C18P1	279.2	119	36	34	5	1	5	1	17
P2	232.8	113	29	35	5	1	5	1	
P3	286.6	121	39	36	5	1 *			
C19P3	239.9	106	29	32	5	1	5	1	18.7
P2	323.4	140	34	36	5	1	5	1	
P3	289.3	110	33	35	5	1 *			
C20P1	345.2	135	38	40	5	1	5	1	20.4
P2	359.6	130	38	36	5	1	5	1	
P3	415.7	151	36	35	6	1 *			

Legend: As Table 10 on page 42

4.6 Plant Analysis

4.6. 1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 33) and average fresh and dry weights are presented in figure 68.

The average fresh weight increased two fold between every sampling. The percentage dry matter was 17.5% at transplanting and decreased to 8.4% at harvest.

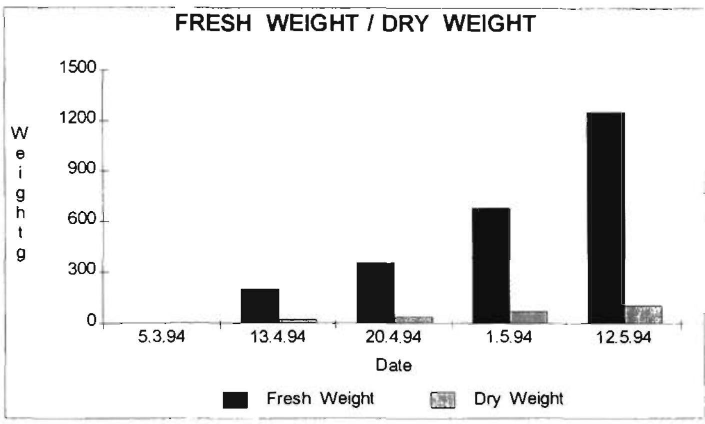


Figure 68: The average fresh weight and dry weight of broccoli plants for site 9.

4.7 Statistical analysis for yield parameters and irrigation application across the three sites for trial 3 (autumn crops).

a) Yield and Quality Analysis

Moderately high correlations between head fresh weight, head diameter, stem diameter and bud diameter were found (Table 28).

TABLE 28: Correlation matrix between Yield and Quality measurements across the three sites (Trial 3).

F. Wt.	1.000							
H.D.	0.904	1.000						
S.D.	0.724	0.655	1.000					
B.D.	0.575	..686	0.556	1.000				
H.S.	0.208	0.120	0.141	0.029	1.000			
Maturity	0.663	0.644	0.420	0.419	0.152	1.000		
M.V.	-0.325	-0.318	-0.236	-0.304	-0.145	-0.520	1.000	
Bd	0.138	0.166	0.087	0.168	0.150	0.298	-0.683	1.000
	F. Wt.	H.D.	S.D.	B.D.	H.S.	Maturity	M.V.	Bd

Regressions of yield measurements on sites 7 and 8 compared with site 9, water applied and hollow stem ratings are summarised below in Table 29.

TABLE 29: Yield and Quality Analysis for Trial 3

Yield	Significance (p-values) of...				
measurement	Site 7	Site 8	Water	Hollow stem	R (%)
F. Wt.	0.204	0.024	0.185	0.034	9
H.D.	0.436	< 0.001	0.464	0.0211	5.9
S.D.	0.926	0.853	0.121	0.078	5
B.D.	< 0.001	< 0.001	0.108	0.983	45.9

Legend As Table 14 on page 59.

Water had no significant effect on any of these yield variables.

There was no significant difference between the sites in hollow stem rating, but the probability of a high hollow stem rating increased with the amount of water applied ($p< 0.0001$).

There was a significant difference in the market value ratings attributable to plants at different sites with plants at site 9 having a higher probability of a high market value rating than the other two sites. Water was also a significant factor with the probability of a higher rating decreasing with volume of water applied, but these "relationships" hinge on three observations at site 7 and should be treated with caution.

4.1.2 LETTUCE

TRIAL 1 (Autumn) March - May 1994.

This trial occurred at one site (site 10) only. Lettuce is a new crop for this region and all the time of these trials was not grown so well, so only preliminary studies were undertaken.

SITE 10

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this site was a **clay loam** (visual examination) and its moisture retention curve exhibited water content percentage (g/g) values between 52.5% and 11.6% over a range of water potentials (Figure 69).

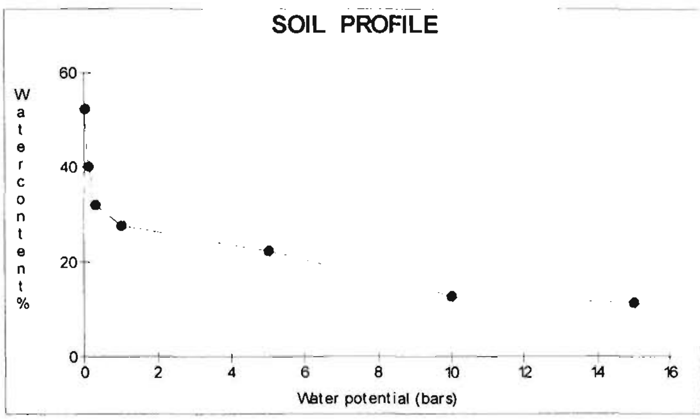


Figure 69: Moisture characteristic curve at different water potentials for site 10.

4.4 & 4.5 Irrigation, Yield and Quality measurements

The assessment for various quality attributes (sec. 3.5.2), yield measurements and total water applied over three irrigations are given in Table 30. The water delivered throughout the crop was very uneven. Some plants received more than twice the amount of water (e.g. around cans 10, 12, 14, 15, and 20) than others (e.g. around can 3). The grower used movable overhead sprinklers in the first irrigation after transplanting and then an overhead travelling spray gun irrigator was used. The quality of the harvested heads was very poor. Most of the plants had head rot (photo 4 - plate 2). The heads selected for market quality assessment were chosen from the nearest good heads to the cans as some of the tagged plants were not suitable for quality assessment because of very bad head rot (Photo 4 - Plate 2).

TABLE 30: Yield Measurements & Irrigation at site 10 (March - May 1994).

SAMPLE	H.Wt.	H.D.	FIRMNESS	ATURITY	H. ROT	M.V.	Bd.	WATER
	g	mm						mm
C1P1	477.6	150	2	1	5	4	1	28.2
P2	284.2	140	2	3	2	1	3	
C2P1	272.2	140	2	1	5	1	3	26.9
P2	354.4	140	3	1	5	2	3	
C3P1	736.3	180	1	2	2	3	2	18.7
P2	671.3	170	1	2	5	3	3	
C4P1	275	160	1	3	5	5	1	34
P2	397.7	150	3	1	5	*		
C5P1	446.2	170	2	1	2	3	1	38.8
P2	322.9	150	3	1	2	1	3	
C6P1	504.3	170	2	1	2	*		34.4
P2	377.7	160	2	1	3	1	3	
C7P1	410.3	140	2	3	2	*		43.2
P2	340.3	150	2	1	5	1	3	
C8P1	497	180	3	1	5	4	1	38.8
P2	472	160	2	1	2	*		
C9P1	518.5	160	3	1	5	1	3	34.4
P2	692.9	190	3	1	5	5	1	
C10P1	492.9	170	2	1	5	*		42.2
P2	539.1	180	3	1	3	*		
C11P1	501.1	160	3	1	5	4	1	33.3
P2	339	130	1	3	5	5	1	
C12P1	596.3	150	3	1	5	5	1	42.2
P2	505.6	140	3	1	4	4	2	
C13P1	400.2	110	3	1	5	*		27.5
P2	559.6	160	3	1	5	3	2	
C14P1	541	150	3	1	5	4	2	46.2
P2	492.4	140	3	1	5	5	1	
C15P1	553.6	150	3	1	5	5	1	41.5
P2	666.7	180	1	2	1	*		
C16P1	539.5	140	3	1	5	5	1	39.8
P2	407.3	155	3	1	5	4	1	
C17P1	634.4	140	2	2	2	4	1	37.1
P2	445.1	120	3	1	2	*		
C18P1	519.5	140	2	2	3	*		42.2
P2	645.2	150	2	2	5	3	2	
C19P1	443.3	150	2	1	5	4	1	27.2
P2	562.8	150	2	1	5	3	2	
C20P1	364.2	170	2	1	5	*		46.6
P2	502.7	140	2	1	2	3	3	

Legend: As Table 10 on page 42

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 34) and average fresh and dry weights are presented in figure 70.

The average dry matter at transplanting was 14.3% and decreased to 4.3% at harvest.

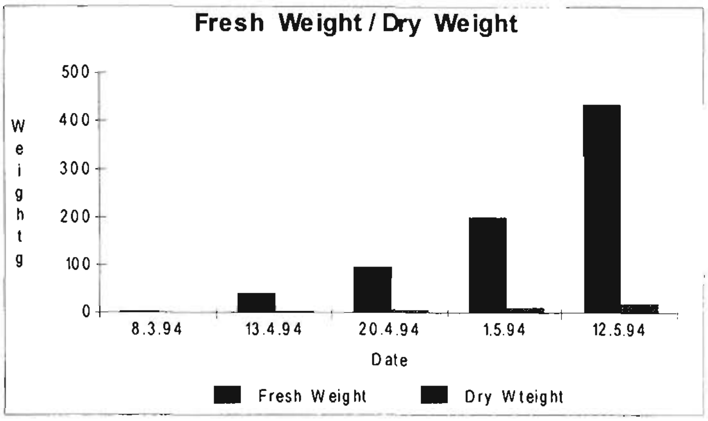


Figure 70: The average fresh and dry weights of lettuce plants for site 10.

4.7 Statistical Analysis

The correlation matrix between head weight, head diameter and water volume is given below in Table 31.

TABLE 31: Correlation Matrix between fresh weight, head diameter and water.

Fresh weight	1.000		
Head diameter	0.426	1.000	
Water applied	-0.333	-0.210	1.000
	Fresh weight	Head diameter	Water applied

Salient points of the analysis in Table 31 are:

* A small positive correlation between fresh weight and head diameter.
* No obvious relationship between fresh weight and water applied or between head diameter and water applied.
* No relationships between water and any of the quality ratings (head rot, firmness etc.)

4.2 FIELD TRIALS: Year 2 (1995)

4.2.1 BROCCOLI: SITE 11

Four experimental plots were established at this site: two installed with a drip irrigation and two with fixed overhead sprinklers.

The drip irrigation was controlled with a tensiometer, fixed at 30 cm depth, in the experimental plot, which turned irrigation on automatically whenever the tensiometer reading reached 20 centibars.

DRIP IRRIGATION - 1

4.3 Soil Analysis

4.3.1 Soil Profile

The soil type in this plot was a **clay loam** (visual examination) and its moisture characteristic curve (Figure 71), exhibited water content percentage (g/g) values between 63% and 20.1% over a range of water potentials.

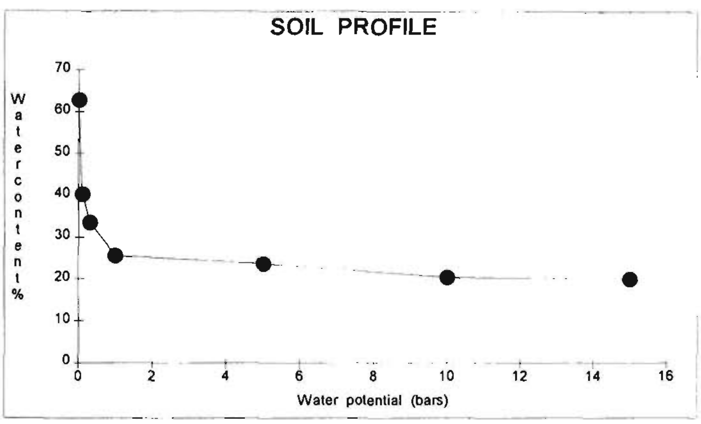


Figure 71 : Moisture retention curve at different water potentials for site 11 (Drip irrigation-1).

4.5 Yield and Quality measurements

The quality assessment of harvested broccoli heads for various attributes (sec. 3.5.1) and yield measurements are given in Table 32. Five out of twenty two heads (23%) had hollow stem with ratings of 2 - 3.

TABLE 32: Yield Measurements at Site 11 (Drip Irrigation-1) Jan. - Mar. 1995.

SAMPLE	H.Wt	S.D.	B.D.	H.D.	Maturity	H.S.	M.V.	Bd
	g	mm	mm	mm				
1	310	40	33	130	5	3	*	
2	326.9	45	36	140	6	3	*	
3	362.5	45	35	140	5	2	*	
4	322.4	40	32	130	5	1	4	1
5	218.4	38	30	115	5	1	5	1
6	330.5	45	32	130	5	1	5	1
7	385.8	40	30	148	5	1	*	
8	258.9	45	35	130	5	1	5	1
9	339.1	48	35	125	5	1	4	1
10	366.4	45	35	135	5	1	5	1
11	309.3	40	32	120	5	1	*	
12	263.3	40	32	120	5	1	5	1
13	257.2	40	32	118	5	1	5	1
14	331.3	45	36	124	5	1	5	1
15	280.6	40	32	115	6	1	4	1
16	370.6	50	35	130	5	2	*	
17	333.3	40	32	130	6	1	*	
18	342.1	38	35	130	5	1	5	1
19	318.3	40	33	120	5	1	5	1
20	326.4	40	35	130	7	2	5	1
21	281.8	45	35	125	5	1	5	1
22	261.3	42	33	120	5	1	5	1

Legend

Sample	Tagged harvested broccoli head.
H. Wt.	Fresh weight of harvested broccoli head.
S.D.	Stem diameter of harvested broccoli head.
B.D.	Bud diameter of harvested broccoli head.
H.D.	Head diameter of harvested broccoli head.
Maturity	Maturity of harvested broccoli head.
H.S.	Hollow stem rating of harvested head.
M.V.	Market value of broccoli heads after taking out from cool room.
Bd.	Breakdown (rot) in broccoli heads after taking out from cool room.
*	Samples taken for nutrient analysis.

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in Table 35 of the appendix and average fresh and dry weights are presented in figure 72.

The average dry matter at transplanting was 20.7%. This decreased to 10.4% (Table 35 in the appendix) at harvest.

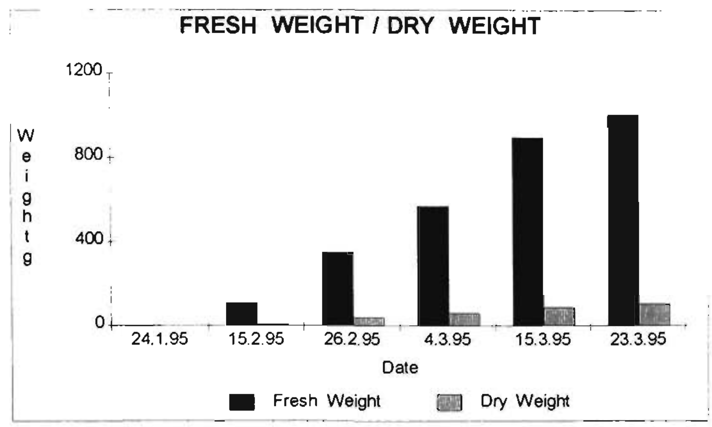


Figure 72: The average fresh and dry weights of broccoli plants for site 11 (drip irrigation - 1)

4.6.3 Nutrient analysis

The concentrations of N, B, K and Ca in head samples are given in the appendix (Table 36).

Graphs of parameters which are known to significantly affect hollow stem are presented below in figures 73 - 74. B concentration in broccoli head was found to be positively related to the occurrence of hollow stem: the greater the B concentration, the lower the hollow stem rating (Figure 73).

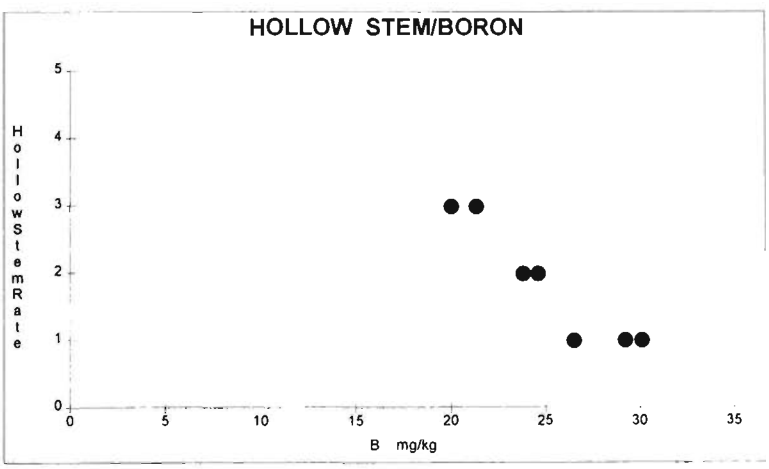


Figure 73: Hollow stem rating as affected by B concentration.

The higher concentration of N was found to be correlated with a higher hollow stem rating (Figure 74).

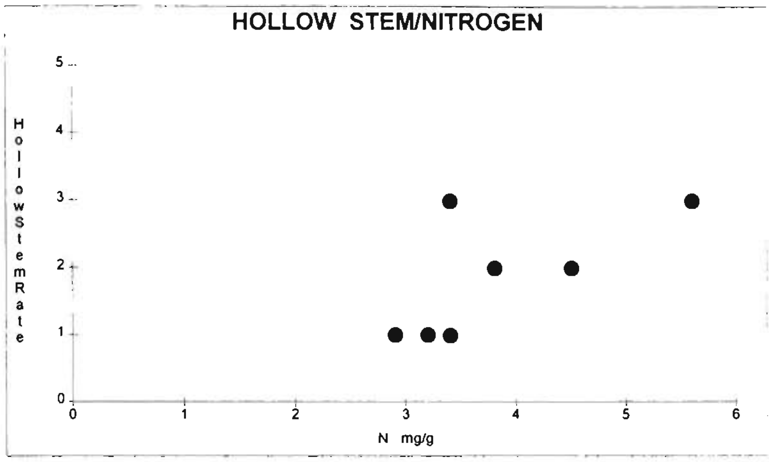


Figure 74: Hollow stem rating as affected by N concentration.

DRIP IRRIGATION - 2

4.3 Soil Analysis

4.3.1 Soil Profile

The soil type in this plot was a **clay loam** (visual examination) and its moisture characteristic curve (Figure 75), exhibited water content percentage (g/g) values between 65.2% and 20.9% over a range of water potentials.

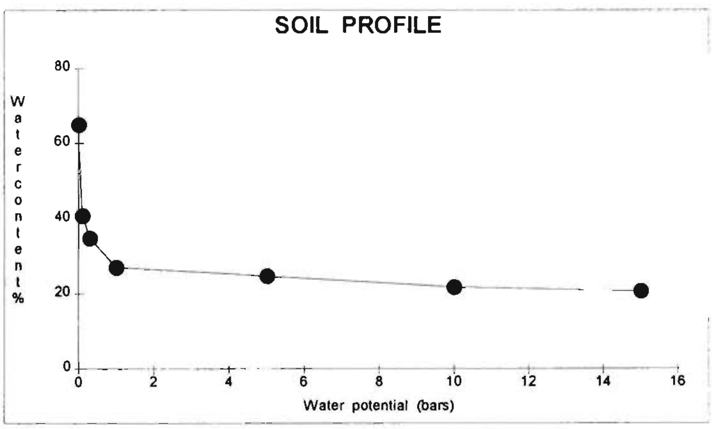


Figure 75: Moisture retention curve at different water potentials for site 11 (Drip irrigation - 2).

4.5 Yield and Quality measurements

The quality assessment for various attributes (sec. 3.5.1) and yield measurements are given in Table 33. Four out of twenty two heads (18%) had hollow stem (2-5 rating).

TABLE 33: Yield Measurements at site 11 (Drip Irrigation-2) Jan. - Mar. 1995.

SAMPLE	H.Wt	S.D.	B.D.	H.D.	Maturity	H.S.	M.V.	Bd
	g	mm	mm	mm				
1	247.2	38	30	118	5	1	5	1
2	259.5	40	35	128	6	1	5	1
3	334.3	40	32	130	5	4	*	
4	363	45	40	135	6	1	4	1
5	340.2	38	40	150	5	1	5	1
6	243.1	35	38	130	6	1	5	1
7	446.6	45	45	155	5	5	*	
8	255	30	28	120	5	1	5	1
9	272.1	38	30	115	6	2	4	1
10	309.8	45	40	130	5	1	5	1
11	268.3	40	35	120	5	2	*	
12	275.7	38	32	125	4	1	5	1
13	344.3	40	33	130	5	1	5	1
14	298.2	40	35	122	5	1	*	
15	235.7	35	32	125	5	1	4	1
16	376.5	40	40	140	5	1	*	
17	290.6	42	35	120	5	1	5	1
18	321.2	40	30	128	5	1	5	1
19	347.6	40	32	140	5	1	*	
20	296.6	35	38	118	5	1	5	1
21	219.6	32	28	115	5	1	5	1
22	245	35	35	120	5	1	*	

Legend As Table 32 on page 98

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage of dry matter are given in the appendix (Table 37) and average fresh and dry weights are presented below in figure 76.

The average dry matter at transplanting was 20.2%. This decreased to 9.6% (Table 37 in the appendix) at harvest.

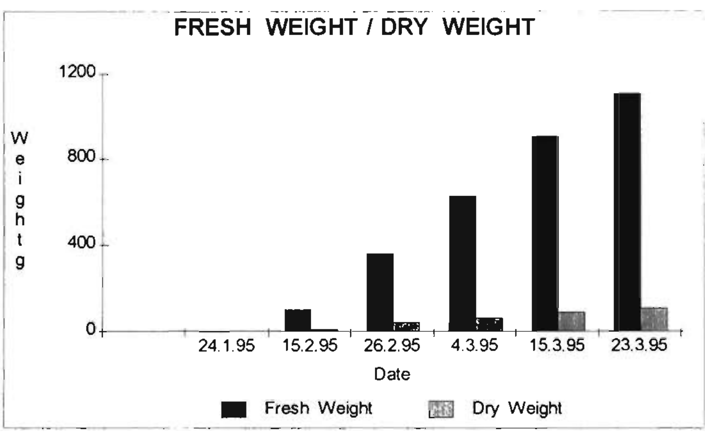


Figure 76: The average fresh and dry weights of broccoli plants for site 11 (drip irrigation - 2)

4.6.3 Nutrient Analysis

The results of the tissue analysis are presented in the appendix (Table 38). The significant relationships are plotted below in figures 77 - 78.

B concentration was found to be positively related to the occurrence of hollow stem; as B concentration decreased, hollow stem rating increased (Figure 77).

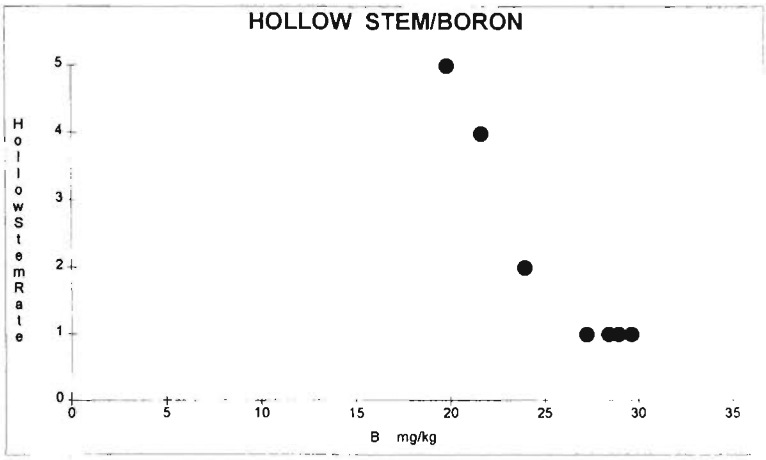


Figure 77: Hollow stem rating as affected by B concentration.

Similarly, a higher concentration of N was found to be associated with a higher hollow stem rating (Figure 78).

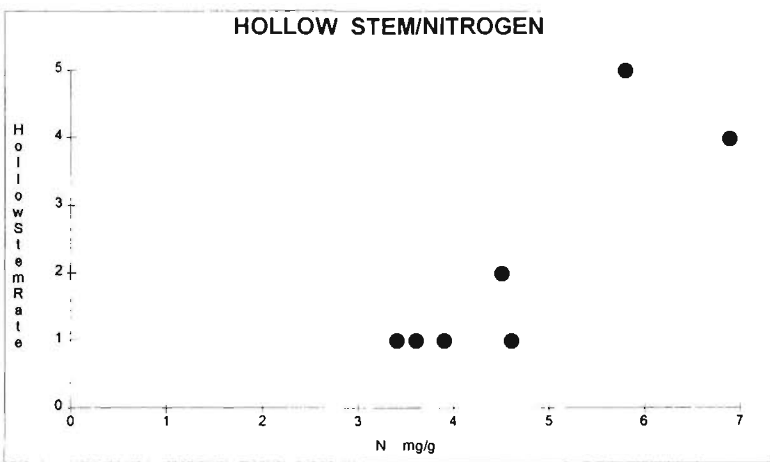


Figure 78: Hollow stem rating as affected by N concentration.

OVERHEAD SPRINKLER - 1

4.3 Soil Analysis

4.3.1 Soil Profile

The soil type in this plot was a **clay loam** (visual examination) and its moisture characteristic curve (Figure 79), exhibited a water content percentage (g/g) values between 66.1% and 21.7% over a range of water potentials.

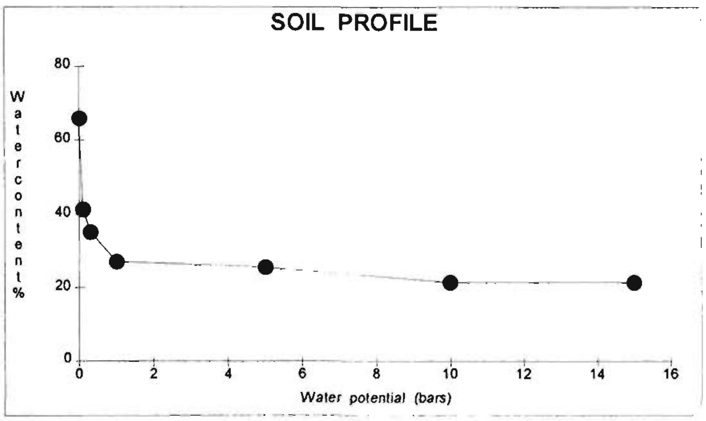


Figure 79: Moisture retention curve at different water potentials for site 11 (overhead sprinklers - 1).

4.5 & 4.6 Irrigation, Yield and Quality measurements

The quality assessment for various attributes (sec. 3.5.1), yield measurements and total amount of water delivered over three irrigations (sec. 3.4) are given in Table 34. The smaller volume of water collected in can R1C6 was due to a malfunction in the sprinkler. Some of the plants (e.g. can R3C5) received more than twice the volume of water as others (e.g. cans R2C7 and R2C8). Twelve out of twenty-four heads (50%) had hollow stem but only one of these had the maximum rating of 5.

TABLE 34: Yield Measurements & Irrigation at Site 11 (Overhead Sprinklers - 1) Jan. - Mar. 1995.

SAMPLE	H.Wt.	S.D.	B.D.	H.D.	Maturity	H.S.	M.V.	Bd	Water
	mm	mm	mm	mm					mm
R1C6P1	113.5	30	20	55	1	1	1	1	25.95
P2	135.5	32	20	53	1	1	1	1	
P3	171.9	40	20	60	1	1	1	1	
R2C6P1	291.6	35	35	110	5	1	5	1	54.06
P2	286.3	38	40	105	5	1	*		
P3	244.2	32	35	110	5	1	5	1	
R2C7P1	266.8	45	30	130	4	1	5	1	47.26
P2	200.1	40	25	90	3	1	3	1	
P3	226.3	30	28	88	3	1	4	1	
R2C5P1	211.8	35	28	110	4	2	5	1	70.3
P2	283.4	38	40	130	5	2	5	1	
P3	236.8	40	30	115	5	1	4	1	
R2C8P1	332.6	42	36	125	5	1	*		44.03
P2	311.8	40	35	120	5	1	5	1	
P3	401.3	45	45	140	6	1	4	1	
R3C5P1	379.6	50	40	150	5	3	5	1	98.61
P2	397.4	50	45	150	6	5	*		
P3	381	45	40	140	5	3	5	1	
R3C6P1	306.6	40	40	150	5	2	5	1	70.38
P2	295.2	40	30	135	5	1	5	1	
P3	386.5	35	40	150	6	2	*		
R3C7P1	363.8	40	40	142	5	3	5	1	82.28
P2	324.5	45	32	140	5	2	*		
P3	293.4	40	33	120	5	3	5	1	
R3C8P1	280.5	38	31	122	5	1	5	1	61.2
P2	288.1	40	33	128	5	2	4	1	
P3	285.4	42	35	120	5	2	*		

Legend As for Table 32 on page 98 + given below:

Sample: Tagged harvested broccoli head.

R 1-3: Marked rows for plant tagging.

C 5-8: Cans placed in different rows to collect irrigation water.

P 1-3: Three plants tagged around each can.

Water: Total amount of water delivered during three irrigations.

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage of dry matter are given in the appendix (Table 39) and average fresh and dry weights are presented in figure 80

The average dry matter at transplanting was 22.7%. This decreased to 10.3% (Table 39 in the appendix) at harvest.

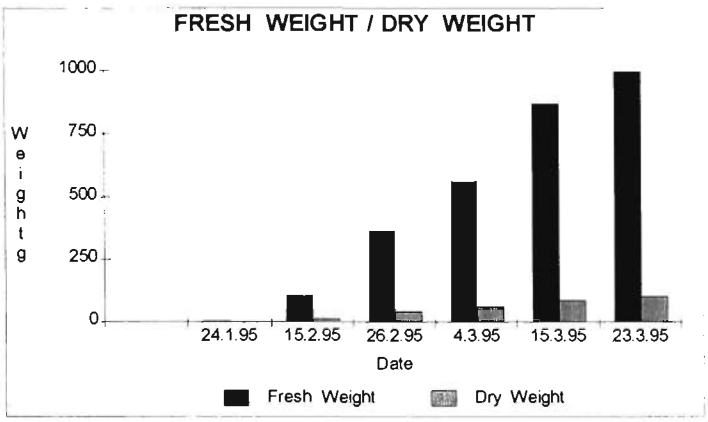


Figure 80: The average fresh and dry weights of broccoli plants for site 11 (overhead sprinklers - 1).

4.6.3 Nutrient Analysis

The results of the tissue analysis are given in the appendix (Table 40). The parameters which were significantly correlated with yield, hollow stem and nutrient uptake are plotted below in figures 81 - 85.

The head weight increased with increasing amounts of water applied (Figure 81).

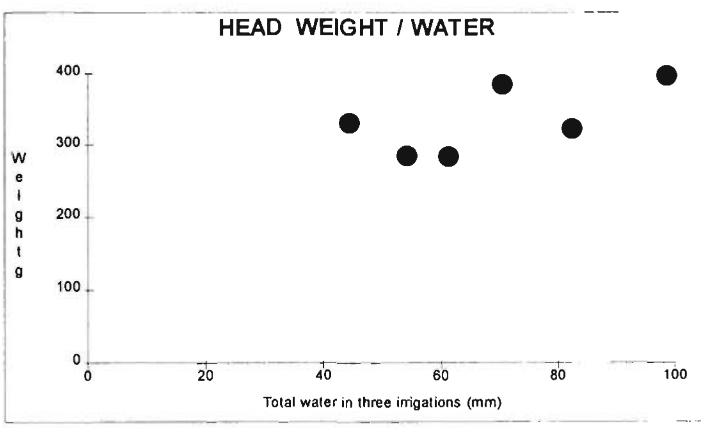


Figure 81: Head weight as affected by irrigation water.

The hollow stem rating increased with increasing amount of water applied (Figure 82).

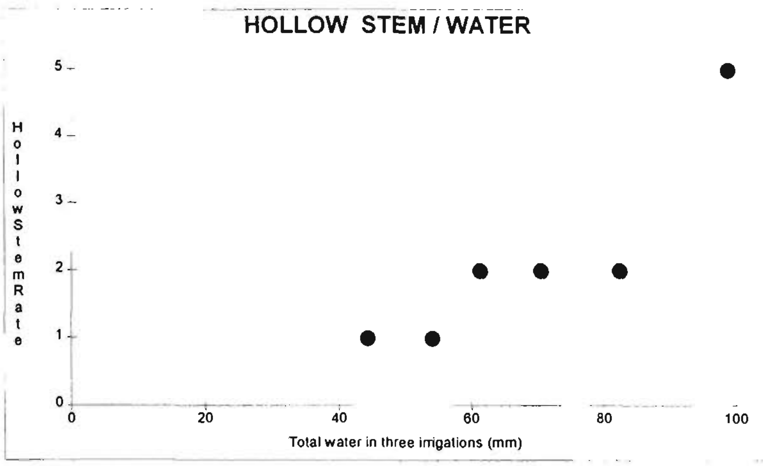


Figure 82: Hollow stem rating as affected by irrigation water.

As B concentration decreased the hollow stem rating increased (Figure 83).

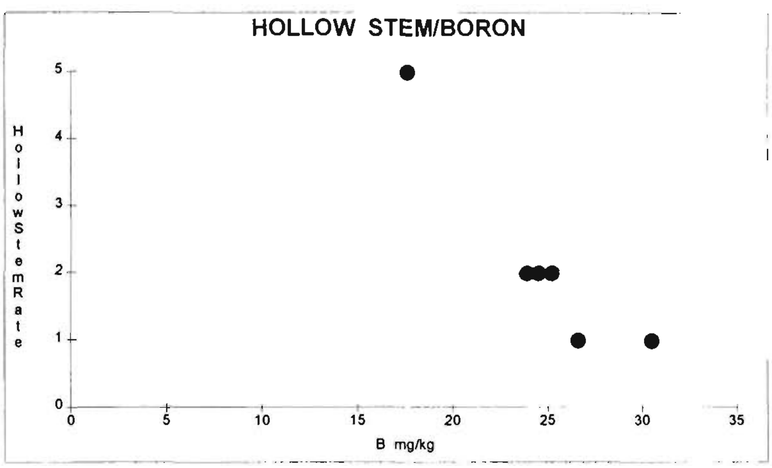


Figure 83: Hollow stem rating as affected by boron concentration.

B concentration was found to decrease when a greater volume of water was applied (Figure 84).

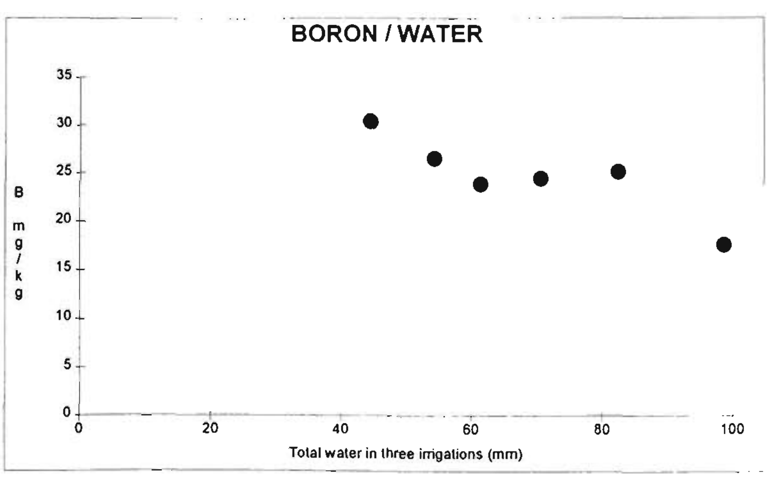


Figure 84: B concentration as affected by irrigation water.

A higher concentration of N is more likely to be associated with a higher hollow stem rating (Figure 85), although three heads with N concentration from 3 to 4.5 mg/g showed same hollow stem rating (2).

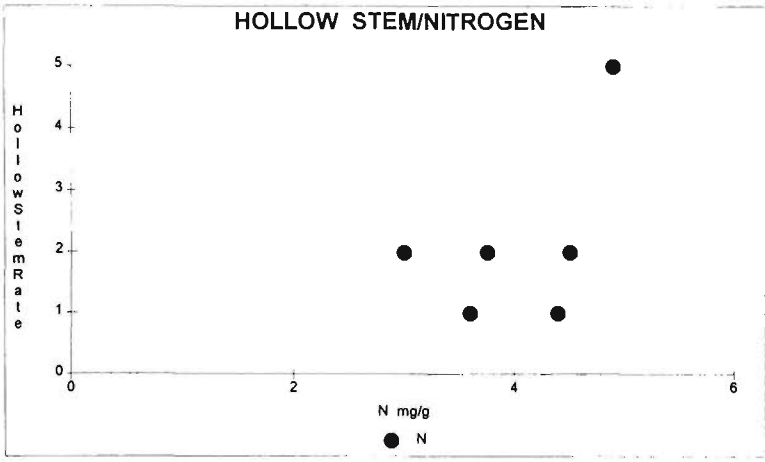


Figure 85: Hollow stem rating as affected by N concentration.

OVERHEAD SPRINKLERS - 2

4.3 Soil Analysis

4.3.1 Soil Profile

The soil type in this plot was a **clay loam** (visual examination) and its water characteristic curve (Figure 86), exhibited water content percentage (g/g) values between 65.1% and 19.9% over a range of water potentials.

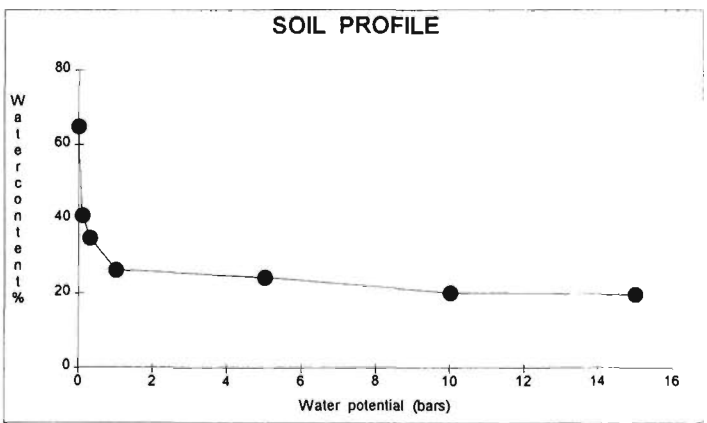


Figure 86: Moisture retention curve at different water potentials for site 11 (overhead sprinklers - 2).

4.4 & 4.5 Irrigation, Yield and Quality measurements

The quality assessments for various attributes (sec. 3.5.1), yield measurements and total amount of water delivered over three irrigations (sec. 3.3) are given in Table 35. Nine out of thirty-three heads (27%) were affected with hollow stem; however only three had high hollow stem ratings (4 - 5). The water delivered with these sprinklers was more even compared with the trial described for sprinklers 1 and hollow stem percentage was also low compared with the sprinklers 1 trial (50% heads had hollow stem).

TABLE 35: Yield Measurements & Irrigation at site 11 (Overhead Sprinklers - 2) Jan. - Mar. 1995.

SAMPLE	H.Wt.	S.D.	B.D.	H.D.	Maturity	H.S.	M.V.	Bd	Water
	g	mm	mm	mm					mm
R2C8P1	337.2	45	40	140	6	1	5	1	55.42
P2	398.9	50	45	150	5	1	5	1	
P3	369	48	38	138	5	1	5	1	
R2C10P1	378.2	40	35	138	6	2	5	1	68
P2	410.4	42	40	150	6	1	5	1	
P3	434.1	45	38	148	7	2	•		
R3C9P1	390.2	48	35	145	5	2	•		57.29
P2	329.8	40	32	130	5	1	5	1	
P3	344.6	45	42	140	6	2	•		
R4C9P1	261.1	40	35	130	5	1	5	1	66.3
P2	317.3	45	33	135	5	1	5	1	
P3	391.3	48	35	150	6	2	•		
R5C10P1	327.1	45	32	135	5	1	5	1	56.95
P2	277.2	35	30	115	5	1	5	1	
P3	321.4	40	35	120	5	1	4	1	
R3C1P1	303.4	42	35	140	6	1	5	1	62.22
P2	288.7	40	30	110	5	1	5	1	
P3	287.4	40	30	115	5	1	5	1	
R5C1P1	279.1	35	28	110	4	1	5	1	60
P2	337.8	38	32	118	5	1	5	1	
P3	355.8	40	35	130	5	1	5	1	
R5C2P1	315.4	40	40	135	6	1	5	1	45.9
P2	404.8	40	40	155	6	1	5	1	
P3	419.1	45	42	160	6	1	4	1	
R1C2P1	323.5	38	32	150	5	4	5	1	77.69
P2	483.9	50	40	165	6	5	•		
P3	340.3	40	33	150	5	4	5	1	
R4C2P1	298.2	40	35	110	4	1	5	1	53.4
P2	355	40	38	130	5	1	5	1	
P3	314.1	35	32	125	6	1	5	1	
R3C2P1	267.3	40	35	122	5	1	5	1	52.87
P2	298	39	30	130	5	2	•		
P3	357	48	33	130	5	1	5	1	

Legend As for table 32 and 34 on pages 98 and 104.

4.6 Plant Analysis

4.6.1 Plant growth

The average fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 41) and average fresh and dry weights are presented in figure 87.

The average dry matter at transplanting was 20.9%. This decreased to 10.5% (Table 41 in the appendix) at harvest.

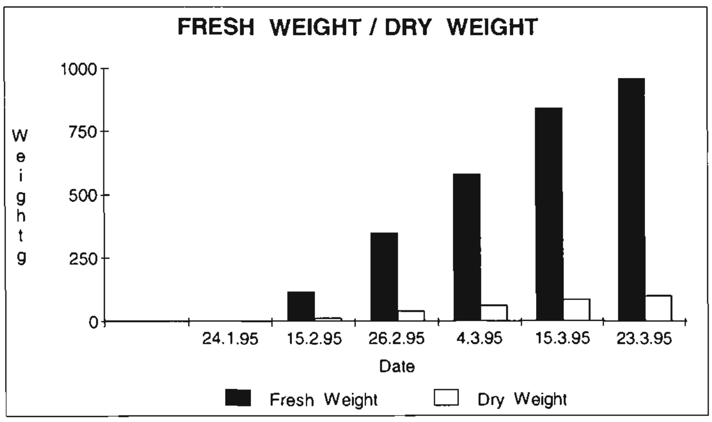


Figure 87: The average fresh and dry weights of broccoli plants for site 11 (overhead spriklers - 2).

4.6.3 Nutrient Analysis

The results of the tissue analysis are presented in the appendix (Table 42).

The parameters which significantly correlated with head weight, hollow stem and nutrient uptake are plotted in figures 88-92 The head weight increased with increasing amounts of water applied (Figure 88).

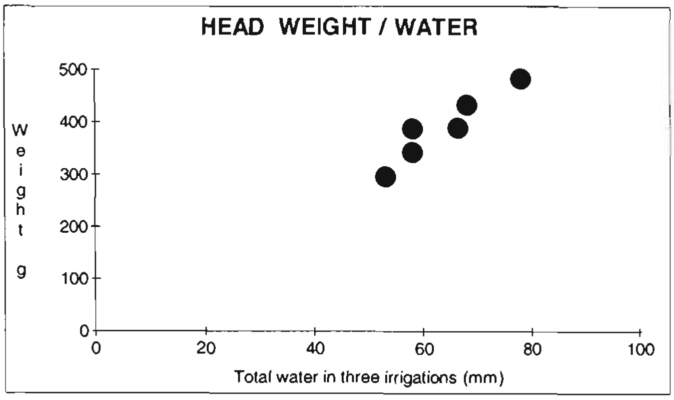


Figure 88: Head weight as affected by irrigation water.

The hollow stem rating was found to be greater with increasing amount of water applied for one sample only (Figure 89). Due to smaller number of broccoli heads which exhibited hollow stem a strong relatioship between water applied and hollow stem incidence could not be demonstrated.

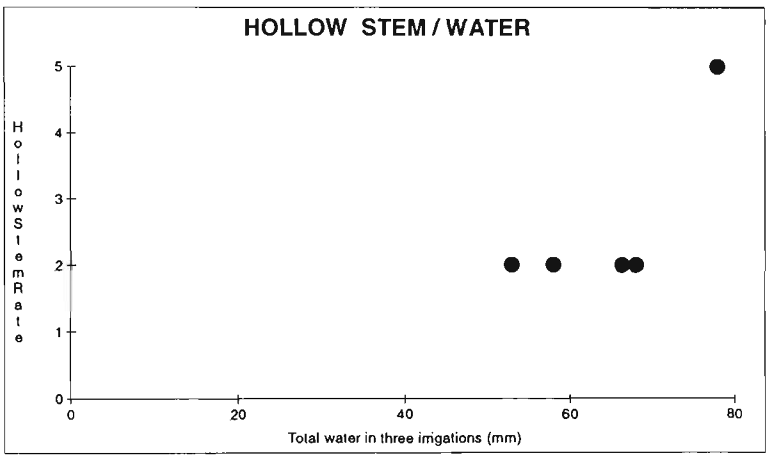


Figure 89: Hollow stem rating as affected by irrigation water.

Hollow stem rating increased with decreasing B concentrations in one sample of broccoli head tissue (Figure 90). Due to lower number of affected heads, a strong relationship between B content and hollow stem incidence could not be demonstrated.

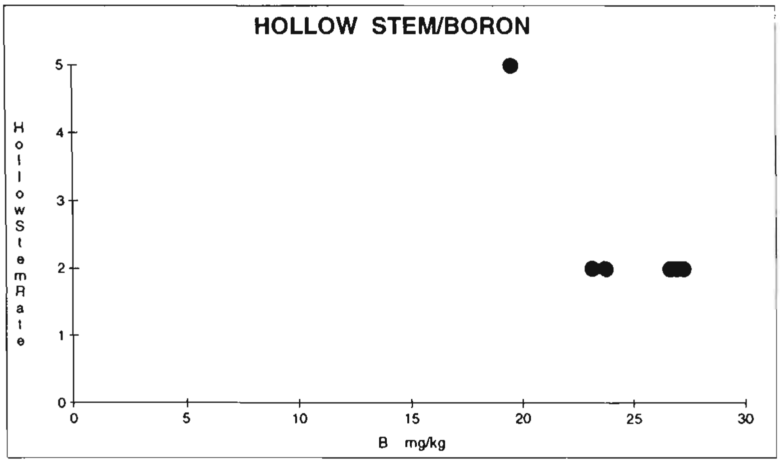


Figure 90: Hollow stem rating as affected by B concentration.

B concentration was found to decrease with greater volumes of water applied (Figure 91). Due to smaller number of affected broccoli heads, a strong relationship between B and water distribution could not be demonstrated.

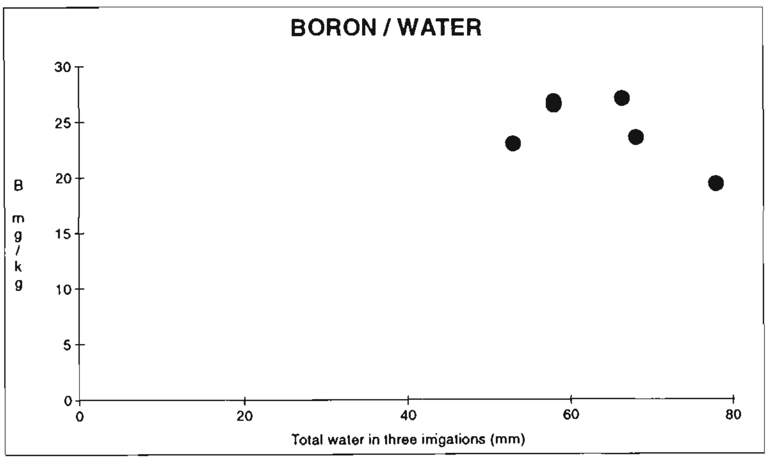


Figure 91: B concentration as affected by irrigation water.

Higher concentrations of broccoli head tissue N were associated with higher hollow stem ratings for one sample only (Figure 92). Due to smaller number of affected heads, a strong relationship between N concentration and hollow stem incidence could not be demonstrated.

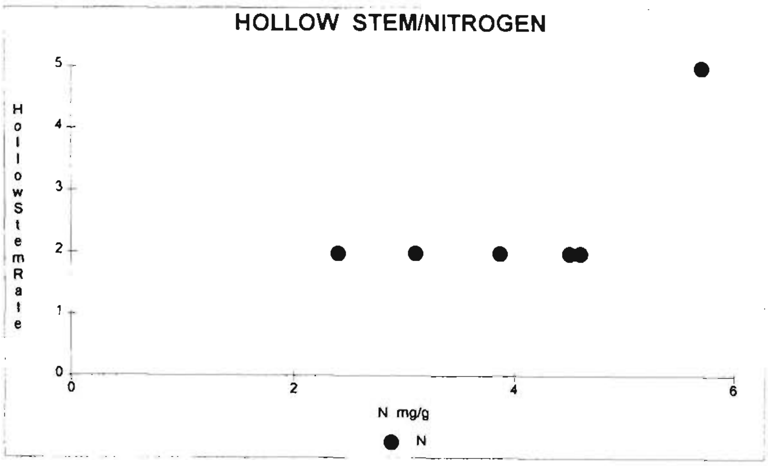


Figure 92: Hollow stem rating as affected by N concentration.

4.7 Statistical analyses of parameters measured in Drip and Overhead fixed sprinkler systems

a) Yield and Quality measurements

Moderately high correlations between head weight, head diameter and bud diameter (as expected) were found in both systems (drip and overhead sprinklers) given below in Tables 36 and 37.

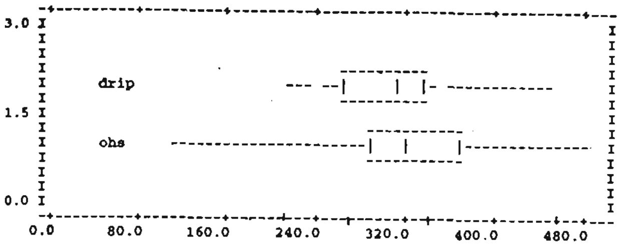
TABLE 36: Correlation matrix between Yield and Quality measurements at site 11 (Drip irrigation - 1 and 2).

Fresh weight	1.000			
Stem diameter	0.566	1.000		
Bud diameter	0.497	0.414	1.000	
Head diameter	0.780	0.363	0.550	1.000
	Fresh weight	Stem diameter	Bud diameter	Head diameter

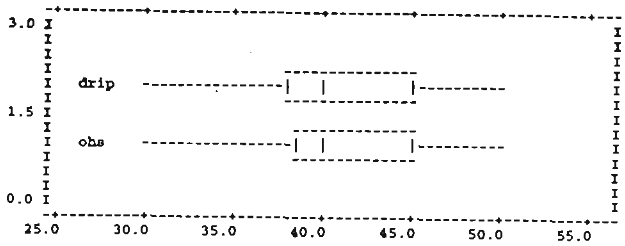
TABLE 37: Correlation matrix between Yield and Quality measurements at site 11 (Overhead fixed Sprinklers - 1 and 2).

Fresh weight	1.000			
Stem diameter	0.689	1.000		
Bud diameter	0.800	0.554	1.000	
Head diameter	0.887	0.652	0.785	1.000
	Fresh weight	Stem diameter	Bud diameter	Head diameter

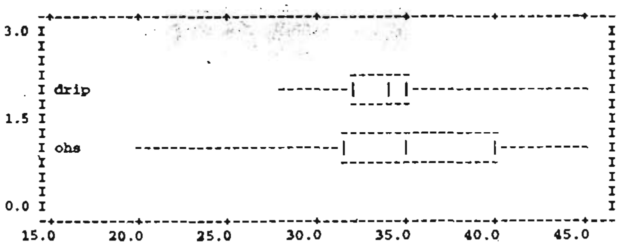
No significant differences in head weight, stem diameter, bud diameter, head diameter, maturity, hollow stem or market value between the two irrigation systems were found. However, in both the overhead sprinkler plots, the variation in all measured parameters was greater than in the drip irrigation plots as shown in the following box graphs (93.1 - 93.6).



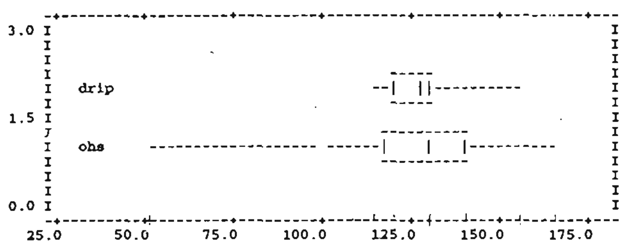
93.1: Head weight (g)



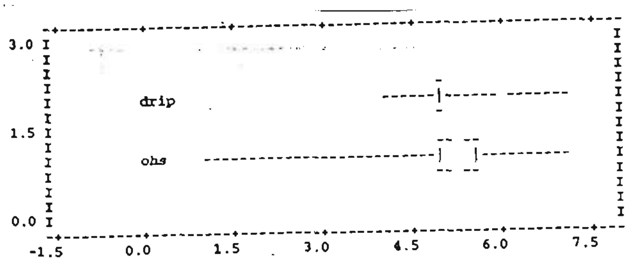
93.2: Stem diameter (mm)



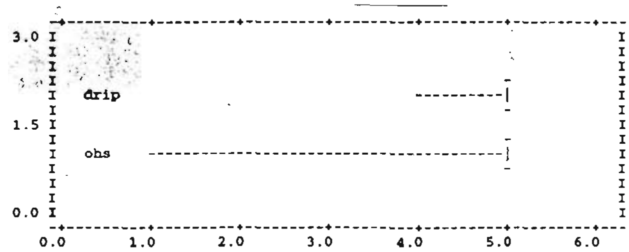
93.3: Bud diameter (mm)



93.4: Head diameter (mm)



93.5 Maturity



93.6: Market value

Figure 93: Variation in yield parameters with drip and overhead sprinkler irrigations.

Legend		
	mean	I
	range of actual values	_________
	variation above the mean	I I

b) Nutrient Analysis

No significant differences in hollow stem occurrence, boron, nitrogen, potassium, and calcium tissue concentrations between the two systems were found. A moderately negative correlation between nitrogen and boron was found as presented below for the two systems (Table 38).

TABLE 38: Correlation matrix between Nitrogen and Boron for the two systems.

Boron	1.000			
Nitrogen	-0.574	1.000		
Potassium	-0.339	-0.069	1.000	
Calcium	0.146	-0.069	0.139	1.000
	Boron	Nitrogen	Potassium	Calcium

4.2.2 BROCCOLI: SITE 12 (Travelling Irrigator)

4.3 Soil Analysis

4.3.1 Soil Profile

The soil at this site was a **loamy sand** (visual examination) and its moisture characteristic curve (Figure 94), which exhibited a water content percentage (g/g) values between 39.6% and 5.5% over a range of water potentials.

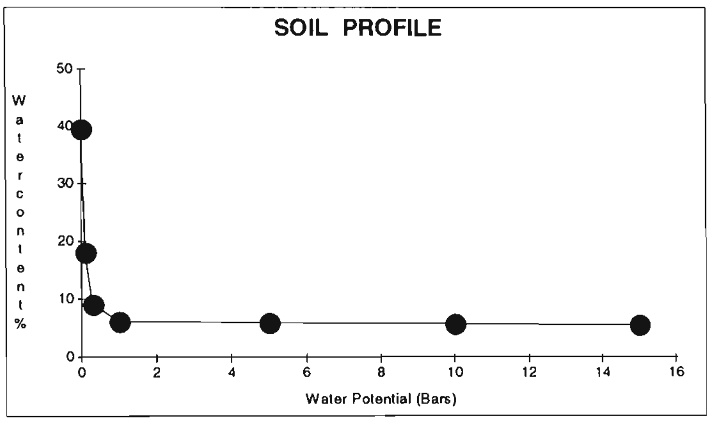


Figure 94: Moisture retention curve at different water potentials for site 12.

4.4 & 4.5 Irrigation, Yield and Quality measurements

The quality assessment for various attributes (sec. 3.5.1), yield measurements and total amount of water delivered over four irrigations (sec. 3.3) are given in Table 39. Twenty-two out of sixty harvested heads (37%) had hollow stem with eight having a severe hollow stem rating (4 -5).

TABLE 39: Yield Measurements & Irrigation at site 12 (Jan.-Mar. '95).

SAMPLE	F.Wt.	H.D.	B.D.	S.D.	MATURITY	H.S.	M.V.	Bd	WATER
	g	mm	mm	mm					mm
C1P1	272.5	120	30	40	5	1	5	1	47.94
P2	268.8	120	38	37	6	1	4	1	
P3	236	115	32	38	5	1	5	1	
C2P1	264.1	115	35	35	4	1	5	1	54.06
P2	232.1	110	35	40	5	1	*		
P3	263.7	120	38	40	5	1	5	1	
C3P1	352.9	130	40	44	6	1	4	1	52.53
P2	275.6	110	34	37	5	1	5	1	
P3	270.6	125	33	41	6	2	4	1	
C4P1	356	125	35	42	5	3	*		68
P2	281	125	33	40	5	2	5	1	
P3	289	110	32	45	7	2	4	1	
C5P1	235.2	110	32	38	5	4	*		70.04
P2	242.4	115	30	40	4	3	5	1	
P3	247.2	115	32	40	5	4	5	1	
C6P1	305.3	135	35	40	5	3	5	1	68.34
P2	289.3	120	40	40	6	2	5	1	
P3	290.8	130	32	38	5	2	5	1	
C7P1	242.9	110	32	40	4	1	4	1	61.54
P2	224.5	110	30	35	5	1	5	1	
P3	290.4	115	30	38	5	2	5	1	
C8P1	241	130	35	34	5	2	*		65.45
P2	242.2	120	30	35	5	1	5	1	
P3	250.4	120	35	40	5	2	5	1	
C9P1	366.3	135	40	45	5	5	5	1	78.71
P2	268.5	108	35	35	4	4	5	1	
P3	276.3	110	38	40	5	5	5	1	
C10P1	468.1	135	36	40	5	1	5	1	59.16
P2	486.5	140	42	43	6	1	4	1	
P3	354.9	130	32	35	6	1	4	1	
C11P1	266.6	130	32	38	5	1	*		57.8
P2	245	110	30	36	5	1	5	1	
P3	236.4	118	30	39	5	1	5	1	
C12P1	454.3	140	40	37	5	1	5	1	55.42
P2	347.4	130	35	38	5	1	5	1	
P3	338.6	130	32	43	5	1	5	1	
C13P1	391.7	132	38	40	5	5	4	1	75.14
P2	308.7	125	38	46	6	5	*		
P3	232.6	110	33	40	5	5	5	1	
C14P1	287	118	32	36	5	1	*		40.8
P2	255.7	120	30	34	5	1	5	1	
P3	304.7	120	42	38	5	1	5	1	
C15P1	248.1	130	35	36	5	1	*		40.46
P2	239.5	120	32	35	5	1	5	1	
P3	215.8	115	34	35	5	1	5	1	
C16P1	298.1	128	38	40	7	1	4	1	47.26
P2	242.4	128	31	37	5	1	5	1	
P3	230	125	32	36	5	1	*		
C17P1	248.7	120	28	36	5	1	5	1	51.51
P2	170.3	98	32	32	4	1	4	1	
P3	163.7	100	22	31	4	1	4	1	
C18P1	80.1	60	15	30	1	3	6	1	60.69
P2	55.9	50	12	25	1	3	6	1	
P3	113.7	80	20	32	2	1	5	1	
C19P1	307.9	135	34	38	6	1	4	1	45.39
P2	226.4	125	30	36	5	1	5	1	
P3	216.9	115	32	32	6	1	4	1	
C20P1	249.1	120	32	40	5	2	*		60.35
P2	281.3	135	40	40	5	1	5	1	
P3	277.1	128	35	37	6	1	4	1	

Legend: As Table 10 on page 42

4.6 Plant Analysis

4.6.1 Plant growth

The average values for fresh weight, dry weight, number of leaves and percentage dry matter are given in the appendix (Table 43) and average fresh and dry weights are presented in figure 95.

The average dry matter at transplanting was 20.9%. This decreased to 10.5% (Table 43 in the appendix) at harvest.

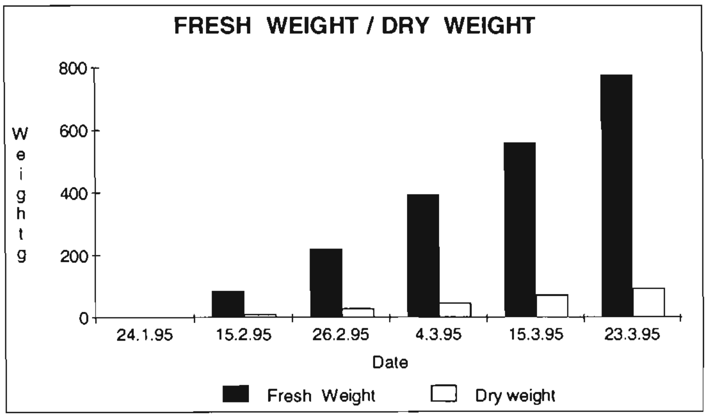


Figure 95: The average fresh and dry weights of broccoli plants for site 12.

4.6.3 Nutrient Analysis

The results of the tissue analysis are presented in the appendix (Table 44).

The parameters which correlated significantly with hollow stem, head weight and nutrient uptake are plotted in figures 96 - 100.

The hollow stem rating was found to be greater with increasing amounts of water applied above 60 mm (Figure 96).

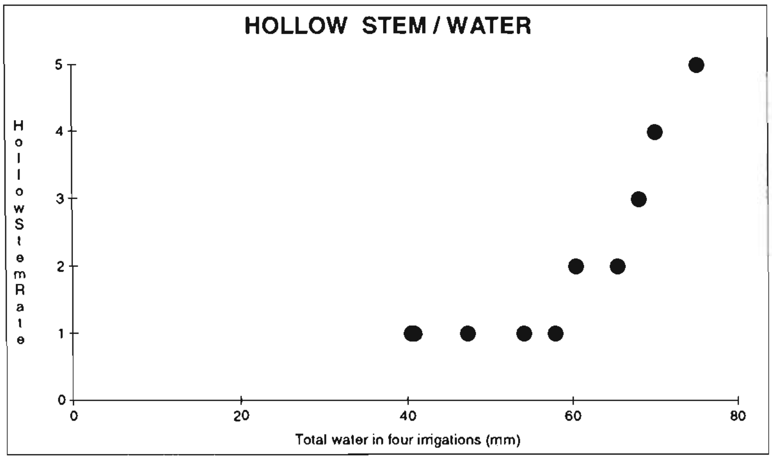


Figure 96: Hollow stem rating as affected by irrigation water.

B concentration was found to decrease with greater volume of water applied above 60 mm (Figure 97).

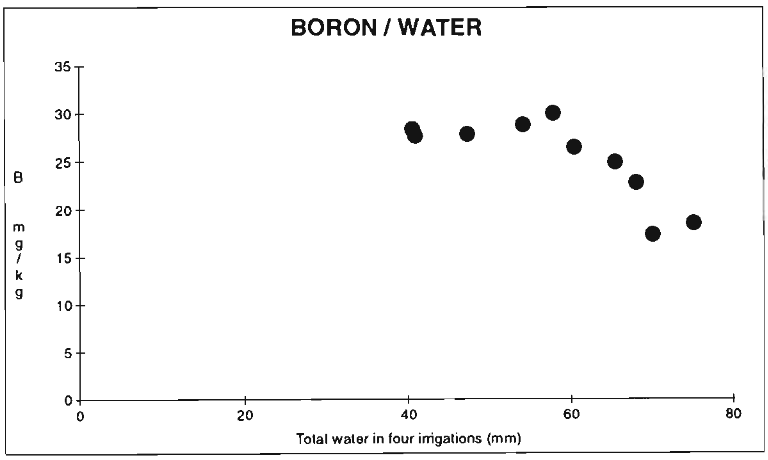


Figure 97: B concentration as affected by irrigation water.

Hollow stem rating increased with decreasing B concentration (Figure 98).

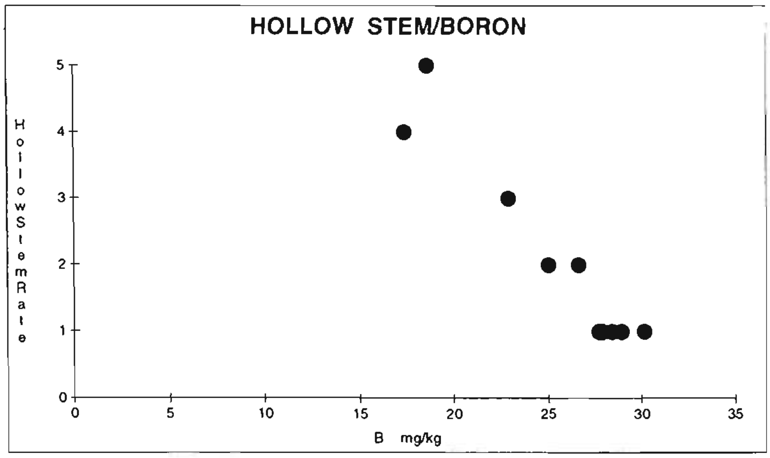


Figure 98: Hollow stem rating as affected by B concentration.

Increasing N concentration increased the high hollow stem rating (Figure 99).

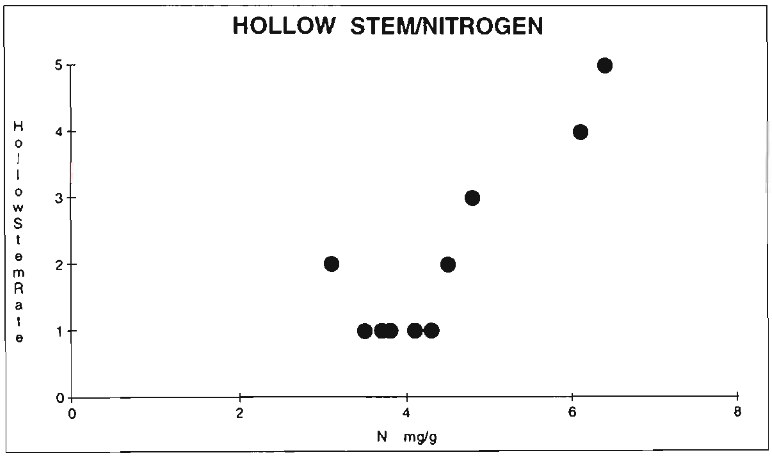


Figure 99: Hollow stem rating as affected by N concentration.

Broccoli head weight increased with increase in volume of water applied but not as much as found in previous trials of year 1 (Figure 100).

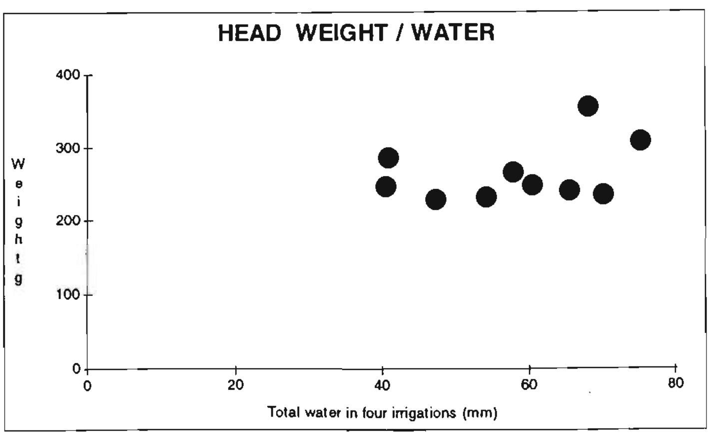


Figure 100: Broccoli head weight as affected irrigation water.

4.7 Statistical Analyses between three systems of irrigation

a) Yield and Quality measurements

Moderately high correlations between fresh weight, head diameter, bud diameter and stem diameter (as expected) were found (Table 40).

TABLE 40: Correlation matrix between Yield and Quality measurements for site 12

Fresh weight	1.000			
Head diameter	0.807	1.000		
Bud diameter	0.762	0.795	1.000	
stem diameter	0.662	0.625	0.682	1.000
	Fresh weight	Head diameter	Bud diameter	Stem diameter

b) Nutrient Analysis

A moderately large negative correlation between N and B was found (Table 41).

TABLE 41: Correlation matrix between N, B, K, Ca and water for site 12.

Water	1.000				
Boron	-0.774	1.000			
Nitrogen	0.649	-0.832	1.000		
Potassium	0.510	-0.443	0.262	1.000	
Calcium	-0.211	0.016	-0.122	0.175	1.000
	Water	Boron	Nitrogen	Potassium	Calcium

No apparent differences in B or hollow stem ratings between irrigation systems (drip, overhead sprinklers and travelling irrigator) at sites 11 and 12 were found.

There was no difference between the sites in hollow stem rating but the probability of a high hollow stem rating increased with decreasing concentration of B, and increased concentration of N. However, as nitrogen and boron have a moderately high negative correlation, the regression model with B as the sole predictor was as good as the model with both B and N as predictors.

5. DISCUSSION

5.1 BROCCOLI: Year 1 (1993 / 94) and Year 2 (1995)

5.1.1 Field Capacity, Water availability, Soil types and Irrigation

The results of this study demonstrate comprehensively that current irrigation practises used by growers in East Gippsland often result in either overwatering or underwatering with both usually occurring in the same paddock. At sites 3, 6 and 9 (same grower's property) irrigation was heavier and less frequent compared with the other sites. Some of the water applied would have not reached its target, as much of it would have been in excess of plant requirements and eventually drained to groundwater and / or may have resulted in reduced aeration due to temporary waterlogging conditions. During waterlogging, plant roots commonly experience temporary periods of oxygen deprivation when soil becomes flooded with excess irrigation water, and warm temperatures encourage rapid consumption of oxygen by soil microorganisms and roots (Drew, 1992). However, in practice, soil properties and farming techniques sometimes combine to produce an environment that is unfavourable for the growth and function of plant roots of most agricultural species. When soil aeration is transiently impeded by excess water, water blocks the soil pore space that is normally available for oxygen diffusion and convection. As a result oxygen dissolved in the soil water and in any entrapped air, is soon consumed by respiring organisms (Focht 1992). In well structured freely draining soils aeration is seldom a problem.

The ability of a soil to hold water during dry intervals between falls of rain or irrigation depends on its texture, profile and composition. Soil water characteristic curves are prerequisites for quantifying field soil water balance and predicting water flow (Shouse *et. al.,* 1995). In general, heavy soils (clay, clay loam, sandy clay loam) hold more water than do light soils (sandy, sandy loam and loam). The soil profile affects the extent of root penetration. A uniformly light profile may allow roots to penetrate deeply, and so to tap greater stores of water. But if a tight impenetrable layer is present underneath, any water stored at or below this point is useless. The amount of water a soil can hold is called its field capacity and is the percentage of water held in soil between one or two days after a thorough soaking (whether by rain or irrigation).

The moisture characteristic curves at sites 1, 4 showed the available water capacity for these soils is approximately 23-18% i.e. the amount of water held in the soil between field capacity (30 kPa or 0.3 bar) and permanent wilting point (1500 kPa or 15 bar)) was approximately 23-18%. Because the paddocks were irrigated when soil moisture content dropped to 12%. This showed that plants might have experienced drought conditions before irrigation. Field capacity of these soils is low but most of the water present is available to the plants. These soils have good drainage and waterlogging is not a problem. Along with the above properties sandy loam soils tend to be deficient in soil nutrients and retention of soil moisture is poor in the root zone.

The moisture characteristic curve at site 5 showed that available water capacity for plants in this soil was from 32% (30 kPa) - 12.6% (1500 kPa). The paddock was irrigated when the soil moisture content dropped to 16% which appears adequate. The moiosture characteristic curves at sites 7 and 8 showed the available water capacities for these soils range between 24% (30 kPa) - 7% (1500 kPa). The paddocks were irrigated when the moisture content was around 13%. These soils also have good drainage and their field capacity is higher than for the paddocks with sandy loam. The retention of soil moisture would have been better in the root zone in these soils than in sandy loams.

The moisture characteristic curves at sites 2 and 9 showed that available water capacities for plants were between 28 - 16.8% (site 2) and 23 - 9.4% (site 9). The plants were irrigated at moisture content of 12% (site 2) and 17% (site 9) which appeared good for this type of soil (clay soil) but could also lead to temporary waterlogging conditions after heavy irrigation because of clay soils. These soils hold more water than in the paddocks discussed above but the advantage of this is offset because some of this water is not available to the plants, being held very tightly by the soil. The drainage would have been poor and the plants would have experienced temporary waterlogging during heavy rain or irrigation.

The moisture characteristic curves at site 7 exhibits that available water capacity for plants at this site is 22 - 6.8% and the plants were irrigated at moisture content of 14%.

Sites 1, 4 and 7 were irrigated frequently, but the volume of water applied during an irrigation was less than at other sites. Conversely, sites 3, 6 and 9 were irrigated infrequently with large volumes of water applied at each irrigation. Sites 2, 5 and 8 were watered more than sites 1, 4 and 7 but less than 3, 6 and 9. Distribution of water over a paddock at each site was found to be very uneven which provided different soil moisture and aeration to different plants in the same paddock. As shown in the graphs in chapter 4, (for example at sites 3, 4, 5 6, 8 and 9) irrigation was initiated only at a very high tensiometer reading. The higher (65-90) readings on the shallow tensiometer indicated that plants were under stress and needed water badly.

When plants are irrigated at high readings such as these, they experience consecutive drought and flooding, which leads to discontinuity in growth and a high risk of nutrient deficiency and disorders related to these deficiencies.

The field soil moisture values at sites 3, 5, 6 and 9 were found to be reasonably high compared with values at other sites during an irrigation cycle. But as discussed earlier, the soil type at the sites 3, 6 and 9 was clay loam and at site 5 was loam. The amount of available water to plants on these soils, especially clay loam, would not have been the same as most of it would have been held very tightly by soil particles and beyond the reach of plants. This explains why the tensiometers showed high readings, even though in theory there was enough water. The deep tensiometer readings at sites 2, 3 and 5 falling to less than 10 centibars within two days after irrigation suggest that the grower applied more water than the root zone could hold (Henderson and Webber, 1993). In their experiments, Henderson and Webber (1993) also found that broccoli, if irrigated at 40 centibars every 5-6 days for seven weeks after transplanting with 15-20 mm followed by every 4-5 days (after seven weeks) with 20-25 mm gave optimum yields and produce quality on black earthen soils in southern Queensland.

The results with the enviroSCAN also showed that the water applied over an irrigation was quite uneven and sometimes irrigation applied at site 8 created waterlogging conditions and sometimes excess irrigation was wasted by draining down to the ground water. EnviroSCAN, a powerful management tool, which continuously monitors soil water, has potential for increasing yields, improving quality, saving power costs, reducing salinity effects on crops and minimising seepage and damage to the environment.

5.1.2 Irrigation, Boron uptake and hollow stem in Broccoli (for year 1993 / 94 and 1995 trials).

The consistently lower B concentration and high N concentration found in the broccoli heads with high hollow stem rating are in agreement with the findings of other workers (Shattuck and Shelp 1987; Tremblay 1989). According to theory, B translocates readily in xylem, but once in the leaves, it becomes one of the least mobile micronutrients (Pate, 1975; Welch, 1986). Broccoli Plants grown under flooded or water deficit conditions had reduced mobility of B to the younger (growing) parts and as demonstrated in these trials showed B deficiency and high hollow stem rating (Welch 1986).

There are number of factors which can affect the availability of soil B to plants including: the soil type and its various physical and chemical characteristics; plant species and genotypes; environmental factors; and the interaction of B with other nutrients (Gupta, 1993). The factors examined in this study are soil type, soil moisture content, seasonality and B interaction with other nutrients like N, K, and Ca.

Significant differences between the sites 1, 2 and 3 in hollow stem rating ($p<0.0001$) were found with a significantly higher probability of higher hollow stem rating at site 3, compared to other sites. The probability of a high hollow stem rating increased with the amount of water delivered ($p<0.0001$) at each site (1, 2 and 3).

There was no significant difference between the sites 7, 8 and 9 in hollow stem ratings, but the probability of a high hollow stem rating increased with the amount of water delivered ($p<0.0001$) at all sites. This is the first time water volume has been correlated with hollow stem occurrence in broccoli.

Sites 1, 4 (sandy loam) and 5, 7, 8 (loam) showed lower percentages of broccoli heads affected with hollow stem compared with the broccoli heads harvested at sites 2, 3, 6 and 9 (clay loam). As discussed earlier, sandy loam and loam, being light soils, provide good draining properties and better aeration to the plants and the root growth. Because of the non-ionic nature of boron, once it is released from the soil minerals, it can be leached from soil fairly rapidly, which explains why plants grown in these (well drained) soils, when heavily irrigated, are still short of boron. These soils, especially the sandy loams have poor water holding capacity and can subject plants to moisture deficit quickly after irrigation. The availability of B also decreases sharply under drought conditions which has been attributed partly to the reduced number of microorganisms that can release B from the parent materials (Bowen, 1977). Soil moisture deficit reduces the mobility of B, thus restricting its uptake by plant roots via mass flow mechanism.

Clay loams (heavy soils), with infrequent and heavy irrigation at sites 2, 3, 6 and 9 probably developed some waterlogging for short periods, that created loss of adequate soil aeration and creating temporary periods of oxygen deprivation to plant roots. The inadequate soil aeration would have inhibited the uptake of boron and more hollow stem was found in harvested broccoli heads at these sites (2, 3, 6 and 9). As well, the longer period between the irrigations at sites 3, 6 and 9 probably caused periodic moisture deficits (drought) because in clay soils usually only a small fraction of water held by the soil particles is easily available to plants.

In this study, B concentration was found to decrease with increasing hollow stem rating and increasing water volume applied to plants in all trials at all sites. No work has been published on the effects of water application on hollow stem occurrence and the abundant literature found on hollow stem covers the effects of boron and nitrogen concentration, plant density, seasonality and genotypes. In this study, the results demonstrated comprehensively that high volumes of water applied during an irrigation induced more hollow stem (along with other physiological factors). The grower at sites 3, 6 and 9 who always applied more water over an irrigation and for a longer period, had maximum hollow stem occurrence in each trial. This is contrary to what would be expected for the summer harvest (found by statistical analysis), for a fixed combination of water and B at each site, the probability of low hollow stem rating is highest at site 6 and lowest at site 5. For example if plants had water measurements of 72 mm and boron measurements of 25 ppm at each site, then the probabilities [p] of various hollow stem ratings are given in Table 32.

TABLE 42: Model probabilities of hollow stem ratings with one measurement of water and Boron at three sites (summer planting) 1994.

Site	p [1]	p [2]	p [j>2]
4	0.19	0.47	0.34
5	0.05	0.26	0.69
6	0.51	0.38	0.11

Legend: p[1, 2 and j>2] - Probabilities of hollow stem ratings at different levels (1, 2 and >2).

However, at sites 4, 5 and 6 the hollow stem ratings were 33%, 66% and 93% respectively. The grower at site 4 watered more frequently but with smaller volumes compared with the grower at site 6, who irrigated less frequently with a larger volume. It is more likely that plants were more stressed by alternative drought/waterlogging cycles at site 6 and experienced discontinuity in their growth cycle and uptake of nutrients.

High N concentrations were found in the broccoli heads affected by hollow stem in trial 1 (1993 / 94) and in year 2 (1995). Hipp (1974) and Tremblay (1989) also found that increasing N application induced more hollow stem. This could be because of the greater and rapid vegetative growth at higher N application and supports the possibility that the hollow stem may have a physical origin in cracks created by radial strains that develop in the stem during rapid growth.

The broccoli head samples analysed for nitrogen in the summer trial of year 1 (1993/94) did not give the same results as those harvested in the autumn trial and year 2 (1995) trial. The reason for this could be the longer preservation of these samples after distillation to run on aquatec (N analyser) and these distillates might have lost some N. The samples in other trials (autumn 1993 / 94 and year 2 - 1995 harvests) which were analysed immediately on aqua-tech after distillation or within a week gave results similar to previous findings reported in the literature.

The concentration of K and Ca did not show any correlation with hollow stem occurrence or B uptake by plants. This supports previous findings reported in the literature.

The trials carried out in different seasons in 1993 / 94 showed varying percentages of hollow stem (Tables 10 - 13, 16 - 18, 21 - 23). The greatest occurrence and maximum ratings being found in the summer harvest and minimum occurrence and rating in the spring harvest which suggests that in summer the plants grew rapidly, because of more sunlight and frequent irrigation, whereas the growth was slower in autumn and spring trials because weather was cooler and plants were not irrigated as frequently. The plant and head sizes were bigger at the summer harvest than those harvested in the spring and autumn trials. This also supports the theory that hollow stem may have a physical origin, as in summer, because of the bigger size of the inflorescence, radial strains would have been created in stems during flowering due to faster growth (Zink, 1968; Hipp, 1974). Also, it has been found in this study that the vegetative frames of broccoli plants at sites 3, 6 and 9 were large compared with other sites. These were the sites which also showed maximum hollow stem ratings in all trials (Figures 101 - 106)

The weekly change in growth (g) has been plotted against the time interval between each to show the rate of growth and vegetative frames of plants (Figures 101 - 106). Weekly growth rate at each site has been calculated as the difference between the average fresh/dry weight of fifteen samples at two consecutive sampling dates.

Comparision of fresh/dry weights for consecutive sampling dates showed that seedlings were of same weight when planted in each of the paddocks and growth rate at site 3 was faster compared to the sites 1 and 2 and plant frames were larger (Tables 10, 11 and 12). The plants at site 3 had more hollow stem compared with plants at site 2 and 3 (Figures 101-102). Fresh weight growth (101, 103, and 105), show that after approximately 6 weeks (i.e. 42, 44, and 46 days after transplanting in paddocks) the growth rates at sites 3, 6 and 9 were much higher when compared to the other sites. This is the time at which head initiation would have been taking place. It is likely that the faster growth at this stage induced the hollow stem.

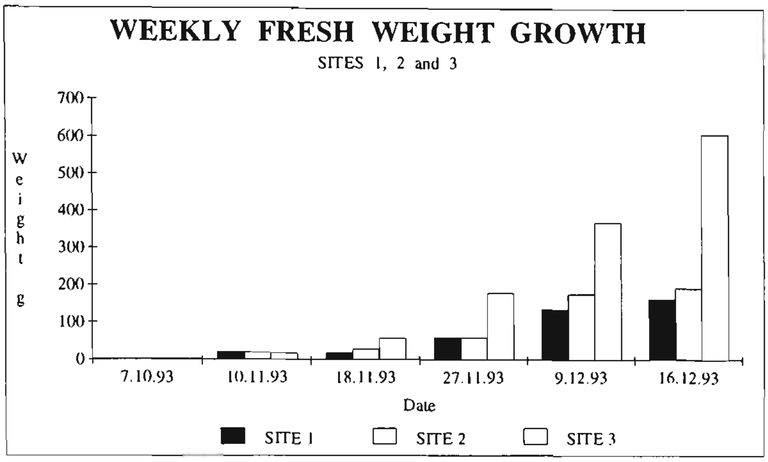


Figure 101: Comparision of weekly fresh weight growth at sites 1, 2, and 3.

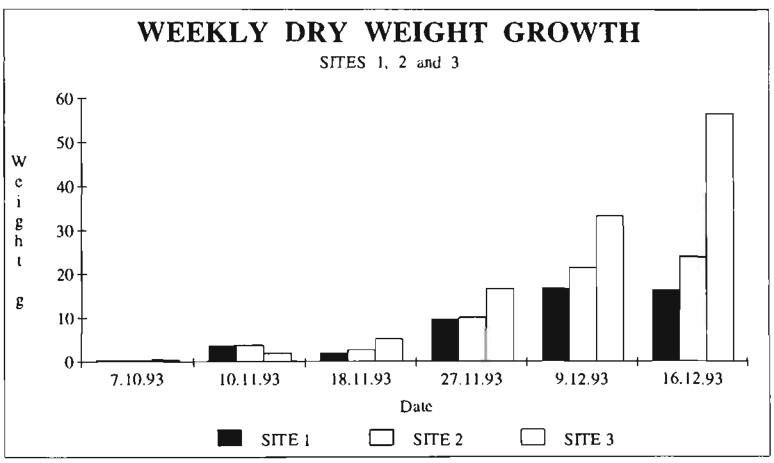


Figure 102: Comparision of weekly dry weight growth at sites 1, 2, and 3.

Similarly comparision of fresh/dry weights for consecutive sampling dates showed that growth rate at sites 6 and 9 was faster when compared to the sites 4, 5 and 7, 8 and plant frames were larger (Tables 17, 18, 19, 25, 26 and 27). The plants at site 6 and 9 had more hollow stem compared with plants at site 4, 5 and 7, 8 (Figures 103-106).

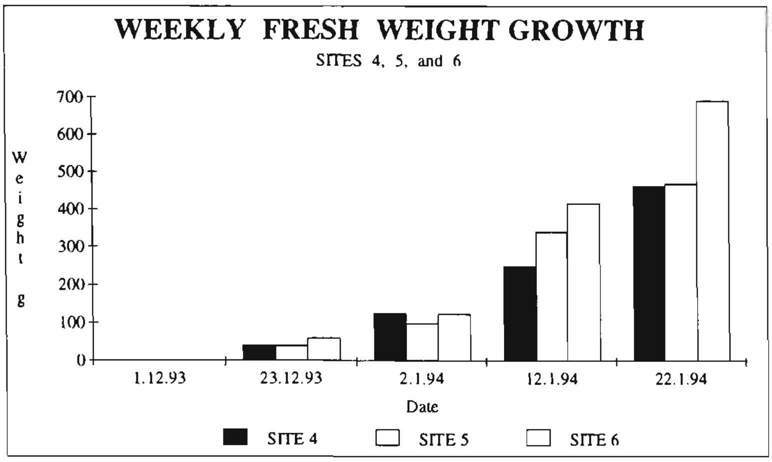


Figure 103: Comparision of weekly fresh weight growth at sites 4, 5, and 6.

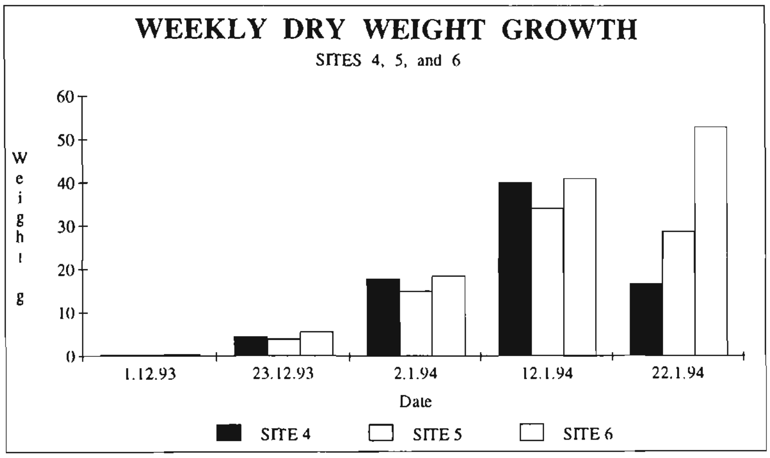


Figure 104: Comparision of weekly dry weight growth at sites 4, 5, and 6.

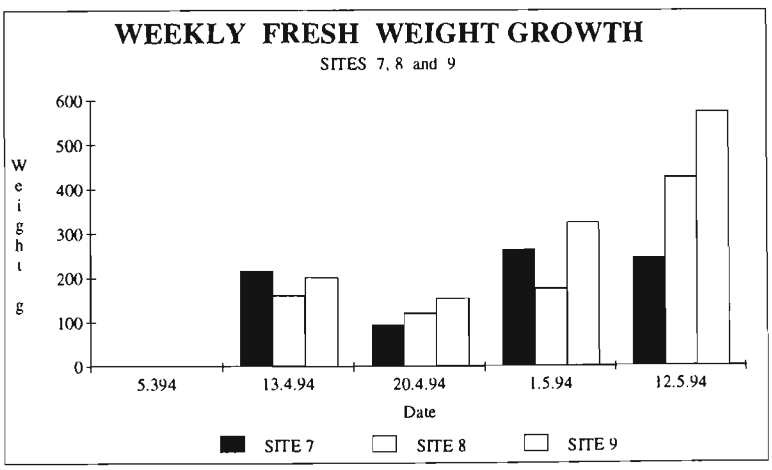


Figure 105: Comparision of weekly fresh weight growth at sites 7, 8, and 9.

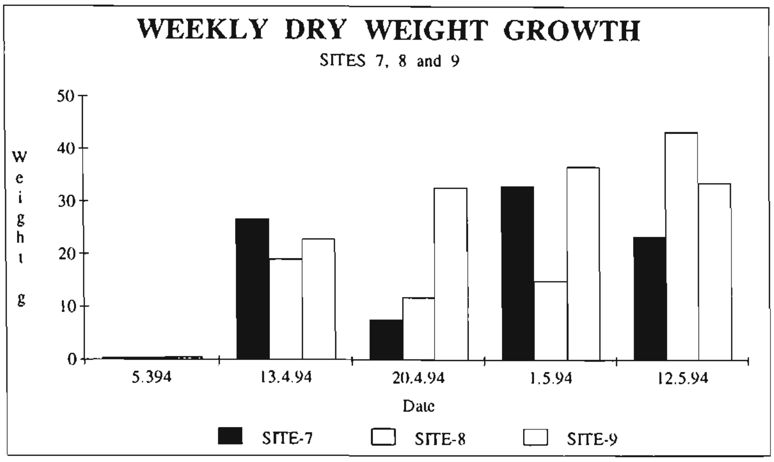


Figure 106: Comparision of weekly dry weight growth at sites 7, 8, and 9.

5.1.3 Comparison of three irrigation systems (Drip irrigation, overhead sprinklers and spray gun travelling irrigator) in 1995 Trial.

In 1995 (year 2), the broccoli plants irrigated with drip irrigation and overhead sprinklers showed better quality produce and lower hollow stem ratings compared with the 1994 (year 1) summer trial which was irrigated with overhead traveller irrigators (spray gun at sites 4 and 5, and arm type at site 6). No significant difference in hollow stem rating in the 1995 trials were found between site 11 (drip irrigation and overhead sprinklers) and site 12 (travelling spray gun) although at each site the probability of a high hollow stem rating increased with increasing amount of water. The grower at site 12, in the 1995 trial, irrigated more often with lower volumes of water applied over each irrigation compared with the irrigation in previous trials (1993 / 94). In addition the soil profile at site 12 was a sandy loam, which provided better aeration and nutrient uptake to the plant roots. The soil type at site 11 (drip irrigation and overhead sprinklers) was found to be a clay loam (heavy soil), which can provide unhealthy conditions for plant growth if heavily irrigated which could have occurred with overhead sprinklers.

The subjective quality assessment of harvested broccoli heads showed more variation in head weight, head diameter, bud diameter, maturity and market value (Figure 89 in chapter 4) when irrigated with overhead sprinklers compared with heads harvested from the drip irrigation plots. In drip irrigation plots small volumes of water were applied frequently to the root zone, when tensiometer reading fell to 20 centibars and growth (plant size) was found to be more uniform compared with that in the sprinkler and travelling type irrigator plots (Tables 27, 28, 29, 30 and 31 in chapter 4). In this study the data for the amount of water delivered in drip irrigation was not collected. However, it is clear from previous studies that the sprinklers deliver a greater water volume than drip irrigation (Sutton and Merit, 1993; Bogle and Hartz, 1985). Part of the reason for this is that the sprinklers are required to rewet the entire plot area during each irrigation cycle, while the drip irrigation system rewets only the volume of soil in the root zones. Hollow stem occurred in approximately 20% of plants in drip irrigation plots (again correlated with low boron and high nitrogen) compared with 30 - 50% in overhead sprinklers and 37% in the travelling irrigator plots (Tables 27, 28, 29, 30 and 31). This again is suggesting over watering with overhead and travelling irrigators leads to greater hollow stem.

The travelling irrigators (spray gun and arm type) have more risk of spreading disease and weeds from paddock to paddock, compared with fixed overhead sprinklers and drip irrigation systems.

5.2 LETTUCE: Year 1 (1994).

The preliminary study on lettuce in autumn did not establish any conclusive findings and it can only indicate whether further trial work has potential. Because of the relationships between water, boron, nitrogen and hollow stem in the summer season with broccoli it is reasonable to conclude that it would be of benefit to repeat the lettuce trial in summer. The reasons for this include:

* Lettuce is a very new crop in this region and not many growers are growing it, so the preliminary trial had poor quality produce.

* The trial occurred during autumn and most of the heads harvested in this trial were affected with bacterial rots.

* Time was not available to run the extensive trials like broccoli with different growers over a range of sites and to compare the results.

5.3 CONCLUSIONS

The results of this study, set in the context of previous studies, suggest that:

* Hollow stem in broccoli is a physiological disorder, associated with boron deficiency, high nitrogen levels and fast growth rate.

* High hollow stem ratings were noted in plants receiving abnormally highor low irrigation water. This can be explained as follows:
Excess water either leaches some nutrients (B and N) below the root zone or creates an unhealthy growing environment (water logging) which in turn affects nutrient uptake. By comparison drought conditions affect the uptake of B, thus exacerbating hollow stem disorder. Because of the correlation of hollow stem with high nitrogen concentration, it is likely that excess water was not leaching nutrients but rather producing waterlogging conditions.

* A moderately negative correlation between tissue B and tissue N was found in most cases suggesting that high N concentration in tissue promotes hollow stem along with B deficiency.

* No correlations between B, K and Ca in relation to hollow stem was found. Similarly, K and Ca are not correlated with hollow stem disorder.

* High hollow stem ratings were found in plants from the summer trial compared with the spring and autumn trials suggesting that faster growth promotes hollow stem.

* The amount of water to be delivered during an irrigation should depend upon the soil type and plant requirement including growth stage as well as environmental factors (temperature, wind and rainfall). It is better to irrigate more often with smaller volumes of water delivered at one time.

* Irrometers / Tensiometers can be very useful for scheduling irrigation, if they are properly installed and maintained. It is likely that they will be cost effective.

* EnviroSCAN (soil water monitoring system) can also be very useful for scheduling irrigation to maintain soil water level at an adequate level for plant use. Drainage can be avoided since it wastes both water and fertilisers. EnviroSCAN, if connected to the software package available, can make all the work very easy and

simple. The whole system can be programmed depending on plant requirements and soil type. The equipment is expensive but once installed can save time and labour.

* The present irrigation system used in the region (travelling irrigators) is not uniform in water distribution and irrigation timing, the quantity and schedule of delivery usually does not match the plant requirements.

* Drip irrigation, once installed, is likely to be economic in water use and can give more uniform and better produce.

* Fixed overhead sprinklers are equally as good as drip irrigation but the amount of water used for an irrigation is likely to be higher compared with drip irrigation.

Plate 6

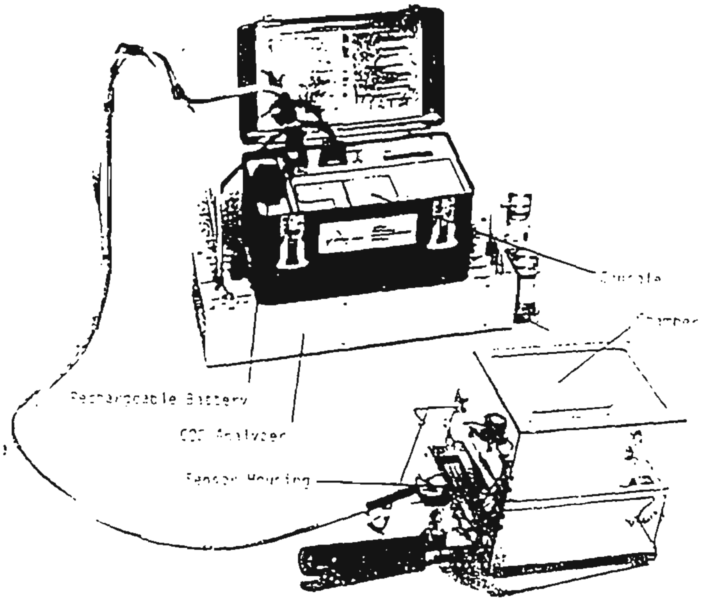


Figure c: LICOR 6000 Portable photosynthesising equipment (adapted from the instruction manual).

Photo 9: Measurements for photosynthesis being made on broccoli plants with LICOR 6000.

6. PHOTOSYNTHESIS

The growth of crop is usually estimated from dry weight changes which are adequate for assessing long-term changes. Measurements of CO_2 uptake provide an alternative and direct method of assessing productivity, with important advantages over measurements of dry weight change; i. e. it is instantaneous, non-destructive, allows separate investigation of individual leaves and allows separation of photosynthetic gain from respiratory losses (Long and Ireland, 1985).

Photosynthesis measurements were made on twenty broccoli plants at each site in year 1 (1993/94) trials. Two plants were tagged around each of ten water recording (Sec. 3.4) cans. Photosynthesis was measured by using a LICOR 6000 (Photo 9 and Figure c - Plate 6) during one irrigation cycle in each trial. The readings were taken one day before the irrigation and every alternate day until the next irrigation.

The LI - 6000 is a portable photosynthesis system designed to measure carbon dioxide (CO_2) and water vapour exchange rates of plants. The essential parts of the LI - 6000 are shown in figure c (Plate 6). The equipment was based on a closed system in which air is pumped from the chamber enclosing the leaf into an infra red gas analyser (IRGA) which continuously records the CO_2 concentration of the chamber. The LI - 6000 incorporates a transient measurement technique, whereby an active (photosynthesising and transpiring) leaf, when enclosed in a container, causes the humidity of the air in the container to increase, CO_2 to decrease. The rate at which the humidity and CO_2 change depends directly upon the stomatal conductance of the leaf and is the apparent photosynthetic rate, once adjustments for the leaf size and the container volume are taken into account.

In the LI - 6000, the closed container is a polycarbonate chamber within which measurements of humidity, air temperature and leaf temperature are made. The CO_2 measurement is made in a separate gas analyser; to achieve this, air is pumped out of the chamber, through the analyser, and back again. The rates of change of humidity and CO_2 were obtained by making each of these measurements separated by intervals of time (2 second in these measurements).

The aim of the photosynthesis study was to establish a soil moisture reading up to which photosynthesis goes up, constants for sometime (optimum) and decreases again. After establishing this soil moisture tension when it shows optimum photosynthesis (an indication of optimum plant growth), the plants would have been watered.

Thus by finding this value of soil moisture tension, it would have been established that the paddocks with this soil type (loam, clay or sandy etc.) be watered at that moisture tension. Photosynthesis measurements were made to find the effect of water on the process of photosynthesis.

In general, where other factors are not limiting biomass production is directly proportional to the supply and use of water. Therefore the measurement of plant water status is an important part of understanding biomass production and in conjuction with a consideration soil water status, for maximising yield over irrigation. The easiest methods to determine the water content are destructive. By comparison, non-destructive methods involve complex and expensive equipment, such as the B-gauge. In future research a statistical approach to selective harvesting could be used to explore the relationship between soil water and productivity.

In present study, upon reflection and after condensation of results obtained, it was unlikely that growth of plants have been predicted from photosynthesis measurements taken during the study and or that any relationship between photosynthesis and the volume of water delivered could be demonstrated. Around the same cans, receiving the same amount of water (Tables 45-49, in the appendix), the two tagged plants sometimes gave very different values (0.5222 and 0.0954 mol/CO_2/m^2/s) for photosynthesis. Many factors are likely to have contributed to the variations in photosynthesis rate recorded during this study. Photosynthesis is a complex process and many factors influence the rate of photosynthesis, for example: water, light, stomata. nutrients, temperature, humidity, as well as the age and genetics of plants. Limited water availability to plants limits the rate of photosynthesis by closing the stomata and thus inhibiting CO_2 uptake. Some of the factors that might have influenced photosynthesis in this study are discussed below:

Measurements of photosynthesis rate were made at different times on each day depending upon the availability of technical assistance. Sometimes the measurements were made early morning or late afternoon, which would have affected the measurements because of different intensity of sunlight, humidity and temperature. In trial 3 (autumn) 1994, at sites 7, 8, 9 and 10 (lettuce), the photosynthesis rate was usually measured very early in the morning (7-8 am.). The plants leaves at that time were found either very wet with dew or covered with a layer of frost and the readings were not consistent. The sample readings for photosynthesis rate quoted above are the mean of ten observations taken every 2 seconds. While making measurements on an individual leaf in the measurement chamber, the plant leaf sometimes switched to net respiration instead of net photosynthesis (i.e. gave out CO_2 instead of taking CO_2 in). Due to this the mean photosynthesis rate measured sometimes was very low or showed negative value. Also the frequent appearance of clouds could have restricted the sunlight and influenced the variations in measurements of photosynthesis rate. The amount of available water to the plants would also have affected the photosynthesis rate by affecting the stomatal activity. The moisture stress first affects the cellular composition and then closes the stomata and as a result, CO_2 intake is altered and net photosynthesis is affected.

Statistical analysis for Photosynthesis and Irrigation applied across the two trials (6 sites) for year 1993 / 94.

The photosynthesis data sets were analysed by taking means (across plants) of the photosynthesis measurements on the first day (before irrigation), the last day (end of irrigation cycle), and all the days (from first to last). The correlations of these mean values and the volume of water recorded were calculated. In one case (site 6 trial 2) the mean of the photosynthesis measurements had a moderately positive correlation with water (0.690). In all other cases these correlations were small and ranged from -0.159 to 0.500. The lack of correlation between could have been most likely due to variations in photosynthesis during measurement by the range of factors discussed above.

7. APPENDIX

BROCCOLI: Year 1 (1993 / 94)

TRIAL 1 (Spring) October - December (1993)

SITE 1

TABLE 1: Field Soil Moisture Content (site 1)

Date	% Moisture at 30 cm	% Moisture at 60 cm
14.11.93	9.7	10.6
17.11.93	11.4	13.3
18.11.93	10.0	11.5
19.11.93	9.8	10.3

TABLE 2: Soil Moisture Tension (site 1)

Date	Soil moisture tension at 30 cm	Soil moisture tension at 60 cm
	(centibars)	(centibars)
14.11.93	36	19
15.11.93	14	8
17.11.93	16	10
18.11.93	24	15
19.11.93	28	16

TABLE 3: Plant Growth (site 1)

Date	*Fresh Wt.	*Dry Wt.	*No.of leaves	*% Dry matter
	g	g		
7.10.93	2.16	0.4	5	18.5
10.11.93	23	4.1	9	17.6
18.11.93	40.5	6.1	10	15.1
27.11.93	99.4	15.8	12	15.9
9.12.93	233.9	32.6	15	13.9
16.12.93	396.9	48.9	18	12.3

* means of fifteen plants at each sampling.

TABLE 4: Nutrient Analysis (site 1)

SAMPLE	B ppm	N mg/g	K ppm	Ca ppm	H. S.	WATER mm	H.Wt. g
C1P3	28.9	4.5	880.4	34.3	1	36.9	223.4
C3P3	30.3	3.6	861.5	38.3	1	38.3	168.9
C7P1	26.4	3.3	704.3	30.3	1	40.9	164.7
C11P1	25.6	2.8	660.9	31.6	1	41.2	99
C14P1	29.1	3.9	899.5	31.3	1	31.9	259.1
C19P3	28.1	3.7	904.5	28.5	1	45.6	188.4
C20P3	27.7	2.8	806.9	20.5	1	53.4	310.5
C16P1	23.2	3.8	699.5	22.5	2	58.7	412.2
C18P3	20.1	4.1	885.5	21.6	2	68.8	399.5
	*	*	n.s.	n.s.		*	
	**	n.s.	n.s.	n.s.	**		

* Significant with hollow stem rating. at 5%
** Significant with volume of water at 5%
n.s. Not significant

Legend

Sample	Harvester broccoli head
B	Boron concenteration
N	Nitrogen concentration
K	potassium concentration
Ca	Calcium concentration
H. S.	Hollow stem rating
H. Wt.	Fresh head weight of harvested broccoli head
C (1 - 20)	Can number
P (1 - 3)	Tagged plant

SITE 2

TABLE 5: Field Soil Moisture Content (site 2)

Date	% Moisture at 30 cm	% Moisture at 60 cm
21.11.93	11.5	12.5
24.11.93	13.8	15.6
25.11.93	12.8	13.9
26.11.93	11.7	13.3
27.11.93	11.3	13.0

TABLE 6: Soil Moisture Tension (site 2)

Date	Soil moisture tension at 30 cm	Soil moisture tension at 60 cm
	(centibars)	(centibars)
21.11.93	54	35
22.11.93	2	0
24.11.93	14	6
25.11.93	18	8
26.11.93	22	10
27.11.93	34	12

TABLE 7: Plant Growth (site 2)

Date	*Fresh Wt.	*Dry Wt.	*No. of leaves	*%Dry matter
	g	g		
7.10.93	1.92	0.35	4	18.2
10.11.93	22.5	4.1	9	18.2
18.11.93	50.4	6.9	11	13.7
27.11.93	110.5	17.1	12	15.4
9.12.93	286.6	38.6	15	13.5
16.12.93	479.3	62.5	18	13

* means of fifteen plants at each sampling.

TABLE 8: Nutrient Analysis (site 2)

SAMPLE	B ppm	N mg/g	K ppm	Ca ppm	H.S.	WATER mm	H.Wt. g
C9P3	28.4	3.4	884.5	23.5	1	82.4	138.1
C3P1	29.6	3.9	897.4	18.5	1	81.5	197.2
C15P2	28.7	5	1119.6	27.7	1	87	295.4
C7P3	32.7	2.5	1023.5	24.5	1	66.6	296.3
C17P2	29.9	3.1	885.8	30.5	1	83.6	328.5
C19P2	23.1	3.8	680.9	22.3	2	76.6	291.7
C20P3	22.1	4.3	890.8	28.3	2	95.4	321.3
C12P2	23.2	4.5	750.9	36.5	2	61	210
C11P3	24.9	4.9	654.7	26.5	3	99.5	262.9
C2P2	21.2	4.4	861.6	22.5	3	101.7	250.6
C5P3	20.8	5.3	818.7	19.5	5	131.4	307.8
	*	*	n.s.	n.s.		*	
	**	n.s.	n.s.	n.s.	**		

* Significant with H.S. at 5%
** Significant with water at 5%
n.s. Not significant

Legend As Table 4 on page 138

SITE 3

TABLE 9: Field Soil Moisture Content (site 3)

Date	% Moisture at 30 cm	% Moisture at 60 cm
25.11.93	20.3	23.8
29.11.93	24.2	28.1
30.11.93	22.2	26.9
2.12.93	20.5	24.5
3.12.93	19.3	22.4

TABLE 10: Soil Moisture Tension (site 3)

Date	Soil moisture tension at 30 cm (centibars)	Soil moisture tension at 60 cm (centibars)
25.11.93	75	18
27.11.93	5	0
29.11.93	43	11
30.11.93	52	12
2.12.93	79	16
3.12.93	92	24

TABLE 11: Plant Growth (site 3)

Date	*Fresh Wt.	*Dry Wt.	*No.of leaves	*% Dry matter
	g	g		
13.10.93	2.4	0.49	5	20.4
10.11.93	20.3	2.3	8	11.3
18.11.93	77.1	7.5	13	9.7
27.11.93	255.6	24.1	15	9.4
9.12.93	625.2	57.4	17	9.2
24.12.93	1232.4	113.9	19	9.2

* mean of fifteen plants at each sampling.

TABLE 12: Nutrient Analysis (site 3)

SAMPLE	B	N	K	Ca	H. S.	WATER	H. Wt.
	ppm	mg/g	ppm	ppm		mm	g
C10P1	28.5	3.9	705.3	40.5	1	44.5	135.2
C9P2	26.4	4	652.2	38.5	2	51.6	254.1
C16P3	22.5	5.2	947.2	35.2	3	61.6	270.2
C12P3	21.2	4.9	931.1	28.5	4	60.9	315.6
C5P2	18.5	6.2	1205.7	25.6	4	88.4	174.8
C19P3	20.5	4.9	827.6	24.5	4	63.2	330.4
C8P2	18	5.7	763.9	38.9	5	94.8	260.8
C11P1	18.8	4.9	871.2	30.2	5	80.7	169.6
C1P3	17.9	5.5	1080	28.5	5	89.5	202.3
	*	*	n.s.	n.s.		*	
	**	n.s.	n.s.	n.s.	**		

* Significant with H.S. at 5%
** Significant with water at 5%
n.s. Not significant

Legend As Table 4 on page 138

TRIAL 2 (summer) December 93 - February 94

SITE 4

TABLE 13: Field Soil Moisture Content (site 4)

Date	% Moisture at 30 cm	% Moisture at 60 cm
20.1.94	11.7	12
22.1.94	14.8	22.4
24.1.94	13.8	20.9
25.1.94	10.3	12.7

TABLE 14: Soil Moisture Tension (site 4)

Date	Soil moisture tension at 30 cm (centibars)	Soil moisture tension at 60 cm (centibars)
20.1.94	80	42
21.1.94	12	8
22.1.94	30	28
23.1.94	59	40
24.1.94	74	42
25.1.94	80	46

TABLE 15: Plant Growth (site 4)

Date	*Fresh Wt. g	*Dry Wt. g	*No.of leaves	*%Dry matter
1.12.93	1.78	0.36	4	20.2
23.12.93	42.4	4.8	9	11.3
2.1.94	167.5	22.6	12	13.5
12.1.94	416.8	62.8	15	15.1
22.1.94	879.1	79.4	17	9.1

* means of fifteen plants at each sampling.

TABLE 16: **Nutrient Analysis (site 4)**

SAMPLE	N	K	Ca	B	H.S.	WATER	H. Wt.
	mg/g	ppm	ppm	ppm		mm	g
C11P1	9.1	153.3	31.6	24.2	1	38.8	115.8
C8P1	11.1	75.2	54.9	32	1	39.2	258.9
C14P3	11	110.0	26.9	29.8	1	40.2	159.9
C16P1	5.6	105.0	34.2	29.7	1	43.5	190
C4P3	3.6	105.4	24.7	34.2	1	45.4	149.5
C17P1	9.7	161.9	34.3	25.1	1	47.4	180.9
C20P1	8.5	174.0	25	22.2	1	49	174.5
C13P2	10.6	105.3	27.3	25.5	1	49.1	211
C3P1	4.6	173.7	22.7	25.3	2	56.8	246.2
C19P3	6.2	128.8	29.6	29.7	2	63.8	205.3
C1P3	6	153.2	46.8	22.7	2	67.2	294.5
C2P1	8.8	172.3	29.6	25.1	5	72.5	218.4
C7P1	9.1	146	32.9	19	5	97.2	192.1
	n.s.	n.s.	n.s.	*		*	
	n.s.	n.s.	n.s.	**	**		***

* Significant with H.S. at 5%
** Significant with water at 5%
*** Significant with water at 10 %
n.s. Not significant

Legend As Table 4 page 138

SITE 5

TABLE 17: **Field Soil Moisture Content (site 5)**

Date	% Moisture at 30 cm	% Moisture at 60 cm
20.1.94	18.1	18.2
23.1.94	22.3	25.1
24.1.94	16.2	17.3
25.1.94	15.3	17.2

TABLE 18: Soil Moisture Tension (site 5)

Date	Soil moisture tension at 30 cm (centibars)	Soil moisture tension at 60 cm (centibars)
19.1.94	64	44
21.1.94	2	0
22.1.94	12	2
23.1.94	20	10
24.1.94	26	22
25.1.94	48	28

TABLE 19: Plant Growth (site 5)

Date	*Fresh Wt.	*Dry Wt.	*No.of leaves	*%Dry matter
	g	g		
30.11.93	1.8	0.34	4	19
23.12.93	40.8	4.2	9	10.3
2.1.94	139.1	19.2	12	13.8
12.1.94	479.7	53.2	16	11.1
22.1.94	948.9	81.9	17	8.6

* means of fifteen plants at each sampling.

TABLE 20: Nutrient Analysis (site 5)

SAMPLE	N	K	Ca	B	H. S.	WATER	H. Wt.
	mg/g	ppm	ppm	ppm		mm	g
C18P3	3.7	123	30.9	32.2	1	40.5	286.2
C4P3	11.3	104	24.6	36.5	1	42.6	229.9
C2P1	6.1	56	22.1	33.6	1	43.9	150.6
C19P3	10.5	63	19.5	32.5	1	45.2	177.8
C5P1	5.03	53.6	20.5	30.9	1	47.6	315.8
C6P2	9.2	96.5	23.6	24.5	2	52.2	230.9
C10P1	10.2	259.8	20.7	24.9	2	54.2	284.2
C3P2	3.7	81	36.5	27.5	2	62.6	363.7
C16P2	8.9	153.8	27.7	23	3	64.9	336.2
C9P1	10.6	253.4	26.3	22.3	4	68.9	188.7
C12P1	5	158.9	27.6	19	5	73.8	256.9
C20P3	6.5	138.7	20.8	28.2	3	79.3	388.4
C14P3	5.2	136.7	27.6	20.4	4	85.4	414.4
C1P2	10.8	125.4	27.1	23.1	4	87.6	129.3
C15P3	2.1	158	22.3	20.5	5	96.9	352.2
	n.s.	n.s.	n.s.	*		*	
	n.s.	n.s.	n.s.	**	**		***

* Significant with H.S. at 5%
** Significant with water at 5%
*** Significant with water at 10%
n.s. Not significant at 5%

Legend As Table 4 on page 138

SITE 6

TABLE 21: Field Soil Moisture Content (site 6)

Date	% Moisture at 30 cm	% Moisture at 60 cm
20.1.94	20.4	23.2
22.1.94	29.3	32.2
24.1.94	23.9	25.5
25.1.94	20.4	22.8

TABLE 22: Soil Moisture Tension (site 6)

Date	Soil moisture tension at 30 cm (centibars)	Soil moisture tension at 60 cm (centibars)
20.1.94	89	58
21.1.94	10	4
22.1.94	29	20
24.1.94	53	37
25.1.94	63	38

TABLE 23: Plant Growth (site 6)

Date	*Fresh Wt.	*Dry Wt.	*No.of leaves	*%Dry matter
	g	g		
30.11.93	1.9	0.36	4	18.9
23.12.93	60.4	5.9	10	9.8
2.1.94	182.5	24.3	13	13.3
12.1.94	598.5	65.4	16	10.9
22.1.94	1289.2	118.5	18	9.2

* means of fifteen plants at each sampling.

TABLE 24: Nutrient Analysis (site 6)

SAMPLE	N	K	Ca	B	H. S.	WATER	H. Wt.
	mg/g	ppm	ppm	ppm		mm	g
C18P1	166.8	186.9	17.9	25.8	3	77.7	165.8
C9P2	99.7	95.4	21.5	24.7	5	146.9	242.8
C17P3	109.4	85.3	23.2	19.7	5	165.2	141.5
C12P3	110.7	59.9	32.7	26.1	4	120.2	161
C1P2	94.2	75.3	29.3	18.9	5	208.1	249.4
C20P2	42.5	101.3	18.8	22.5	4	177.5	228
C11P1	199.1	72.6	15.4	28.8	2	98.8	174.2
C10P2	214.1	79.3	21.2	32.1	1	79.6	203.7
C7P1	227.9	81.2	25.2	33.1	1	79.6	244.7
C2P2	221	111.7	27.7	31.5	1	69.2	181.1
C3P1	162.3	91.2	15.7	19.1	5	160.5	254.9
C19P2	206.1	78.5	22.3	24.1	1	52.2	226.8
C16P3	203	50	12.03	19.2	3	142.2	198
C6P3	67.1	81.5	17	21.2	5	162.6	252.6
	n.s.	n.s.	n.s.	*		*	
	n.s.	n.s.	n.s.	**	**		***

* Significant with H.S. at 5%
** Significant with water at 5%
*** Significant with water at 10 %
n.s. Not significant

Legend As Table 4 on page 138

TRIAL 3 (Autumn) March - May 1994

SITE 7

TABLE 25: Field Soil Moisture Content (site 7)

Date	% Moisture at 30 cm	% Moisture at 60 cm
7.5.94	12.1	14.5
9.5.94	15.4	16.8
11.5.94	12.4	15.2
12.5.94	10.2	13.2

TABLE 26: Soil Moisture Tension (site 7)

Date	Soil moisture tension at 30 cm (centibars)	Soil moisture tension at 60 cm (centibars)
7.5.94	38	22
9.5.94	18	10
11.5.94.	30	21
12.5.94	35	25

TABLE 27: Plant Growth (site 7)

Date	*Fresh Wt.	*Dry Wt.	*No.of leaves	*%Dry matter
	g	g		
5.3.94	1.8	0.4	4	22.2
13.4.94	217.9	27.1	11	12.4
20.4.94	311.7	34.8	14	11.2
1.5.94	574.2	67.8	16	11.8
12.5.94	817.2	91.2	18	11.2

* means of fifteen plants at each sampling.

SITE 8

TABLE 28: Field Soil Moisture Content (site 8)

Date	% Moisture at 30 cm	% Moisture at 60 cm
3.5.94	10.6	13.2
5.5.94	15.4	18.5
7.5.94	13.4	16.8
9.5.94	11.5	14.9
11.5.94	10.2	12.6

TABLE 29: Soil Moisture Tension (site 8)

Date	Soil moisture tension at 30 cm (centibars)	Soil moisture tension at 60 cm (centibars)
3.5.94	80	41
5.5.94	26	18
7.5.94	30	21
9.5.94	46	30
11.5.94	51	34

TABLE 30: Plant Growth (site 8)

Date	*Fresh Wt.	*Dry Wt.	*No.of leaves	*%Dry matter
	g	g		
5.3.94	2.2	0.42	4	19.1
13.4.94	161.8	19.5	12	12.1
20.4.94	281.4	31.4	14	11.2
1.5.94	456.6	46.4	16	10.2
12.5.94	881.9	89.8	18	10.2

* means of fifteen plants at each sampling.

SITE 9

TABLE 31: **Field Soil Moisture Tension (site 9)**

Date	% Moisture at 30 cm	% Moisture at 60 cm
4.5.94	15.1	18.1
7.5.94	18.9	22.5
9.5.94	16.5	19.2
12.5.94	14.2	17.6

TABLE 32: **Soil Moisture Tension (site 9)**

Date	Soil moisture tension at 30 cm (centibars)	Soil moisture tension at 60 cm (centibars)
4.5.94	82	38
5.5.94	10	8
7.5.94	20	15
9.5.94	30	21
12.5.94	35	25

TABLE 33: **Plant Growth (site 9)**

Date	*Fresh Wt.	*Dry Wt.	*No.of leaves	*%Dry matter
	g	g		
5.3.94	2.4	0.42	4	17.5
13.4.94	203.4	23.2	12	11.4
20.4.94	356.5	34.8	14	9.8
1.5.94	680.2	71.5	16	10.5
12.5.94	1253.1	105.1	19	8.4

* means of fifteen plants at each sampling.

LETTUCE (Autumn) March - May 1995

SITE 10

TABLE 34: **Plant Growth (site 10)**

Date	*Fresh Wt.	*Dry Wt.	*No.of leaves	*% Dry matter
	g	g		
8.3.94	2.1	0.3	4	14.3
13.4.94	40.5	2.4	9	5.9
20.4.94	95.6	5.7	12	6
1.5.94	200.5	9.9	15	4.9
12.5.94	435.5	19.4	17	4.3

* means of ten plants on each sampling.

BROCCOLI: Year 2 (1995)

SITE 11

TABLE 35: Plant Growth (Drip Irrigation - 1)

Date	*Fresh Wt.	*Dry Wt.	*No. of leaves	*%Dry matter
	g	g		
24.1.95	2.32	0.48	4	20.7
15.2.95	108.6	11.1	10	10.2
26.2.95	350.8	40.8	14	11.6
4.3.95	570.9	60.1	16	10.5
15.3.95	895.2	85.4	20	9.5
23.3.95	1003.7	104.1	23	10.4

* means of fifteen plants at each sampling.

TABLE 36: Nutrient Analysis (Drip Irrigation - 1)

SAMPLE	H.S.	B	N	K	Ca	H. Wt.
		ppm	mg/g	ppm	ppm	mm
17	1	26.5	3.4	774.8	30.5	333.3
11	1	29.2	3.2	620.3	25.5	309.3
7	1	30.1	2.9	859.2	31.2	385.8
16	2	24.6	3.8	657.4	21.2	370.6
3	2	23.8	4.5	955.5	26.7	365
1	3	21.3	3.4	618.2	25.4	310
2	3	20	5.6	921.4	20.5	326.9
		*	*	n.s.	n.s.	

* Significant with hollow stem rating at 5%.
n. s. not significant

Legend As Table 4 on page 138

TABLE 37: Plant Growth (Drip Irrigation - 2)

Date	*Fresh Wt.	*Dry Wt.	*No. of leaves	*%Dry matter
	g	g		
24.1.95	2.28	0.46	4	20.2
15.2.95	102.3	10.9	10	10.7
26.2.95	361.8	41.3	14	11.4
4.3.95	625.4	64.3	17	10.3
15.3.95	905.2	89.1	21	9.8
23.3.95	1105.2	105.9	24	9.6

* means of fifteen plants at each sampling.

TABLE 38: Nutrient Analysis (Drip Irrigation - 2)

SAMPLE	H.S.	B	N	K	Ca	H. Wt.
		ppm	mg/g	ppm	ppm	mm
3	4	21.6	6.9	657.4	30.5	334.3
7	5	19.8	5.8	865.3	32.6	446.6
11	2	23.9	4.5	962.8	29.4	268.3
14	1	28.9	3.4	735.3	20.1	298.2
16	1	29.6	4.6	705.3	36.5	376.5
19	1	28.4	3.9	884.4	25.4	347.6
22	1	27.2	3.6	1020.5	27.8	245
		*	*	n.s.	n.s.	

* Significant with hollow stem rating at 5%
n. s. Not significant

Legend As Table 4 on page 138

TABLE 39: Plant Growth (Overhead Sprinkler - 1)

Date	*Fresh Wt.	*Dry Wt.	*No. of leaves	*%Dry matter
	g	g		
24.1.95	1.98	0.45	4	22.7
15.2.95	105.2	10.9	10	10.3
26.2.95	364.2	41	14	11.2
4.3.95	562.1	59.6	16	10.6
15.3.95	867.2	86.2	20	9.9
23.3.95	994.2	102.4	22	10.3

*means of fifteen plants at each sampling.

TABLE 40: Nutrient Analysis (Overhead Sprinkler - 1)

SAMPLE	WATER	H.S.	B	N	K	Ca	H. Wt.
	mm		ppm	mg/g	ppm	ppm	g
R2C6P2	54.06	1	26.6	4.4	955.1	41.2	286.2
R2C8P1	44.3	1	30.5	3.6	854.2	38.5	332.6
R3C7P2	82.28	2	25.2	3	898.3	41	324.5
R3C8P3	61.2	2	23.9	3.75	1107.5	34.6	285.4
R3C6P3	70.38	2	24.5	4.5	721.9	28.9	386.5
R3C5P2	98.61	5	17.6	4.9	821.5	26.4	397.4
	*		*	*	n.s.	n.s.	
		**	**	n.s.	n.s.	n.s.	

* Significant with hollow stem rating at 5%
** Significant with volume of water at 5%
n.s. Not significant

Legend As Table 4 on page 138

TABLE 41: Plant Growth (Overhead Sprinkler - 2)

Date	*Fresh Wt.	*Dry Wt.	*No. of leaves	*%Dry matter
	g	g		
24.1.95	2.3	0.48	4	20.9
15.2.95	116.2	12.6	10	10.8
26.2.95	350.9	40.2	13	11.5
4.3.95	583.1	62.1	15	10.6
15.3.95	843.8	86.1	20	10.2
23.3.95	964.2	100.9	22	10.5

* means of fifteen plants at each sampling.

TABLE 42: Nutrient Analysis (Overhead Sprinkler - 2)

SAMPLE	WATER	H.S.	B	N	K	Ca	H. Wt.
	mm		ppm	mg/g	ppm	ppm	mm
R3C2P2	52.87	2	23.1	2.4	868.6	29.5	298
R1C2P2	77.9	5	19.5	5.7	618.2	35.4	483.9
R2C10P3	68	2	23.7	4.6	932.4	26.4	434.1
R3C9P1	57.9	2	26.9	3.87	629.1	34.5	390.2
R3C9P3	57.9	2	26.6	3.1	660.5	36.4	344.6
R4C9P3	66.3	2	27.2	4.5	693.2	20.6	391.3

* * * n.s. n.s.

** ** n.s. n.s. n.s.

* Significant with hollow stem rating at 5%

** Significant with volume of water at 5%

n.s. Not significant

Legend As Table 4 on page 138

SITE 12

TABLE 43: Plant Growth (Site 12)

Date	*Fresh Wt.	*Dry Wt.	*No. of leaves	*%Dry matter
	g	g		
24.1.95	1.9	0.45	4	23.68
15.2.95	84.2	9.67	10	11.5
26.2.95	220.2	28.1	13	12.8
4.3.95	395.1	46.5	15	11.8
15.3.95	559.8	71.8	18	12.8
23.3.95	777.4	93.1	22	12

* means of fifteen plants at each sampling.

TABLE 44: Nutrient Analysis (Site 12)

SAMPLE	WATER mm	H.S.	B ppm	N mg/g	K ppm	Ca ppm	H.Wt. mg
C20P1	60.35	2	26.6	4.5	574.9	26.5	249.1
C16P3	47.26	1	27.9	3.8	688.1	19.8	230
C14P1	40.8	1	27.7	4.1	608.4	29.8	287
C15P1	40.46	1	28.4	3.7	553.1	35.4	248.1
C13P2	75.14	5	18.6	6.4	965.8	20.5	308.7
C8P1	65.45	2	25	3.1	956.1	29.5	241
C5P1	70.04	4	17.4	6.1	1039.6	37	235.2
C4P1	68	3	22.9	4.8	526.8	24.6	356
C2P2	54.06	1	28.9	3.5	1011.1	30.9	232.1
C11P1	57.8	1	30.1	4.3	765.2	28.5	266.6
	*		*	*	n.s.	n.s.	
		**	**	n.s.	n.s.	n.s.	

* Significant with hollow stem rating at 5%

** Significant with volume of water at 5%

n. s. Not significant

Legend As Table 4 on page 138

TABLE 45: Photosynthesis measurements (site 2, trial 1)

DATE	25.11.93		26.11.93		27.11.93		
CAN NO.	P1	P2	P1	P2	P1	P2	WATER
							mm
1	0.5282	0.4944	0.4233	0.4866	0.5012	0.494	60.7
2	0.3422	0.3946	0.6482	0.5149	0.4396	0.3249	101.7
3	0.8184	0.6724	0.4365	0.6724	0.3629	0.7023	81.5
4	0.4344	0.539	0.6643	0.539	0.3208	0.3159	80.4
5	0.6535	0.4983	0.6882	0.4181	0.3218	0.2866	131.4
6	0.5675	0.3991	0.4041	0.4983	0.4456	0.5107	84.6
7	0.542	0.5799	0.5717	0.3991	0.4088	0.1002	66.6
8	0.3889	0.217	0.8172	0.6323	0.217	0.3013	67.9
9	0.8124	0.6482	0.6434	0.5799	0.348	0.4033	82.4
10	0.7184	0.4088	0.5657	0.4801	0.394	0.3496	95

Legend: P1-P2: tagged plants around the cans and the values given are for photosynthesis in mols/CO_2/m^2/s.

TABLE 46: Photosynthesis measurements (site 3, trial 1)

DATE	25.11.93		29.11.93		30.11.93		2.12.93		3.12.93		
CAN NO.	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	WATER
											(mm)
1	0.2804	0.3416	0.3115	0.3173	0.4376	0.3746	0.4272	0.5521	0.3691	0.085	89.5
2	0.3685	0.3612	0.4657	0.4416	0.4379	0.5121	0.318	0.3528	0.3579	0.2662	83.5
3	0.3373	0.2605	0.5791	0.4237	0.1282	0.3188	0.5861	0.2957	0.4139	0.41	67.7
4	0.2648	0.3104	0.5714	0.5766	0.5044	0.3116	0.3576	0.6231	0.2132	0.5167	80.7
5	0.4054	0.427	0.4586	0.4829	0.3656	0.3216	0.1879	0.1979	0.3482	0.2551	88.4
6	0.301	0.2744	0.6023	0.2915	0.5384	0.4295	0.2549	0.4969	0.2289	0.0943	71.7
7	0.3127	0.2816	0.3037	0.4572	0.6727	0.3428	0.5004	0.3926	0.4575	0.401	96.6
8	0.3593	0.1576	0.2947	0.3744	0.1634	0.5721	0.3515	0.3105	0.2913	0.2817	94.8
9	0.1198	0.183	0.3233	0.4433	0.4647	0.2743	0.2063	0.1967	0.1991	0.3275	51.6
10	0.3703	0.3847	0.5506	0.439	0.3185	0.5645	0.1008	0.1644	0.3041	5856	44.5

Legend: See Table 45

TABLE 47: Photosynthesis measurements (site 4, trial 2)

	20.1.94		22.1.94		24.1.94		25.1.94	
CAN NO.	P1	P2	P1	P2	P1	P2	P1	P2
1	0.2737	0.3689	0.7182	0.5688	0.1537	0.0559	0.3022	0.243
2	0.557	0.5704	0.5709	0.3809	0.2783	0.3007	0.209	0.2401
3	0.5571	0.338	0.5335	0.4357	0.5513	0.4345	0.2924	0.243
4	0.5594	0.1878	0.5408	0.527	0.2689	0.4629	0.4197	0.3143
5	0.4444	0.5842	0.5175	0.5307	0.5593	0.5658	0.0757	0.0212
6	0.4866	0.4484	0.5144	0.4925	0.3907	0.6035	0.5404	0.2961
7	0.4851	0.4206	0.5573	0.2906	0.606	0.3599	0.7009	0.3421
8	0.2853	0.3059	0.1989	0.245	0.3419	0.5854	0.1841	0.1393
9	0.6232	0.4867	0.3726	0.3869	0.5438	0.5994	0.0566	0.0189

Legend: See Table 45

TABLE 48: Photosynthesis measurements (site 5, trial 2)

	21.1.94		24.1.94		25.1.94		
CAN NO.	P1	P2	P1	P2	P1	P1	WATER (mm)
1	0.4414	0.3186	0.5046	0.1575	0.532	0.5036	87.6
2	0.2816	0.2078	0.4959	0.2409	0.2639	0.5865	43.8
3	0.1054	0.2253	0.3971	0.4582	0.547	0.4098	62.6
4	0.4565	0.2762	0.4085	0.5711	0.4127	0.2637	42.6
5	0.5469	0.3958	0.3569	0.4083	0.518	0.6307	39.1
6	0.5554	0.2916	0.3113	0.3376	0.2825	0.4144	52.2
7	0.4701	0.3761	0.6286	0.0425	0.3724	0.4469	72.6
8	0.4175	0.3582	0.1513	0.1087	0.4975	0.4759	54.2
9	0.6417	0.4263	0.2821	0.4219	0.7263	0.4403	69
10	0.4766	0.5791	0.166	0.0023	0.3616	0.3415	54.2

Legend: See Table 45

TABLE 49: Photosynthesis measurements (site 6, trial 2)

DATE	20.1.94		22.1.94		24.1.94		25.1.94		
CAN NO.	P1	P2	P1	P2	P1	P2	P1	P2	WATER (mm)
1	0.4248	0.3307	0.3682	0.5343	0.1996	0.01164	0.4863	0.6101	208.1
2	0.2999	0.3931	0.2045	0.1652	0.1476	0.0071	0.3567	0.4546	69.2
3	0.5209	0.3747	0.6153	0.526	0.1009	0.2077	0.5659	0.5542	160.5
4	0.2815	0.0554	0.3134	0.5596	0.1027	0.0858	0.2538	0.2842	17.4
5	0.5863	0.3816	0.5549	0.3739	0.0574	0.0574	0.4402	0.472	41.2
6	0.4156	0.5471	0.5354	0.5004	0.384	0.1011	0.6244	0.5184	162.6
7	0.072	0.2709	0.3561	0.5029	0.1503	0.1147	0.1878	0.385	79.6
8	0.2864	0.3486	0.3582	0.1802	0.0023	0.3647	0.5329	0.6624	164.2
9	0.1678	0.4244	0.584	0.2853	0.2328	0.1397	0.4773	0.5238	146.9
10	0.4951	0.5167	0.4566	0.4177	0.5222	0.0954	0.5286	0.6924	79.6

Legend: See Table 45

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