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CONTRACT REPORT

Protected Celery
Improvement of Quality

HDC PC 84

Final Report - September 1993

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Protected Celery
Improvement of Quality

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Key Words: **Glasshouse celery, quality, cultivars, mineral disorders, 'bolting', 'jug handles', *Sclerotinia*, soft rot, methyl bromide, nitrate levels, post-harvest studies, requirements for research and development**

CONTENTS

Background and Commercial Objective

Early protected crops occupy a potentially profitable niche in the overall celery market, though there can be problems with the variable quality of 'sticks' and the notoriously unpredictable market returns. Climatic conditions in some areas like the South Coast of England are particularly favourable for producing the early heated crops. These are harvested and marketed from late April to June when consumer demand is strong, imports are relatively weak, and supplies of English field celery are unavailable. However, British growers need continually to improve the quality of their produce in order to maintain a competitive edge over foreign rivals. This is especially important in the context of a single market within the EEC.

There are many aspects of quality though, in some respects, the topic can become rather subjective. In this report, attention is given to attributes such as weight, appearance (including colour), flavour, texture and shelf-life of the sticks. The present report was commissioned:

- To review previous researches on quality defects in protected (and field) celery (see pp 5-7).
- To correspond with major retailers and marketing co-operatives in order to gain customers' views of different problems and their relative importance (see p. 8).
- To liaise with British growers and visit glasshouse nurseries (mainly in the South Coast area) in order to discuss problems of both pre- and post-harvest quality defects in early protected celery (see pp 9-11).
- To assess the quality of local samples of protected celery with emphasis on such aspects as senescence, appearance (i.e. 'tightness' of stick), colour, 'softness', odour, dry matter content, and 'shelf-life' (see pp 12-15).
- To recommend where investment in research and development may be required to solve problems of quality defects in celery (p. 16).
- To prioritize future requirements for research and development in order to ensure efforts are directed to those areas which have the greatest benefit for industry (see p. 16).

Review of Previous Researches

An authoritative search of the scientific literature relating to quality defects in protected (and field celery) was instigated at the commencement of the contract in mid May 1993. Unpublished results of relevant researches at both the former Glasshouse Crops Research Institute and the former Experimental Horticulture Stations of ADAS are included for completeness. The review is structured to cover various aspects of cultivation which impact upon the quality of produce.

Crop nutrition

Mineral nitrogen is vital to plant growth. It is part of all the essential constituent of cells, *viz.* the chlorophyll that is essential for photosynthesis, the nucleic acids, DNA and RNA in which the pattern for the plant's growth and development is encoded, the proteins that include the enzymes which catalyse all biochemical processes, and the walls that hold the cell together. Crops that have insufficient mineral nitrogen are stunted, yellowish and sickly looking (Scaife and Turner, 1983). Celery is no exception. Quick-acting nitrogenous fertilizers applied at the right time as side dressings of ammonium nitrate or foliar sprays of urea can both relieve these symptoms and considerably increase the yield of marketable celery. However, excessive use of nitrogenous fertilizers may contribute to increased nitrate levels in underground aquifers and in drinking water. There is also concern about the possible risk to human health arising from high levels of nitrates present in leafy vegetable crops such as glasshouse celery. Nitrate itself is not toxic but may become a problem when it is converted into nitrite. Methaemoglobinaemia (syn. 'blue baby' syndrome) in infants and stomach cancer in adults are two of the health problems which have aroused the fears of the public. At present the medical evidence leaves plenty of scope for debate as to how much nitrate in leafy vegetables is 'safe'. The Commission of the European Communities (C.E.C.) is, however, about to make such a debate redundant in the countries over which it has influence by proposing statutory limits which will vary with the time of year. Addiscott, Whitmore and Powlson (1991) provide a detailed scientific analysis of the controversial issue of fertilizers and nitrate pollution.

Calcium is needed in comparatively large amounts for healthy growth. The element is involved not only in maintaining the structural integrity of cells but also in regulating metabolic processes. Paradoxically, deficiencies of calcium frequently occur when there is no shortage of the element either within the plant or in the soil. The problem is essentially one of inadequate distribution of calcium in the plant and occurs because the rate of transport of the element into the growing point and young leaves is too slow to meet the requirements. Calcium is generally immobile in the phloem and movement of the element is almost entirely through the xylem. Localised deficiencies of calcium will therefore occur when the water supply to the susceptible tissue is restricted. Environmental factors which directly influence transpiration (i.e solar radiation, atmospheric humidity, air movement and soil moisture) can thus cause or aggravate calcium disorders.

'Blackheart' (i.e. blackening and death of the growing point) is the disorder most commonly encountered in practice. The disorder is often associated with rapid growth during hot weather. It may be induced by an excess of other cations such as magnesium, potassium and ammonium (Scaife and Turner, 1983). Celery is especially prone to calcium deficiency, though the occurrence is both erratic and unpredictable. Efforts to establish a critical leaf

concentration of calcium are hindered by the highly variable amounts present in susceptible tissues. Fortnightly sprays of calcium nitrate at a rate of *ca* 16 kg per hectare can help to minimize the occurrence.

Boron deficiency results in brittle tissues which crack easily. Glasshouse celery is especially susceptible to deficiency of boron. Numerous symptoms can occur, though not necessarily simultaneously. Purvis and Ruprecht (1937) describe 'stem cracking' on the outer petioles. This disorder can be detrimental to the appearance of the sticks. It seems that when small transverse cracks appear on the outer surface of the petiole, the epidermis next to the crack curls back and the damaged area goes brown. Other symptoms include the development of axillary shoots, with or without death of the growing point, distortion of young leaves, browning of leaf margins and twisting of petioles (Hewitt, 1945). Susceptibility appears to vary with cultivar (Yamaguchi and Minges, 1956). A critical leaf concentration of 20 mg boron per kg of fresh weight is cited by Scaife and Turner (1983). Prevention of the disorder can be effected by applying commercial borax to the soil during the early stages of growth at a rate of *ca* 10-20 kg per hectare. Alternatively, the addition of 0.5-1 ppm boron in the water supply at each irrigation will help to produce normal growth of celery.

Salt (sodium chloride) is recommended for use with outdoor celery. The crop appears to be responsive to sodium and ADAS currently recommends the application of 400 kg sodium chloride per hectare. There are no recommendations for using salt on glasshouse celery because of concern about the possible accumulation of chloride in the soil and the concomitant increase in electrical conductivity which might restrict the growth and yield of subsequent crops. The influence of salt on the growth and yield of glasshouse celery was investigated by ADAS at a commercial grower's holding in the Sidlesham area during the 1989 and 1990 cropping seasons. Application of sodium chloride increased the concentration of sodium in sticks. The effect on yield was non-significant. There was no evidence to show improvement in the quality of the sticks. However, data were not collected on such aspects as the flavour, composition and texture of the celery.

Crop Physiology

'Bolting' (i.e. the rapid elongation of the main stem coupled with the premature development of flower stalks from a previously initiated umbel type of inflorescence) makes celery unattractive to the market. This leads to a great deal of waste and downgrading of produce with concomitant loss of income for growers. ADAS reckons that in a normal season the losses from bolting can account for about 5 to 10 per cent of the gross production of celery crops. Efforts to economise on fuel by growing crops at lower temperatures have accentuated the problem, especially in areas like the South Coast where growers favour earlier sowing dates. Hand and Roelofse (1989) have reviewed the plant and environmental factors which influence bolting. Temperature and daylength are particularly important because celery needs exposure to low temperature and short-day conditions for flower initiation to occur.

Apical dissections and scanning electron microscopy have been used by various researchers at HRI Littlehampton to study the morphology of flower initiation and development in early crops of glasshouse celery. It seems that autumn- and winter-sown celery initiate an inflorescence at or near the spring equinox. Rapid growth of the main stem and early development of the inflorescence usually follows in response to lengthening day and rising temperature. Studies in daylit, controlled-environment cabinets have shown that autumn- and winter-sown celery crops will invariably initiate an inflorescence when grown at temperatures below 14°C from planting onwards (Roelofse, Hand and Hall, 1990). Observations by Jones, Cribb and Hand (1989) have revealed that most crops on the South Coast are grown at such temperatures during the critical period from planting to the spring equinox. The risk of bolting is, therefore, extremely high. However, growers can mask bolting (though not flower initiation) by cutting their sticks of celery early.

The developmental responses of autumn-sown celery grown at low temperatures (i.e. less than 14°C) can be modified by manipulation of the daylength (Roelofse, Hand and Hall, 1989; Roelofse, Hand and Hall, 1990). In practice, growers can use 'night-break' lighting (similar to that used for the 'year-round' production of chrysanthemums) to delay the onset of flower initiation and bolting (Szmidt, Hand and Horridge, 1986; Hand and Horridge, 1986). The timing of the 'night-break' within the dark period appears to be relatively unimportant provided that the duration of the incandescent lighting is four hours (Hand and Cribb, 1988). There are, therefore, opportunities for growers to both exploit 'off-peak' tariffs for electricity and minimize maximum demand penalties. Cyclic lighting techniques can also be used to reduce costs without loss of efficacy (Hand and Cribb, 1989). By taking full advantage of the cheapest electricity the overall operating costs of night-break lighting are equivalent to about 5 per cent of the likely market price for first quality celery harvested in May. An added benefit is that night-break lighting produces plants with a more erect habit, longer petioles and fewer sideshoots. This makes for easier handling and a better harvest index.

'Jug handles' on celery are a recurrent problem for some producers of early crops in the environs of Chichester. The 'splayed' growth of the outer petioles is highly detrimental to producing first quality sticks of acceptable weights. Jones (1987) has reported that the problem was considered to be moderate to very serious by half the respondents to a questionnaire sent out to growers following the end of cropping in June 1987. No research findings are reported in the literature.

The Customers' View

Traditional greengrocers, market stallholders and other outlets (e.g. corner shops, garages, farm shops etc) presently account for about half of the sales of Britain's fresh vegetable market. However, more and more fresh produce is being sold through the major grocery multiples. This trend seems likely to continue. Indeed, it is noticeable that many supermarkets try to promote fresh produce by putting fruit and vegetables immediately after the entrance to the store. Growers will, therefore, need to pay particular attention to the general acceptability of their produce to shoppers.

Correspondence and discussions with several of the huge supermarket chains has established that there is concern about the quality of English protected celery harvested and marketed from late April to June. Poor taste is a common complaint, especially with cultivars like 'Celebrity' and 'Loret' which are grown extensively in the South Coast area. Reference was made specifically to some of the early crops which had a "soapy petroleum flavour". One large supplier of glasshouse celery reported that on several occasions it had been necessary to reject whole crops on grounds of taste, despite the produce being ideal in every other respect.

Several of the supermarket chains stated a preference for cultivars which are apple green in colour. It seems that cultivars such as 'Victoria', 'Multipak' and 'Greensleeves' are perceived by tasting panels (both consumer and in-house) as having a better flavour than 'Celebrity' and 'Loret'. Excessive bitterness of glasshouse celery can be a problem, with customers preferring the sweeter sticks. Generally, there was little cause for concern with respect to texture. Pithiness can sometimes be troublesome whilst loss of succulence can occur with celery which takes too long to sell (usually a week from harvesting).

At the time of purchase the majority of shoppers are concerned with the 'freshness' of produce. Visual impact is therefore very important. In practice, the customer is looking for celery which is uniform, fully turgid, and with fresh cut ends. In this respect, there is an urgent requirement to reduce the oxidation of cut surfaces after packing. Discolouration of both butt and cut petiole can be as rapid as 8 hours or as slow as several days. After purchase the customer is mainly looking for produce with a strong flavour and a texture which is 'crunchy' and not 'stringy'. Excessive stringiness is believed to lead to reduced uptake in the supermarkets.

The Producers' View

During June 1993 efforts were made to liaise with British growers and visit various glasshouse nurseries (mainly in the South Coast area) in order to discuss problems of quality defects in early protected celery crops. The results of these discussions may be summarized with respect to cultivars, mineral disorders, physiological disorders, pests and diseases, bromide residues, and nitrate levels.

Cultivars

The choice of cultivar is of increasing importance as customers become more discerning in their requirements. 'Lathom Self-Blanching' and its selections 'Celebrity' and 'Loret' are currently the mainstays of the industry. However, growers have found that there is considerable interest in cultivars such as 'Victoria', 'Multipak' and 'Greensleeves'. These cultivars have apple green coloured petioles and are deemed by the major grocery multiples and their customers to have a better taste. Other cultivars undergoing evaluation in growers' trials include 'Harvest Moon' and the F1 hybrid 'Stardust'. These two cultivars with their erect growth habit appear to be ideally suitable for pre-packing in polythene sleeves. A novel development is the introduction of pink celery, though the colour of the sticks may need to be strengthened to improve visual impact on the supermarket shelves.

Mineral disorders

Several growers expressed concern about the problem of 'cracking' on the petioles of celery sticks. Questions were asked about the best means of applying boron as a preventive measure. It was noted that the disorder could be particularly troublesome on a large holding in the Cranleigh area. Mention was made of other disorders attributable to mineral deficiencies. These included the calcium-related disorder 'blackheart' (symptoms - blackening and death of the growing point), and the problems of interveinal chlorosis due to manganese deficiency. An interesting suggestion proffered by one grower was the possible addition of common salt to the mineral nutrient feed in order to offset the bitterness in celery.

Physiological disorders

A recurrent problem for some growers in the South Coast area is the high incidence of celery with 'jug handles'. The splayed growth is detrimental because it increases wastage from trimmings, reduces stick weights, downgrades sticks, makes bagging more difficult, and increases the labour requirement during harvesting. ADAS estimate that jug handles cost growers about £2,500 per hectare in a bad season. The causes of jug handles are not known. Anecdotal evidence suggests that jug handles occur more frequently with the early crops which are planted in January and harvested from late April to early May. Some growers' holdings appear to be more prone to the problem than others, though the reasons for this are not understood. Also, the incidence of jug handles seems to vary considerably from year to year. There is no obvious explanation for this behaviour.

Early protected celery crops produced from late autumn/early winter sowings are liable to 'bolt' at or near harvest in the late spring. Bolting makes the celery unattractive to the market. The environmental factors which control flower initiation and the development of a flower stalk in celery have been the subject of detailed studies in the past (see pp 6-7). Prevention of bolting is mainly a matter for cost-benefit analysis. In this respect there is interest in the possible use of halogen heaters and heat targeting for efficient control of bolting at the lowest possible cost.

Pests and diseases

Slugs and caterpillars are the most troublesome pests, though control measures such as baiting with mollusicide pellets for slugs and spraying with permethrin (as 'Ambush') for caterpillars have usually proved adequate. More problematical is the control of the soil-borne pathogen *Sclerotinia sclerotiorum*. The disease which causes butt rot can be particularly troublesome on crops grown immediately after lettuce. Possible curbs against the use of methyl bromide as a soil fumigant will greatly aggravate the problem. Infection is characterized by the presence of pink lesions at the base of the celery. Eventually, these lesions become covered with a white 'cottony' mycelium within which the oval black sclerotia (resting bodies) develop. The disease can cause devastating losses in the glasshouse and especially in transit from the nursery to the packhouse and supermarket. Growers voiced their concern at the withdrawal of the fungicide vinclozolin (as 'Ronilan') from the MAFF's list of approved products. At present the control of *Sclerotinia* is limited to partial soil sterilization (preferably by steaming) followed by the regular application of benomyl (as 'Benlate') to prevent new infections by the ascospores. There is, therefore, renewed interest in the possibility of using antagonistic fungi such as *Coniothyrium minitans* (as a maizemeal-perlite or other formulations) in the soil to reduce infection with *S. sclerotiorum*.

Plant pathogenic bacteria can cause parenchymal diseases such as soft rot which result in the outer sticks of celery becoming pulpy. The bacteria secrete pectinase enzymes which break down the middle lamella of the host cells. This results in the maceration of the tissue, death of the cells due to water loss and the characteristic symptoms of soft rot. A regrettable feature of the disease is that the sticks may appear healthy at the time of cutting, trimming and bagging. Several days later the symptoms of soft rot develop and the produce has to be rejected by the retailer. This has unfortunate consequences for the growers and their marketing co-operatives. During the heat-wave in May 1992, the symptoms of soft-rot were much in evidence on produce from the South Coast area. There was a general consensus amongst growers that parenchymal diseases such as soft rot merit investigation. A protocol to minimize the problem of soft rot is urgently required by growers.

The potential threat to the English celery industry of alien pests such as *Liriomyza trifolii* was acknowledged by many growers. Despite statutory eradication measures, there is the possibility of this and other alien species of *Liriomyza* becoming established in the U.K. A search for pesticides suitable for its control is hindered by the fact that the pest is statutorily excluded from the U.K. However, control measures have been devised in both California and in The Netherlands where the leaf miner is a major pest.

Bromide residues

Soil sterilization by steaming is considerably more expensive than by fumigation with chemicals such as dazomet and methyl bromide. The cost of treatment with dazomet is considerably less than that of methyl bromide, though the latter is preferred by most growers as it allows a quicker turn round between crops. There is, however, increasing concern over the high levels of bromide residues which can occur in leafy vegetables like celery grown on soils previously fumigated with methyl bromide. In the event of a statutory limit of 100 ppm or less being imposed in Britain, it is difficult to see how methyl bromide could continue to be used as a soil fumigant at current rates of application (i.e. 75-100 g per square metre).

Nitrate levels

High levels of nitrates in leafy vegetables like celery are thought to be undesirable because of a possible link with health problems such as methaemoglobinaemia ('blue-baby' syndrome) in young babies and stomach cancer in adults. Already, some European countries (*viz.* The Federal Republic of Germany and The Netherlands) have statutorily imposed maximum permissible levels of nitrates in leafy vegetable crops. The Commission of the European Communities (C.E.C.) is expected to draft regulations governing the nitrate levels in vegetables. Initially, it is thought that the regulations will only apply to vegetable-based baby foods, lettuce and spinach. However, in due course, the regulations may be extended to include glasshouse- and field-grown celery. This may cause problems for growers as nitrate levels in commercial celery crops may exceed the Commission's proposed statutory limits of 4,000 and 5,000 mg nitrate per kg fresh weight for 'white' and 'green' celery respectively. In this context, it is essential that growers should not be over generous in applying nitrogenous fertilizers to their crops. In practice, it seems that the source of mineral nitrogen is relatively unimportant with respect to the nitrate content of crops.

Post-Harvest Studies

Southgate Growers together with six individual nurserymen in the environs of Chichester provided samples of large (>400 g) and small (<400 g) sticks of marketable celery harvested on two occasions during June 1993. The freshly-cut produce was trimmed and sleeved, and then transferred rapidly (normally within a day of harvesting) to HRI (Littlehampton) for assessment.

Materials and methods

Representative sub-samples of four sticks were taken on both occasions from the produce of each of the growers participating in the trial. Two sticks of celery from each sub-sample were placed in a constant temperature held at 5°C (cool treatment). The two remaining sticks from each of the sub-samples were located in an unheated room with the blinds drawn (warm treatment). Air temperature within each of the rooms was continuously monitored using calibrated thermographs and mercury thermometers. Efforts were made daily at 9 a.m. to assess various aspects of quality such as fresh weight, senescence, 'softness', colour, odour, 'tightness', and health of the leaves. 'Saleability' was assessed and the dates were recorded at which the produce became unsaleable. The assessments and their ratings were:

Fresh weight - the weight (grammes) of a cut stick, excluding the plastic sleeve.

Senescence - a measure of the number of blemishes and the degree of bruising on the stems.

1. No blemishes/bruises.

2. Small blemishes/bruises each of an area less than 100 sq mm.

3. Blemishes/bruises with the majority having an area greater than 100 sq mm but less than or equal to the area of one stem *in toto*.

4. An area equivalent to that of between one and two petioles covered by blemishes/bruises.

5. An area greater than that of two petioles covered by blemishes/bruises.

'Softness' - an estimate of the degree of rigidity and crispness of the sticks as determined by bending the stems.

1. Crisp and fresh with little discolouration of cut ends.

2. Crisp and fresh, but with cut ends well sealed.

3. Acceptable freshness with rigid petioles which crack on bending.

4. Unacceptable limpness with flaccid petioles which bend easily without breaking.

5. Unacceptable limpness with two or more flaccid petioles bending under their own weight when held horizontal.

Colour - an estimate of the overall colour of the sticks in the range between fully blanched and fully green.

1. Completely blanched petioles with no greening.

2. Blanched petioles with evidence of greening and/or cream colouring.

3. Blanched/green petioles about fifty-fifty.

4. Greening of external petioles, but with the colour fading at a point about three-quarters down the length of the stick to a pale cream at the base.

5. Greening of external petioles with the colour extending to the base of the stick.

Odour - an uncertain variate recorded by one person and based on the strength of the smell of the stick within its plastic sleeve.

1. Smell barely noticeable.

2. Smell of fresh celery.

3. Smell of fresh celery but with slightly unpleasant odour.

4. Strong, unpleasant smell.

5. Rank, obnoxious smell.

'Tightness' - an initial description of the compactness of the sticks of celery, and the degree to which individual petioles will compress when a stick is squeezed at the mid-point of its length.

1. Fully tight with no compression when the stick is gently squeezed. Petioles moulded around each other.

2. Reasonably tight, but with some movement when the stick is squeezed.

3. Open stick with individual petioles not touching.

Health of leaves - a description of the freshness of the leaflets and accounts for fully blanched and green leaves together with turgidity and disorders (i.e. yellowing) of leaves, but not for fading colour.

1. Fully turgid, fully blanched or green.

2. Leaflets limp with full colour or turgid with yellow flecking.

3. Half or more of visible leaflets flaccid or fully yellow (excluding blanched leaflets).

'Saleability' - a subjective decision on the overall quality of a stick. Observation and touch are the main criteria, with freshness and turgidity rated most strongly.

Yes the stick merits purchase as Class I celery.

No the stick does not merit purchase as Class I celery.

Summary of results

The assessments of the growers' produce for each storage treatment (*viz.* cold versus warm) are summarized by a series of comparative graphs and tables in the Appendix (see pp 18-38). For illustrative purposes, the results obtained from sample 8 are shown opposite. This sample was selected as being generally typical of the produce used in the assessments. An indication of the date at which produce became unsaleable is given by the solid (first replicate) and dashed (second replicate) vertical lines. The stage at which the leaflets of a stick were deemed unhealthy (i.e. rating 3) is recorded as a date in June unless the leaflets of the produce remained healthy throughout the period of observation. Overall, the results may be summarized as follows:

- During storage the loss in fresh weight (expressed as a percentage of the initial fresh weight at harvest) of the celery sticks was greatest in the warm treatment. The loss in fresh weight was greater for the small (<400 g) sticks.

- The celery sticks became limper more rapidly under the cooler storage conditions, though this was not reflected in the loss in fresh weight.

- The overall effect of the storage temperature was not consistent on the date the sticks were adjudged unmarketable.

- A marked blanching of the green sticks of celery occurred under the warmer storage conditions.

- The odour emanating from the sticks of celery was stronger from the warm treatment and increased as the quality of the sticks deteriorated.

- During storage there was a slight increase in the dry matter content of the sticks of celery, regardless of the temperature treatment.

Conclusions

- Shelf-life depends on the initial quality of the produce.
- Storage temperature has important effects on shelf-life and general acceptability of produce to shoppers.

Requirements for Research and Development

There is neither AFRC nor MAFF-funded work on quality defects in British celery. Indeed, there has been no public funding of research in protected celery since the demise of the ADAS/AFRC Integrated Programme of Horticultural Research and Development in 1989. This unfortunate state of affairs can only lead to a further weakening in the competitive position of British growers. In the interests of economic survival it is, therefore, essential that sufficient funds should be made available for investment in medium- and long-term research and development. Historically, innovation and technological change have led to improved profitability in the glasshouse industry. Celery is no exception, with previous research and development having given good value. For the future, it should be possible to improve the quality of British produce by funding a programme of research and development with the following objectives:

- To gain objective information on consumers' perception of quality with a view to establishing cultural programmes which will help to satisfy the requirements for weight, appearance, colour, flavour, composition and texture of celery.

- To improve quality through greater uniformity of stick weight, and the elimination of mineral (e.g. cracked petioles) and physiological (e.g. 'jug handles' and 'bolting') disorders.

- To devise a protocol for minimizing parenchymal diseases such as soft rot.

- To develop handling and storage methods which will maintain quality and extend the shelf-life of produce.

- To investigate the scope for biologically controlling butt rot caused by the fungus *Sclerotinia sclerotium*, and to develop integrated control measures for soil-borne pathogens.

- To monitor levels of nitrate present in commercial crops, and to devise a protocol for assisting growers to comply with possible EC regulations governing nitrate levels in glasshouse celery.

Ideally, sufficient funds should be made available to develop and sustain a 'rolling' programme of research and development on glasshouse celery. Each of the above objectives merits investigation though, in the present economic climate it will be necessary to direct efforts to those areas which currently have the greatest benefit for industry. The objectives have, therefore, been listed in order of priority.

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Appendix

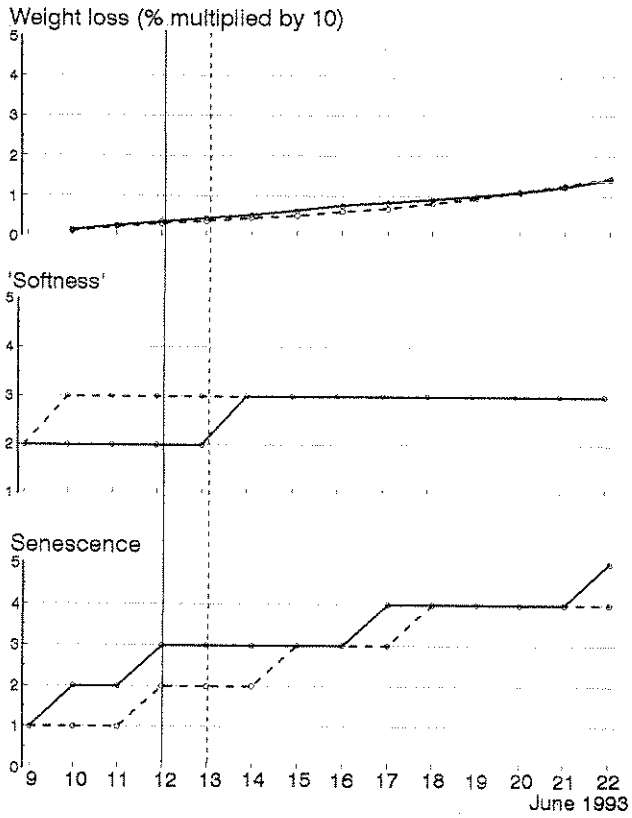
Graphs and Tables

The assessments of growers' produce for each storage treatment (*viz.* cold versus warm) are summarized in the following series of comparative graphs and tables. An indication of the date at which produce became unsaleable is given by the solid (first replicate) and dashed (second replicate) vertical lines. The stage at which the leaflets of a stick were deemed unhealthy (i.e. rating 3) is recorded as a date in June unless the leaflets of the produce remained healthy throughout the period of observation.

Glasshouse Celery (Sample 1)

Storage treatment

Warm



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	3	2	2	2	2	2	2	2	1	1	1	1	1	1
Colour score P(2)	3	2	2	2	2	2	2	1	1	1	1	1	1	1

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	2	2	2	3	3	4	3	3	3	3	3	3	4	5
Smell score P(2)	1	2	2	2	2	2	2	3	2	2	4	4	5	4

Additional Information

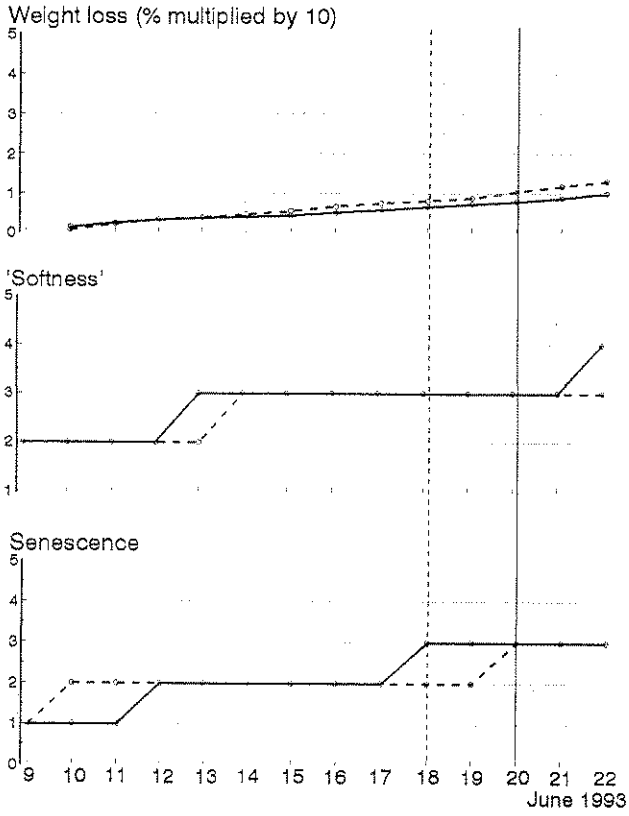
	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	462	471		
Leaves at Stage 3				
'Tightness'	2	2		
Final %dry matter	4.7	5.1		
Int %dry matt (good)			4.7	
Int %dry matt (poor)			4.6	

——— Plant 1 (P1) ---------- Plant 2 (P2)

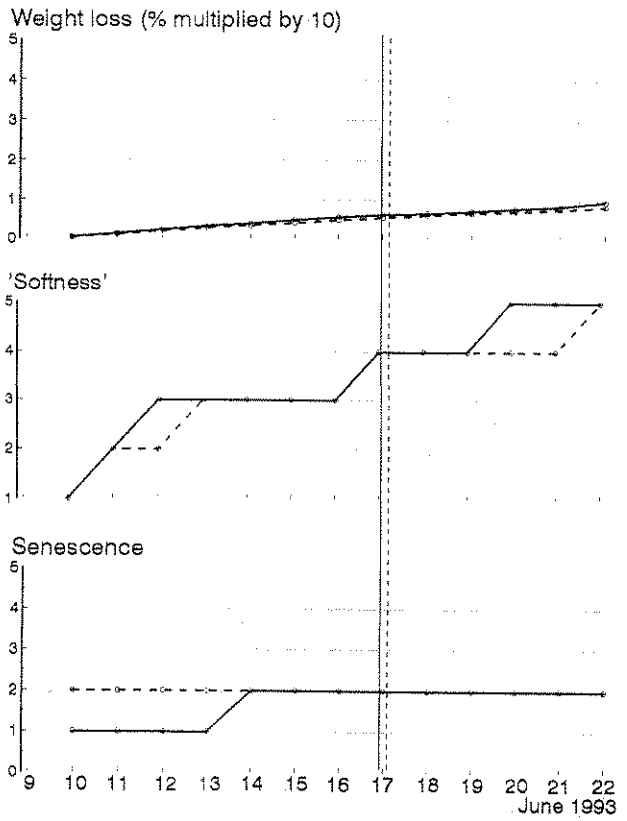
Glasshouse Celery (Sample 3)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	3	3	3	3	2	2	2	2	2	1	1	1	1	1
Colour score P(2)	3	3	3	3	3	3	3	2	2	2	1	1	1	1

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		3	3	3	3	3	3	3	3	3	3	3	3	3
Colour score P(2)		2	3	3	3	3	3	3	3	3	3	3	3	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	2	1	1	2	2	2	2	2	2	3	2	3	3
Smell score P(2)	1	1	1	2	2	2	2	2	2	3	2	2	2	2

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		3	2	1	2	2	2	2	2	2	2	2	2	2
Smell score P(2)		3	2	2	2	2	2	2	2	2	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	472	423		
Leaves at Stage 3				
'Tightness'	2	1		
Final %dry matter	5.0	4.6		
Int %dry matt (good)			4.7	
Int %dry matt (poor)			4.8	

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	622	646		
Leaves at Stage 3		22		
'Tightness'	2	2		
Final %dry matter	4.9	4.7		
Int %dry matt (good)			4.7	
Int %dry matt (poor)			4.8	

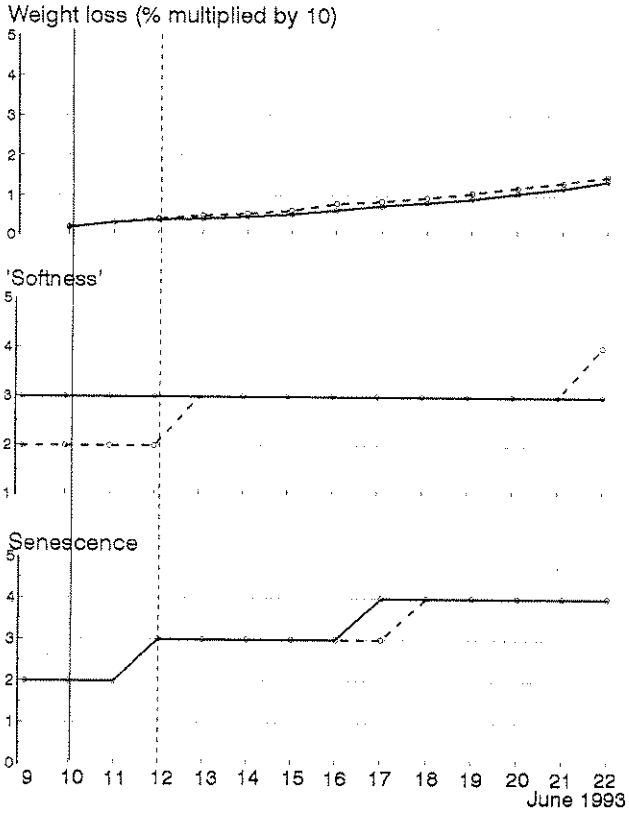
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

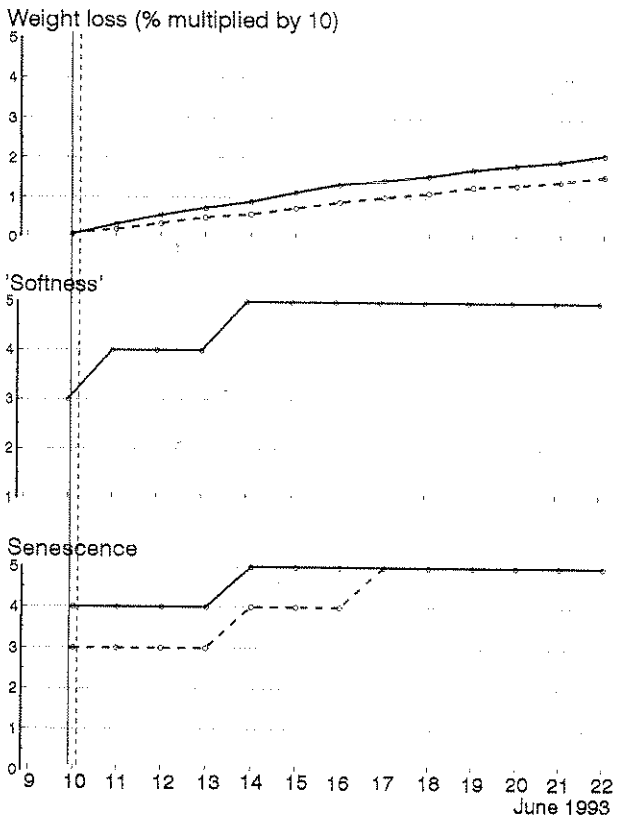
Glasshouse Celery (Sample 5)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	2	2	1	1	1	1	2	1	1	1	1	1	1	1
Colour score P(2)	2	3	2	2	2	2	2	1	1	1	1	1	1	1

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		2	2	2	2	2								
Colour score P(2)		2	1	2	2	2	2	2						

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	2	2	2	2	2	2	3	2	2	2	3	2	3
Smell score P(2)	1	1	1	2	2	2	2	1	2	2	4	4	4	4

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		1	1	1	1	1	4	4	3	4	4	5	5	
Smell score P(2)		2	1	2	2	2	2	2	2	2	2	2	2	

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	357	351		
Leaves at Stage 3	22	22		
'Tightness'	2	2		
Final %dry matter	4.3	4.7		
Int %dry matt (good)			4.5	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	353	384		
Leaves at Stage 3	20			
'Tightness'	2	3		
Final %dry matter	4.5	5.5		
Int %dry matt (good)			4.5	
Int %dry matt (poor)				

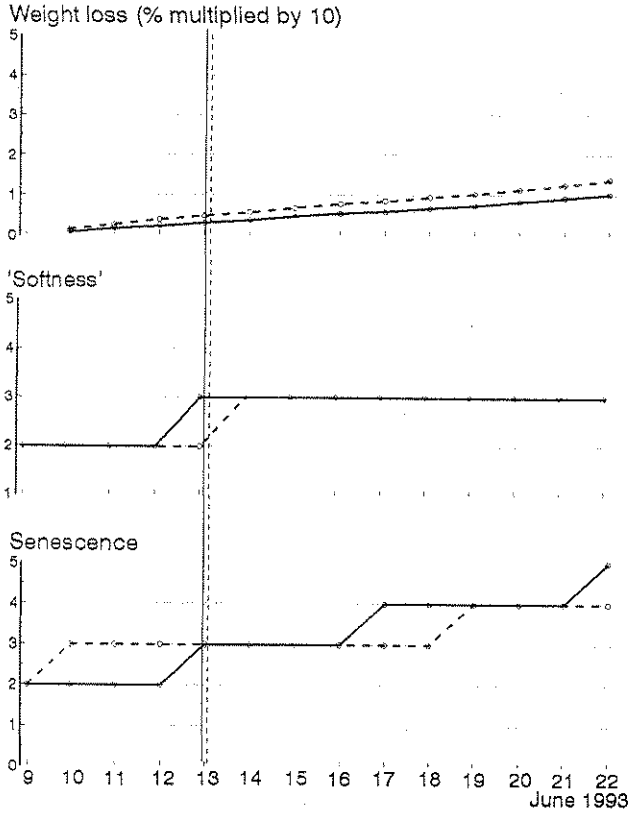
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

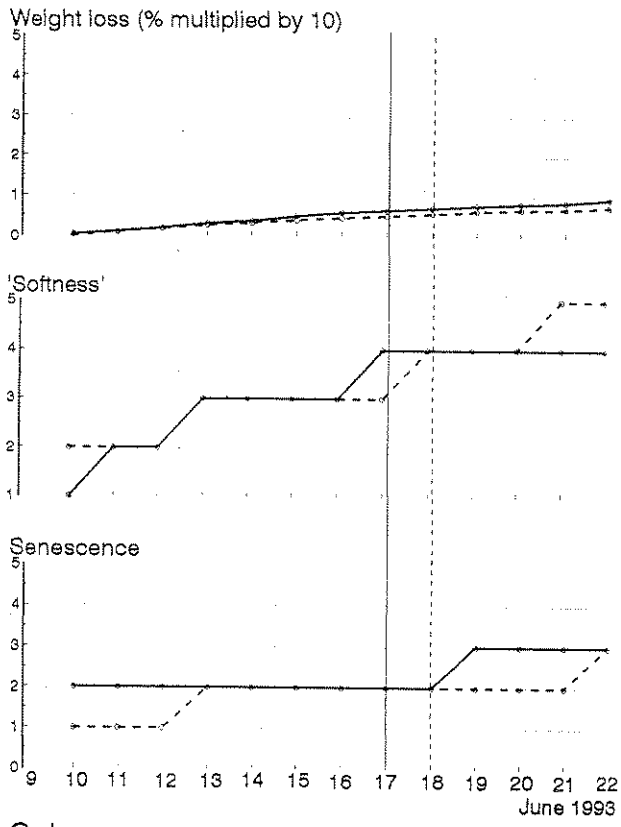
Glasshouse Celery (Sample 6)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	3	3	3	2	3	2	2	2	1	1	1	1	1	1
Colour score P(2)	3	3	3	3	3	3	2	2	2	2	1	1	1	1

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		2	2	3	3	3	3	3	3	3	3	3	3	3
Colour score P(2)		3	3	3	3	3	3	3	3	3	3	3	3	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	1	2	2	2	2	2	2	2	2	4	3	5	4
Smell score P(2)	1	1	1	1	2	3	2	2	2	2	2	3	2	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		3	1	1	2	2	2	2	2	2	2	2	2	2
Smell score P(2)		3	2	2	2	2	2	2	2	2	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	443	514		
Leaves at Stage 3		22		
'Tightness'	2	2		
Final %dry matter	4.5	4.7		
Int %dry matt (good)			4.8	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	589	535		
Leaves at Stage 3				
'Tightness'	2	2		
Final %dry matter	4.8	4.8		
Int %dry matt (good)			4.8	
Int %dry matt (poor)				

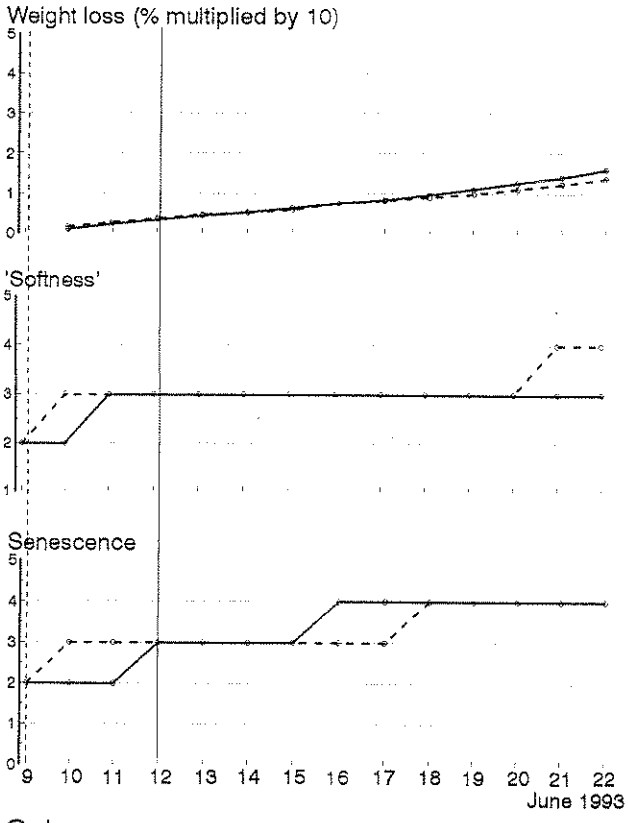
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

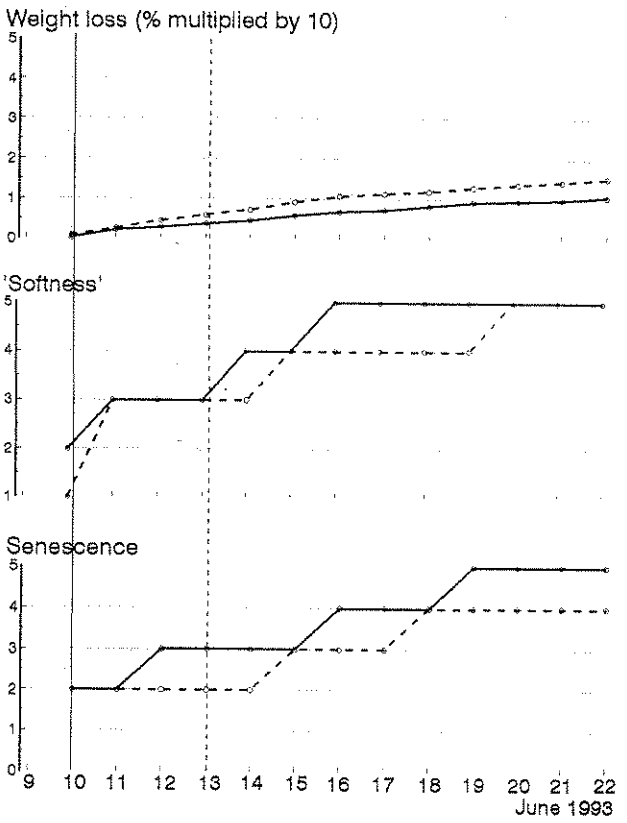
Glasshouse Celery (Sample 7)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	3	2	2	2	2	2	2	1	1	1	1	1	1	1
Colour score P(2)	3	2	2	3	2	2	2	1	1	1	1	1	1	1

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		3	3	3	3	3	3	3	3	3	2	2	2	3
Colour score P(2)		2	2	2	2	2	2	2	1	2	2	2	1	2

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	2	2	1	1	2	2	2	2	1	3	4	4	5	4
Smell score P(2)	2	2	2	2	3	3	2	2	3	3	2	2	5	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		1	1	1	1	1	1	2	2	2	2	1	1	2
Smell score P(2)		2	2	2	2	2	2	2	2	2	2	2	1	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	360	326		
Leaves at Stage 3				
'Tightness'	3	3		
Final %dry matter	4.9	4.4		
Int %dry matt (good)			5.1	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	356	342		
Leaves at Stage 3		22		
'Tightness'	3	3		
Final %dry matter	5.7	5.4		
Int %dry matt (good)			5.1	
Int %dry matt (poor)				

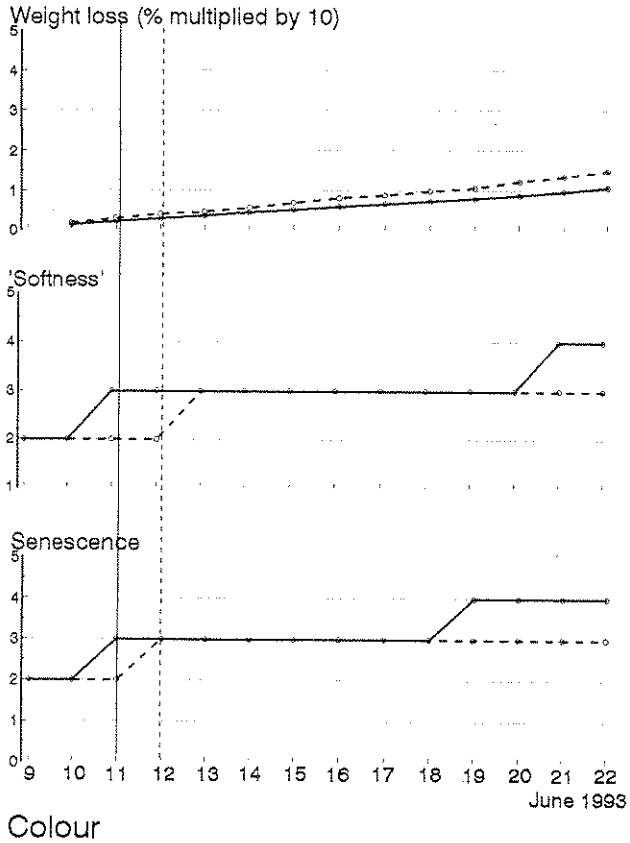
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

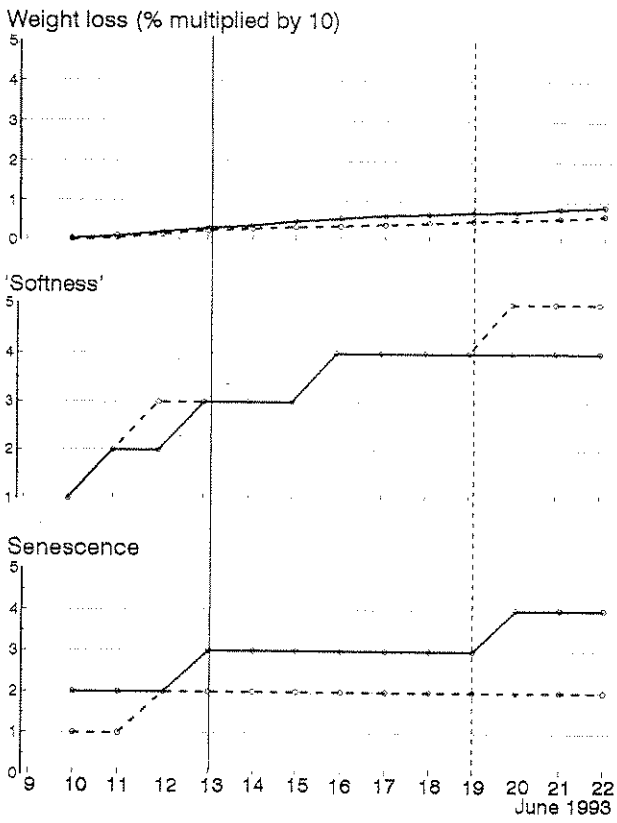
Glasshouse Celery (Sample 8)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	3	2	2	1	1	1	1	1	1	1	1	1	1	1
Colour score P(2)	3	3	3	3	3	3	3	1	1	1	1	1	1	1

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		2	2	2	2	2	2	2	2	2	2	2	2	2
Colour score P(2)		3	3	3	3	3	3	3	3	3	3	3	2	2

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	1	2	1	1	2	2	2	2	2	2	2	3	4
Smell score P(2)	1	1	1	2	1	3	2	2	2	2	2	2	3	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		2	1	2	3	2	3	2	2	2	2	2	1	2
Smell score P(2)		2	1	1	1	1	2	2	1	1	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	368	345		
Leaves at Stage 3				
'Tightness'	3	3		
Final %dry matter	4.5	5.4		
Int %dry matt (good)			4.3	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	448	396		
Leaves at Stage 3				
'Tightness'	3	3		
Final %dry matter	4.4	5.7		
Int %dry matt (good)			4.3	
Int %dry matt (poor)				

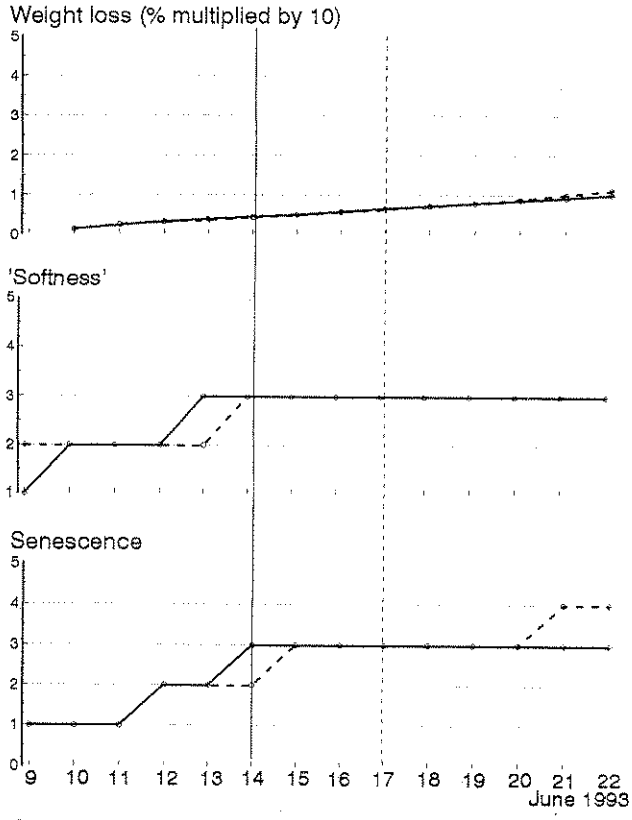
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

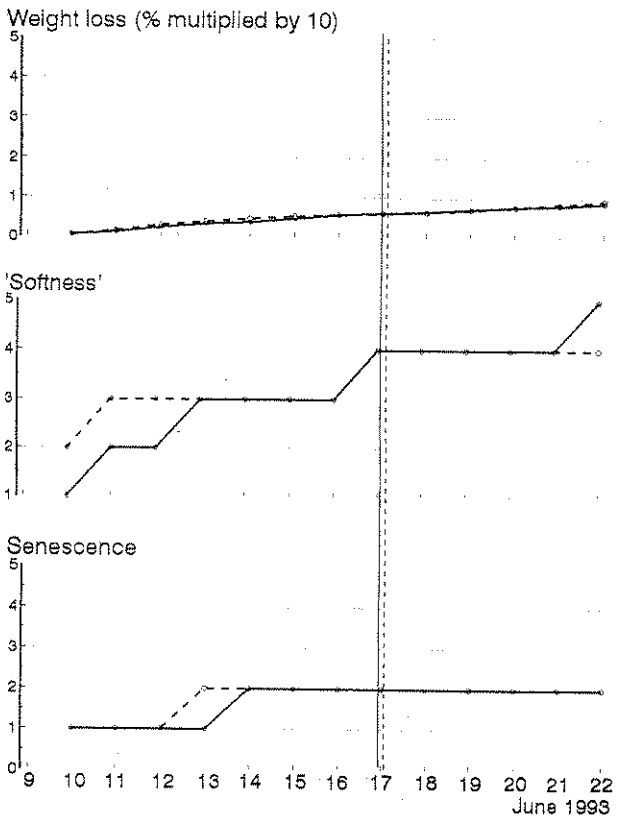
Glasshouse Celery (Sample 9)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	5	4	4	4	4	3	3	3	3	3	3	2	2	2
Colour score P(2)	4	3	3	3	3	3	3	2	3	2	2	2	2	

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	4	4	4	4	4	4	4	4	4	4	4	3	3	3
Colour score P(2)	4	4	4	4	4	4	4	3	3	3	3	3	3	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	1	1	2	2	3	2	2	2	2	2	2	3	3
Smell score P(2)	1	1	1	2	2	3	2	2	2	2	2	2	4	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		1	1	1	1	2	2	2	1	2	2	2	2	2
Smell score P(2)		1	1	1	2	3	1	2	2	2	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	595	570		
Leaves at Stage 3				
'Tightness'	2	2		
Final %dry matter	4.8	5.2		
Int %dry matt (good)			5.2	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	816	613		
Leaves at Stage 3				
'Tightness'	1	2		
Final %dry matter	5.7	5.2		
Int %dry matt (good)			5.2	
Int %dry matt (poor)				

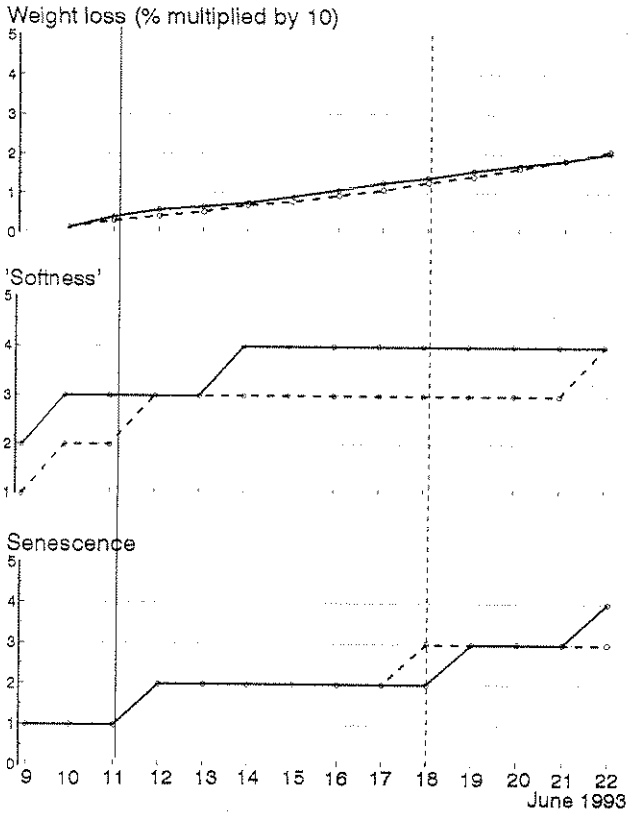
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

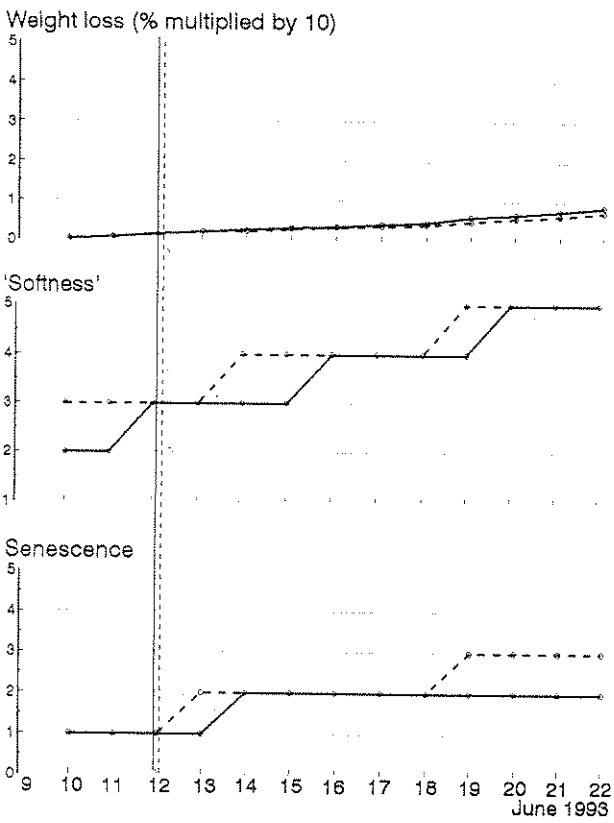
Glasshouse Celery (Sample 10)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	5	5	5	4	4	4	4	4	3	3	3	3	2	2
Colour score P(2)	5	4	4	3	4	4	4	3	3	3	3	3	3	2

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		4	4	5	4	4	5	4	4	4	4	3	3	4
Colour score P(2)		5	5	5	5	5	5	5	5	4	4	4	4	4

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	1	1	1	1	2	1	2	3	2	3	3	4	4
Smell score P(2)	1	1	2	2	2	3	2	2	2	2	2	3	4	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		1	1	1	2	1	2	2	2	1	2	2	1	1
Smell score P(2)		2	2	2	2	2	2	3	2	1	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	245	258		
Leaves at Stage 3	11			
'Tightness'	3	3		
Final %dry matter	6.1	6.0		
Int %dry matt (good)			5.5	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	322	334		
Leaves at Stage 3				
'Tightness'	3	3		
Final %dry matter	6.1	5.9		
Int %dry matt (good)			5.5	
Int %dry matt (poor)				

——— Plant 1 (P1) ---------- Plant 2 (P2)

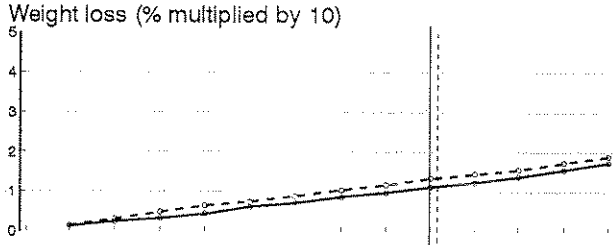
——— Plant 1 (P1) ---------- Plant 2 (P2)

Glasshouse Celery (Sample 11)

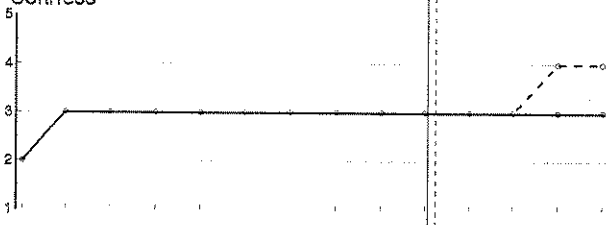
Storage treatment

Warm

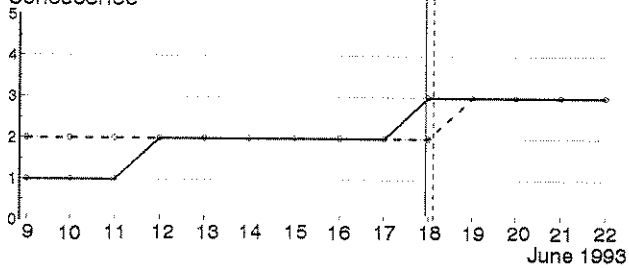
Weight loss (% multiplied by 10)



'Softness'

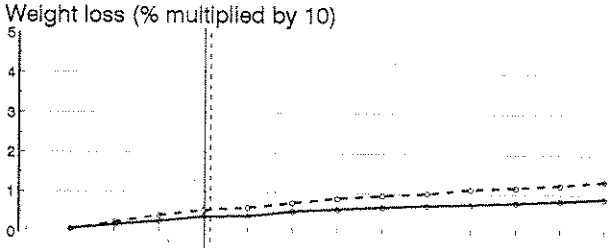


Senescence

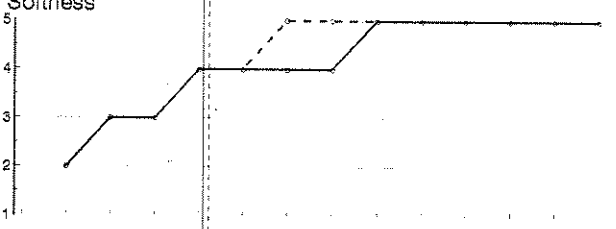


Cold

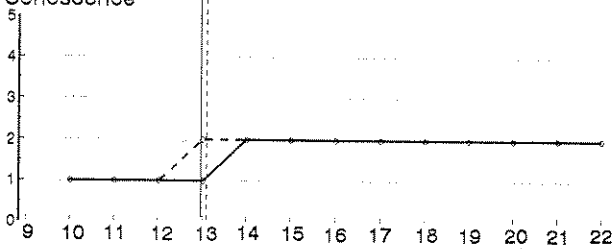
Weight loss (% multiplied by 10)



'Softness'



Senescence



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	5	5	4	4	4	4	4	3	3	3	3	2	1	2
Colour score P(2)	5	5	5	4	4	4	4	4	3	3	3	3	2	2

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		4	4	5	5	5	5	5	5	4	4	4	4	4
Colour score P(2)		4	4	4	4	4	4	4	4	4	4	4	4	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	1	1	1	2	2	2	3	3	3	2	2	3	3
Smell score P(2)	1	1	1	1	2	2	1	2	3	3	2	3	3	4

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		2	1	1	1	2	2	2	2	2	2	2	2	2
Smell score P(2)		2	1	2	2	2	2	2	2	2	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	429	383		
Leaves at Stage 3	20			
'Tightness'	2	2		
Final %dry matter	5.4	6.3		
Int %dry matt (good)			4.8	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	442	462		
Leaves at Stage 3	20	19		
'Tightness'	3	3		
Final %dry matter	5.5	5.4		
Int %dry matt (good)			4.8	
Int %dry matt (poor)				

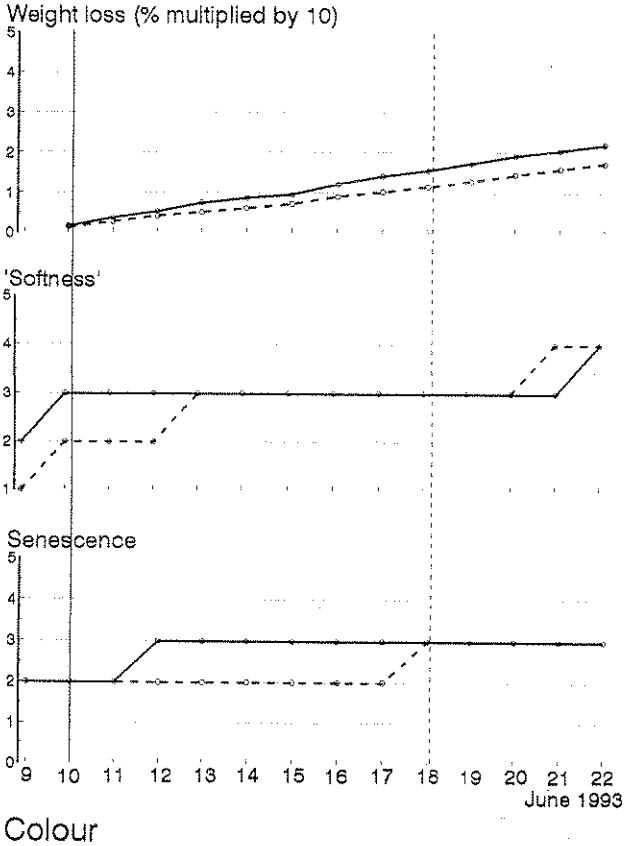
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

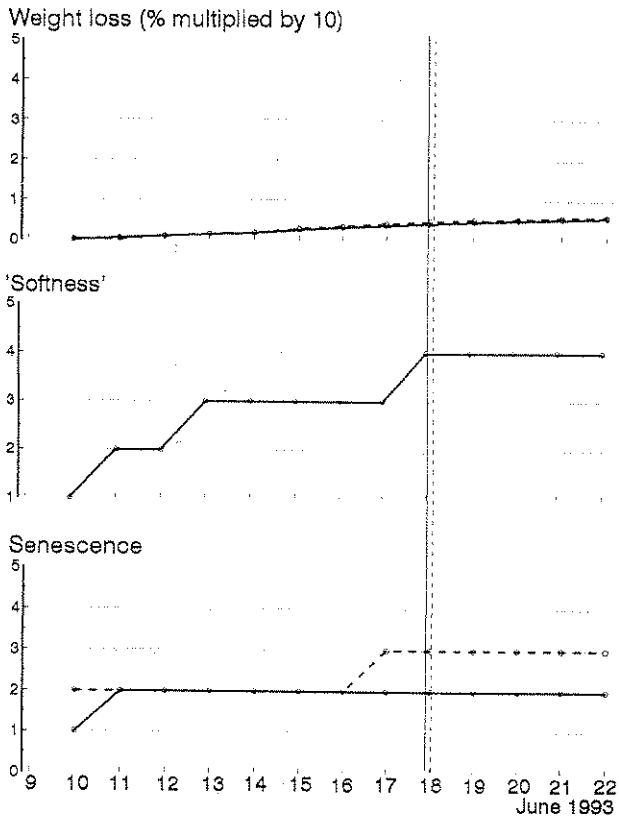
Glasshouse Celery (Sample 12)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	2	1	1	1	1	1	1	1	1	1	1	1	1	1
Colour score P(2)	3	2	2	2	2	2	2	2	2	2	2	2	2	2

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		2	2	2	2	2	2	2	2	2	2	2	2	2
Colour score P(2)		2	2	2	2	2	2	2	2	2	2	2	2	2

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	1	2	1	1	3	2	2	3	3	2	2	3	3
Smell score P(2)	1	1	1	1	1	1	1	2	2	2	2	2	2	2

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		1	1	1	2	2	1	2	1	2	2	2	2	1
Smell score P(2)		2	2	2	2	2	2	1	2	2	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	293	353		
Leaves at Stage 3				
'Tightness'	2	2		
Final %dry matter	5.7	5.0		
Int %dry matt (good)			4.5	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	540	548		
Leaves at Stage 3				
'Tightness'	1	1		
Final %dry matter	4.6	4.6		
Int %dry matt (good)			4.5	
Int %dry matt (poor)				

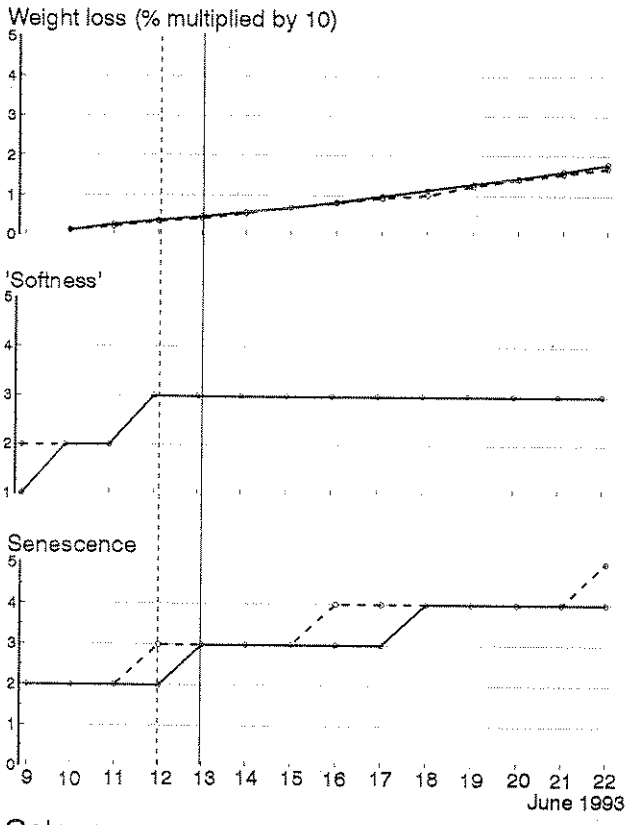
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

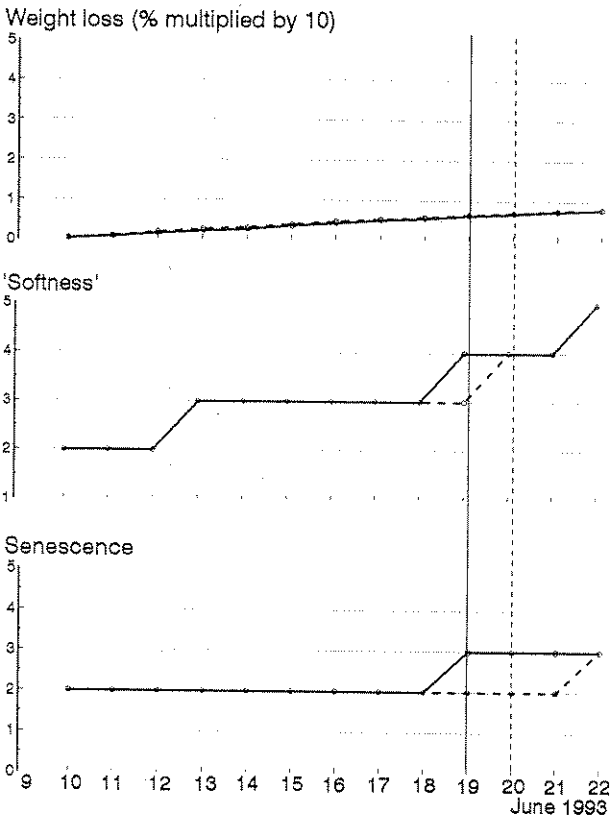
Glasshouse Celery (Sample 13)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	3	2	3	2	2	2	2	1	1	1	1	1	1	1
Colour score P(2)	3	2	2	2	2	1	1	1	1	1	1	1	1	1

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		1	1	1	2	2	2	2	2	1	1	1	1	1
Colour score P(2)		2	2	2	3	3	3	3	3	2	2	2	2	2

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	2	1	2	2	3	2	3	3	2	3	3	4	3
Smell score P(2)	1	1	2	2	2	2	2	2	2	2	3	4	4	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		2	1	1	2	3	3	2	2	1	2	1	2	2
Smell score P(2)		1	2	1	2	2	2	2	2	2	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	581	458		
Leaves at Stage 3				
'Tightness'	1	2		
Final %dry matter	5.0	4.7		
Int %dry matt (good)			4.3	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	543	605		
Leaves at Stage 3				
'Tightness'	3	2		
Final %dry matter	4.8	5.1		
Int %dry matt (good)			4.3	
Int %dry matt (poor)				

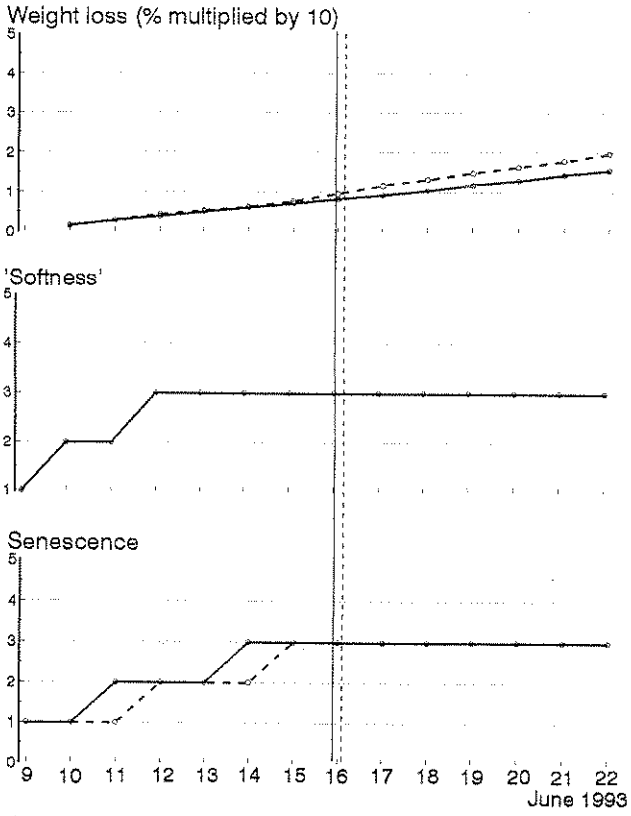
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

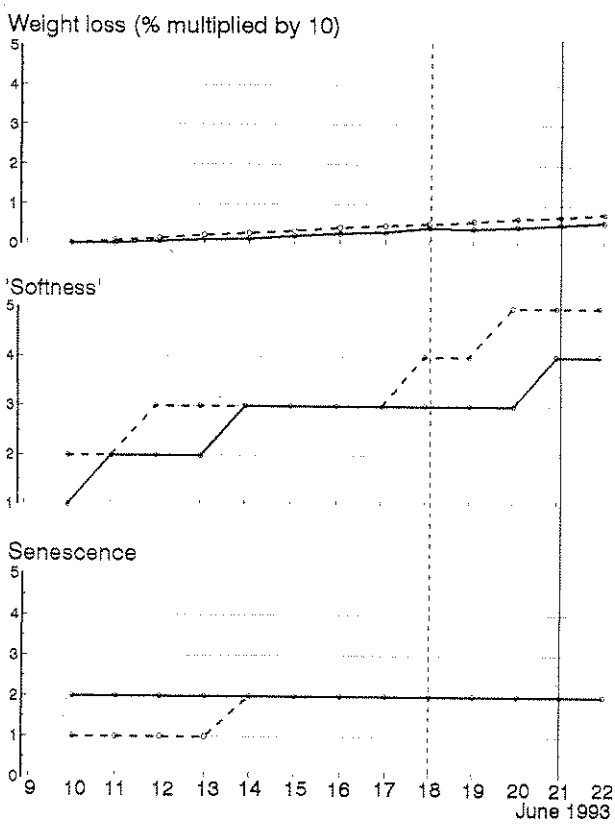
Glasshouse Celery (Sample 14)

Storage treatment

Warm



Cold



Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)	4	3	3	3	3	3	3	3	3	3	2	2	2	2
Colour score P(2)	4	3	3	3	3	3	3	2	2	2	1	1	1	1

Colour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Colour score P(1)		3	3	3	3	3	3	3	3	3	3	3	3	3
Colour score P(2)		3	3	3	3	3	3	3	3	3	3	3	3	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)	1	1	1	1	2	1	1	1	2	1	2	2	2	3
Smell score P(2)	1	2	2	2	2	3	2	2	2	3	2	3	3	3

Odour

Date (June 1993)	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Smell score P(1)		2	1	2	2	2	2	2	1	1	2	2	2	2
Smell score P(2)		1	1	2	2	2	2	1	2	1	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	437	376		
Leaves at Stage 3				
'Tightness'	2	2		
Final %dry matter	5.6	5.9		
Int %dry matt (good)			5.4	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	395	441		
Leaves at Stage 3				
'Tightness'	2	2		
Final %dry matter	5.2	5.7		
Int %dry matt (good)			5.4	
Int %dry matt (poor)				

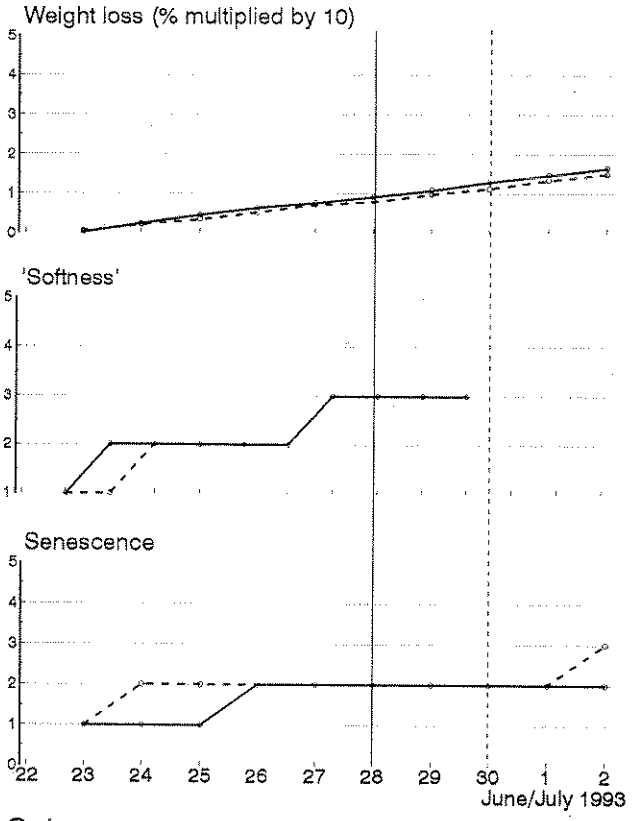
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

Glasshouse Celery (Sample 3, Harvest II)

Storage treatment

Warm



Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	3	3	3	3	3	2	2	2	2
Colour score P(2)		2	2	2	2	2	2	2	2	2	2

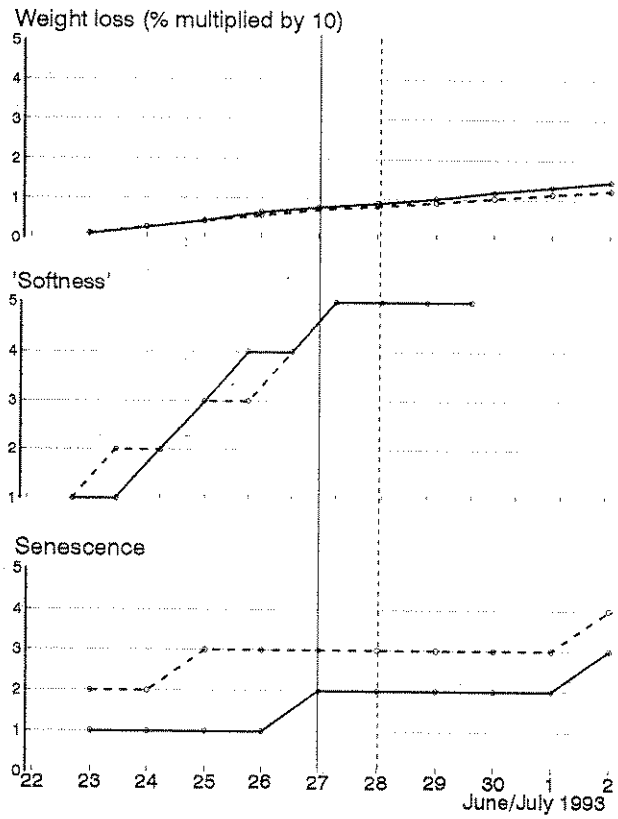
Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		2	2	2	2	2	2	2	2	4	4
Smell score P(2)		2	2	2	2	2	2	3	2	2	3

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	375	288		
Leaves at Stage 3				
'Tightness'	3	3		
Final %dry matter	5.6	5.3		
Int %dry matt (good)			5.4	
Int %dry matt (poor)				

Cold



Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	3	3	3	3	3	3	3	3	2
Colour score P(2)		3	3	3	3	3	3	3	3	3	3

Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		1	1	1	2	2	1	2	2	2	2
Smell score P(2)		1	2	1	1	1	1	2	2	2	1

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	284	374		
Leaves at Stage 3	1			
'Tightness'	3	3		
Final %dry matter	6.5	6.2		
Int %dry matt (good)			5.4	
Int %dry matt (poor)				

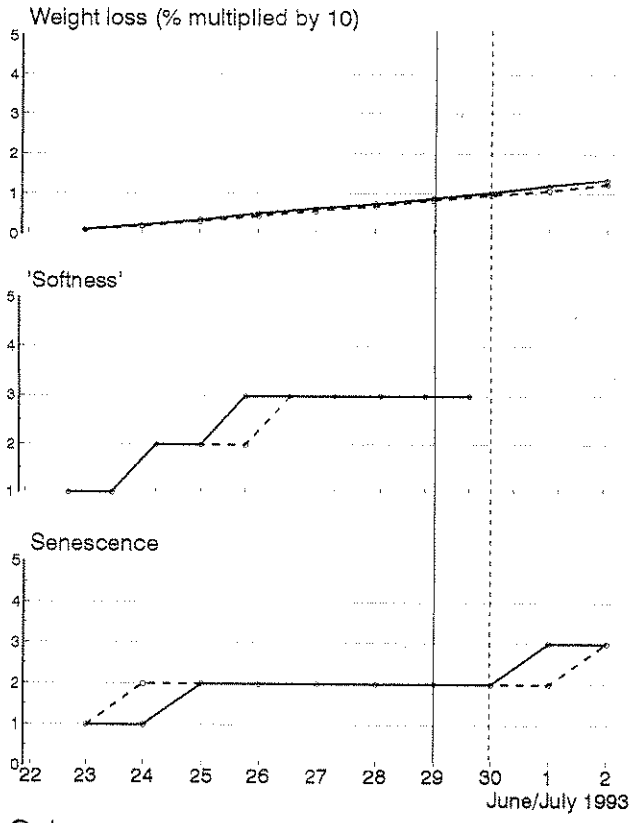
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

Glasshouse Celery (Sample 6, Harvest II)

Storage treatment

Warm



Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	2	2	2	2	2	2	1	1	1
Colour score P(2)		3	3	3	3	3	2	2	2	2	2

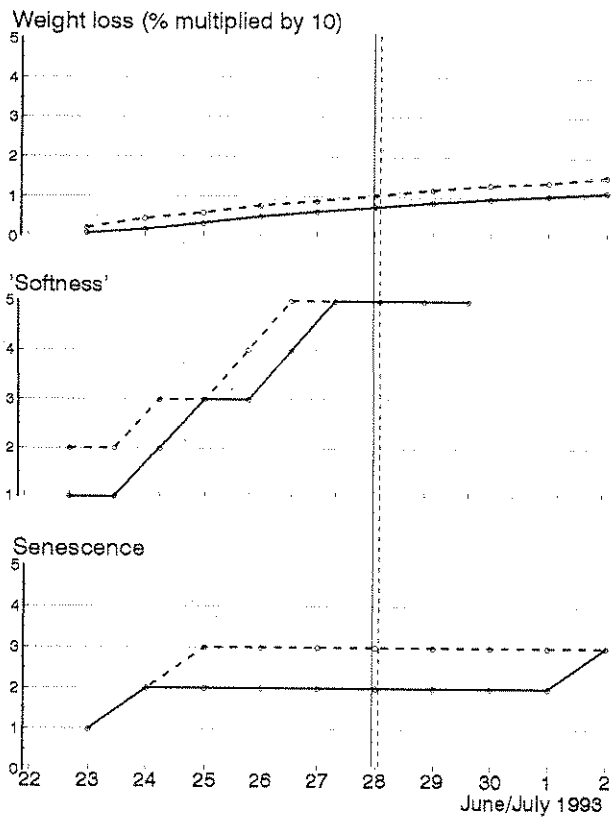
Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		2	2	1	2	1	2	2	2	2	2
Smell score P(2)		2	2	1	2	2	2	2	2	3	4

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	472	495		
Leaves at Stage 3				
'Tightness'	3	3		
Final %dry matter	6.4	5.2		
Int %dry matt (good)			5.2	
Int %dry matt (poor)				

Cold



Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		2	3	3	3	3	3	3	3	3	3
Colour score P(2)		3	3	3	3	3	3	3	3	3	3

Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		1	1	1	1	1	1	1	2	1	2
Smell score P(2)		2	2	1	1	1	2	2	1	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	455	486		
Leaves at Stage 3	30	29		
'Tightness'	3	3		
Final %dry matter	5.7	6.2		
Int %dry matt (good)			5.2	
Int %dry matt (poor)				

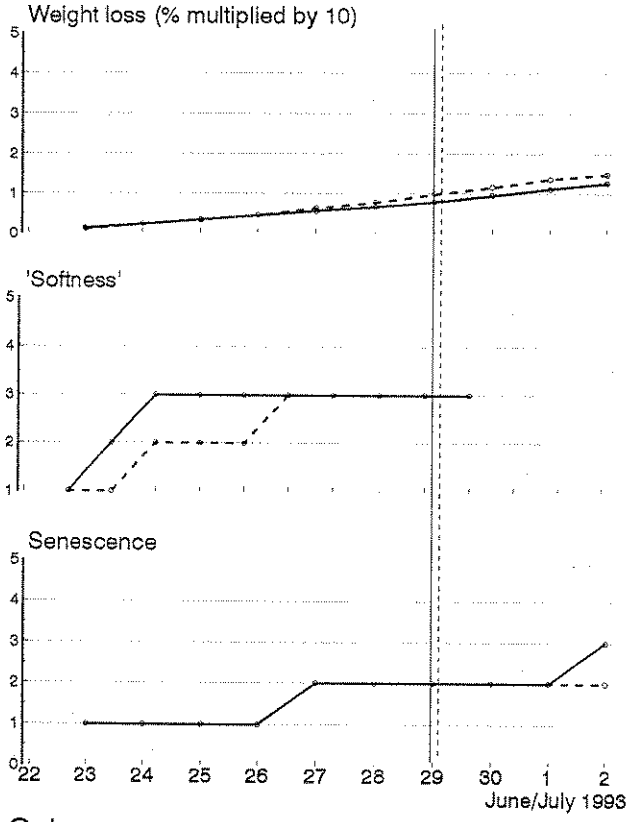
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

Glasshouse Celery (Sample 7, Harvest II)

Storage treatment

Warm



Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	3	3	3	3	2	2	2	2	2
Colour score P(2)		3	3	3	3	3	2	2	2	2	2

Odour

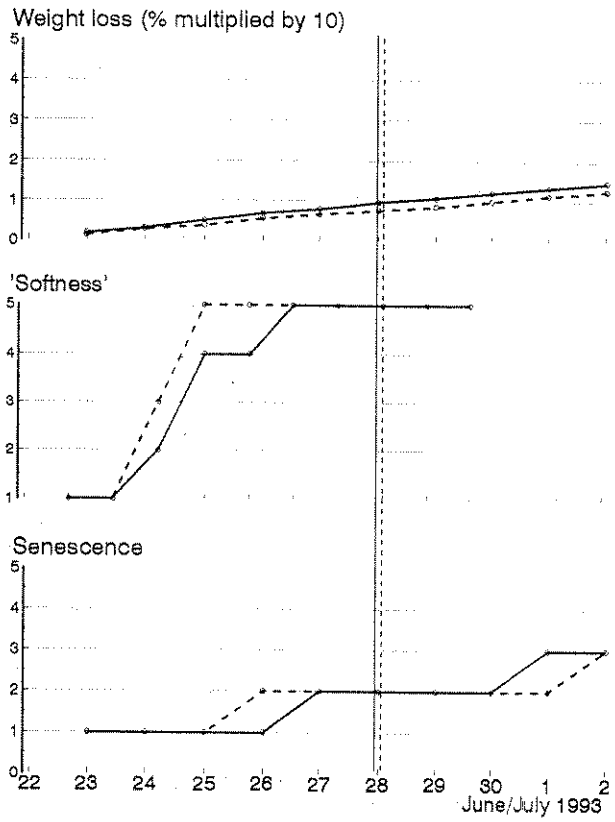
Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		1	1	2	2	2	2	2	2	3	3
Smell score P(2)		1	2	2	2	2	2	3	3	4	3

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	369	299		
Leaves at Stage 3				
'Tightness'	3	2		
Final %dry matter	6.1	6.1		
Int %dry matt (good)			5.3	
Int %dry matt (poor)				

——— Plant 1 (P1) ---------- Plant 2 (P2)

Cold



Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	3	3	3	3	3	3	3	3	3
Colour score P(2)		3	3	3	3	3	3	3	3	3	3

Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		1	2	1	1	1	1	2	2	2	1
Smell score P(2)		1	1	2	1	1	2	1	2	1	2

Additional Information

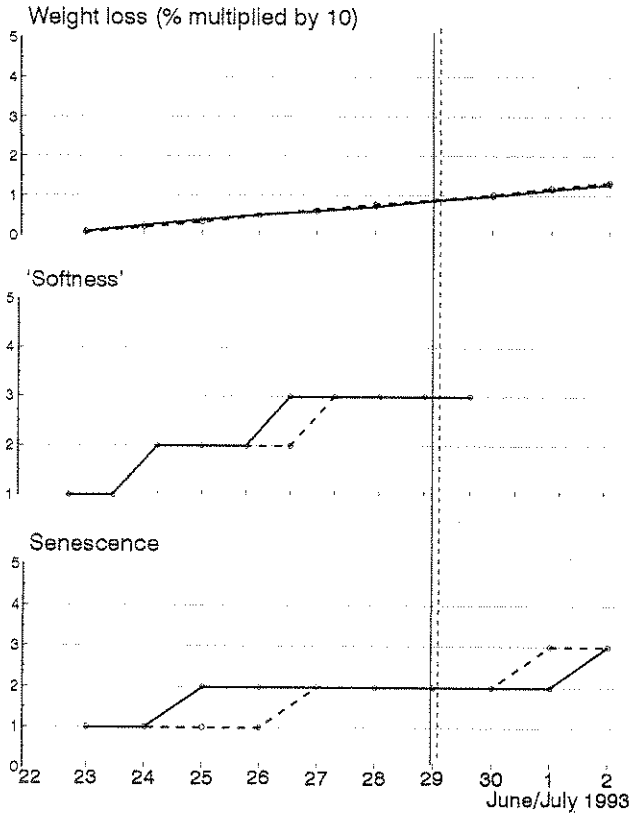
	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	277	280		
Leaves at Stage 3	29	28		
'Tightness'	3	2		
Final %dry matter	6.1	6.3		
Int %dry matt (good)			5.3	
Int %dry matt (poor)				

——— Plant 1 (P1) ---------- Plant 2 (P2)

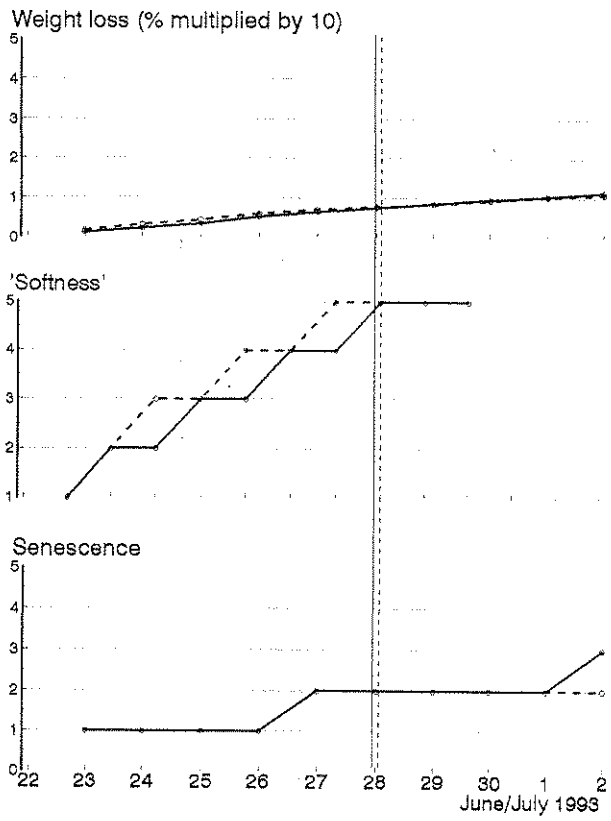
Glasshouse Celery (Sample 8, Harvest II)

Storage treatment

Warm



Cold



Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	3	3	2	2	2	2	2	2	1
Colour score P(2)		3	3	3	3	2	2	2	2	2	1

Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	3	3	3	3	3	3	3	3	2
Colour score P(2)		3	3	3	2	3	3	3	3	3	3

Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		2	1	1	2	2	3	2	3	3	2
Smell score P(2)		2	1	1	1	2	1	2	2	3	2

Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		1	1	1	1	2	2	1	2	1	2
Smell score P(2)		2	2	1	1	1	1	2	2	1	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	500	474		
Leaves at Stage 3				
'Tightness'	3	3		
Final %dry matter	5.4	5.1		
Int %dry matt (good)			5.2	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	456	508		
Leaves at Stage 3	1	30		
'Tightness'	3	2		
Final %dry matter	6.0	5.9		
Int %dry matt (good)			5.2	
Int %dry matt (poor)				

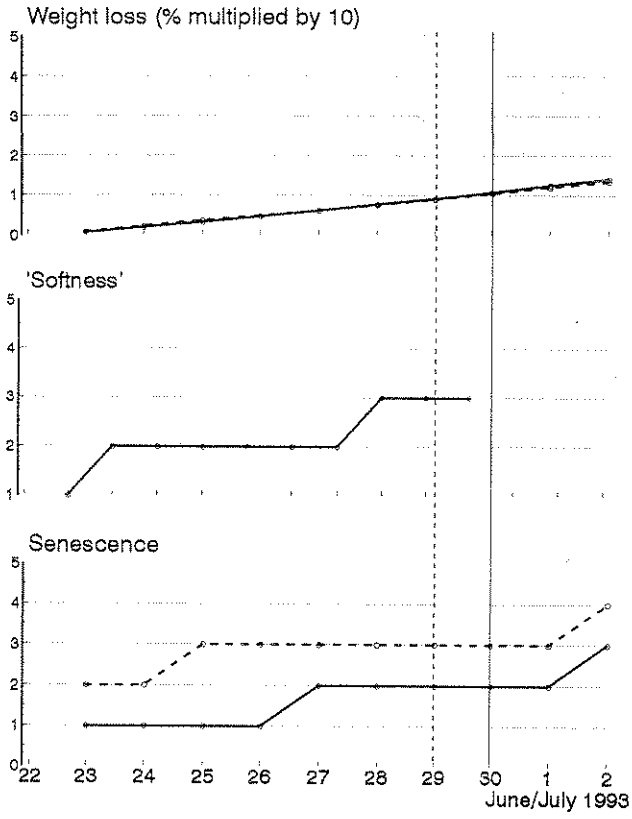
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

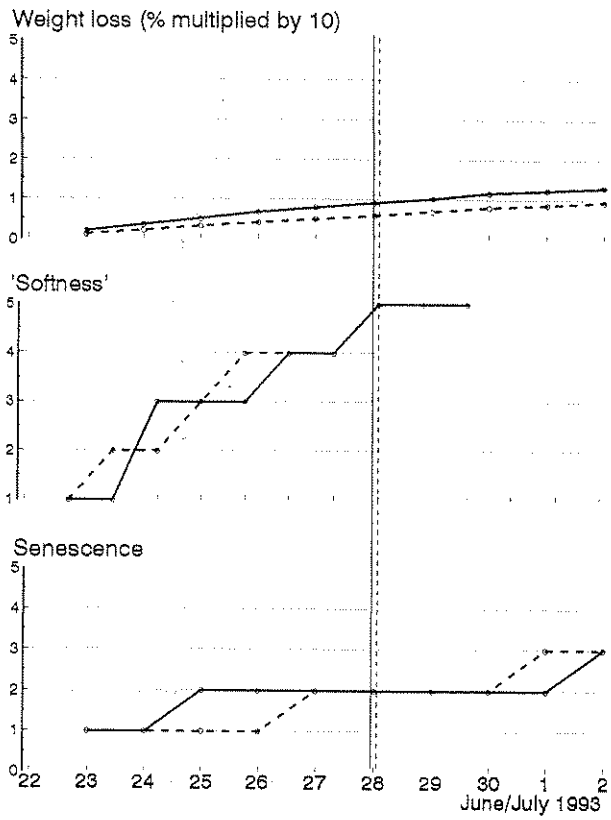
Glasshouse Celery (Sample 12, Harvest II)

Storage treatment

Warm



Cold



Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	3	3	2	2	2	2	2	2	1
Colour score P(2)		3	3	2	2	2	2	2	1	1	1

Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	2	2	2	2	2	2	2	2	2
Colour score P(2)		2	2	2	2	2	2	2	2	2	2

Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		2	2	2	2	3	3	3	3	3	3
Smell score P(2)		2	2	2	2	2	2	3	2	3	3

Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		1	2	2	2	1	2	2	2	2	2
Smell score P(2)		1	1	1	2	1	2	2	2	1	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	595	564		
Leaves at Stage 3				
'Tightness'	2	3		
Final %dry matter	6.4	5.8		
Int %dry matt (good)			5.4	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	488	416		
Leaves at Stage 3				
'Tightness'	2	3		
Final %dry matter	6.4	6.1		
Int %dry matt (good)			5.4	
Int %dry matt (poor)				

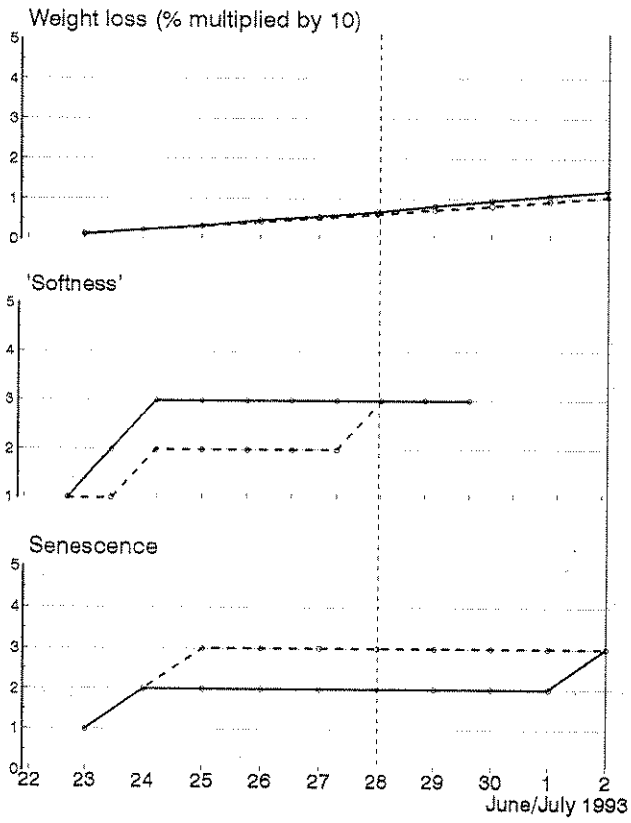
——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

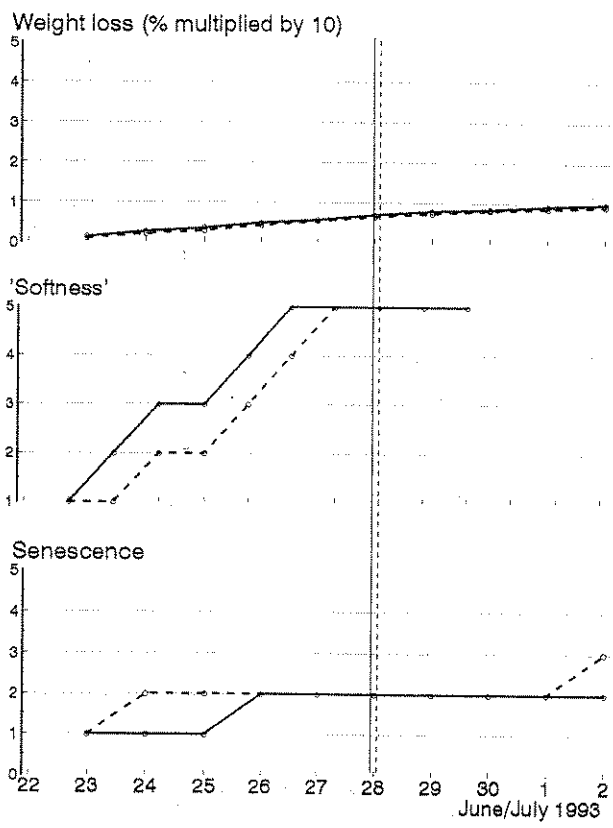
Glasshouse Celery (Sample 13, Harvest II)

Storage treatment

Warm



Cold



Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		4	3	3	2	2	2	2	2	2	1
Colour score P(2)		3	3	3	3	2	2	2	2	2	2

Colour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Colour score P(1)		3	3	3	3	3	3	3	3	3	3
Colour score P(2)		3	3	3	3	3	3	3	3	3	2

Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		2	3	3	3	3	3	3	3	3	3
Smell score P(2)		2	2	2	2	2	3	2	3	4	5

Odour

Date (Jun/Jul 1993)	22	23	24	25	26	27	28	29	30	1	2
Smell score P(1)		1	2	2	2	2	2	2	2	1	2
Smell score P(2)		1	2	2	1	2	2	2	2	2	2

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	552	820		
Leaves at Stage 3				
'Tightness'	3	2		
Final %dry matter	7.1	5.8		
Int %dry matt (good)			5.0	
Int %dry matt (poor)				

Additional Information

	Plant 1	Plant 2	Other Plants	Other Plants
Initial Fresh Wt	744	534		
Leaves at Stage 3				
'Tightness'	3	2		
Final %dry matter	6.3	7.0		
Int %dry matt (good)			5.0	
Int %dry matt (poor)				

——— Plant 1 (P1) ---------- Plant 2 (P2)

——— Plant 1 (P1) ---------- Plant 2 (P2)

Contract between HRI (hereinafter called the "Contractor") and the Horticultural Development Council (hereinafter called "Council") for research/development project.

PROPOSAL

1. TITLE OF PROJECT

Contract No: PC84
Contract date: 21.5.93

PROTECTED CELERY - IMPROVEMENT OF QUALITY OF BRITISH PRODUCE

2. BACKGROUND AND COMMERCIAL OBJECTIVE:

Early protected crops occupy a potentially profitable niche in the overall celery market, though there can be problems with the variable quality of 'sticks' and the notoriously unpredictable market returns. Climatic conditions in some areas like the South Coast of England are particularly favourable for producing the early heated crops. These are harvested and marketed from late April to June when consumer demand is strong, imports are relatively weak, and supplies of English field celery are unavailable. However, British growers need to continually improve the quality of their produce in order to maintain a competitive edge over foreign rivals. This is especially important in the context of a single market within the EEC.

3. POTENTIAL FINANCIAL BENEFIT TO THE INDUSTRY

Supplies of celery to the UK market totalled nearly 86,000 tonnes in 1991, with English protected and field crops accounting for 13% and 57% of the tonnage respectively. Imports (mainly from Spain, Israel and USA) have risen steadily during the past decade and in 1991 totalled 25,300 tonnes (excluding those from the Channel Islands) with a market value of £12.8 million. Clearly, there are opportunities for import substitution, especially from late April to June when about 2,750 tonnes of celery (mainly from Spain) enter the UK. It has been estimated that it would need an extra 30-40 hectares of cropping under protected cultivation for the market to be served solely by British celery during May. This would create new business opportunities for both capital and labour, and could increase the present area (164 hectares) of home production by about 15-25%, or about £1 million to £1.7 million in terms of likely output value. In this context, it is essential that the quality of British produce is second to none.

4. SCIENTIFIC/TECHNICAL TARGET OF THE WORK

The aims of the project will be:

(i) to identify the main quality defects of British celery,

(ii) to suggest possible solutions to 'simple' problems,

(iii) to identify where research and development (R & D) may be required to solve problems of quality defects in celery, and

(iv) to prioritize future R & D requirements in order to ensure efforts are directed to those areas which will have the greatest benefit for industry.

5. CLOSELY RELATED WORK COMPLETED OR IN PROGRESS

Historically, funding of research and development on the glasshouse celery crop has been extremely modest by comparison with other protected crops. During the late 1980s the main research efforts were directed to the prevention of 'bolting' in early heated crops and to the use of micro-organisms for the biological control of *Sclerotinia* disease. Both of these topics are relevant to improving the quality of British celery. Bolting (ie the rapid elongation of the main stem coupled with the premature development of flower stalks from a previously initiated umbel type of inflorescence) makes the celery unattractive to the market. At harvest this leads to excessive wastage, a high proportion of second grade sticks and concomitantly reduced income. Similar results are obtained when developing plants are infected by the soil-borne pathogen, *Sclerotina sclerotiorum*. The disease which causes butt rot of celery can be particularly troublesome on crops grown immediately after lettuce.

Losses from bolting in early celery crops can reduce the amount of produce marketed by 5-10% and cost the industry between £0.25 million and £0.5 million in a normal season. Researches at the GCRI demonstrated that by using 'night-break' lighting (similar to that used for the 'year-round' production of chrysanthemums) it is possible to delay or inhibit flower initiation in early heated crops. The pattern of night-break lighting which gives the most efficient control of bolting at lowest cost was established for growers. Further, by taking advantage of the cheapest electricity, it was shown that the overall operating costs of night-break lighting could be kept to within about 5% of the likely market price for high quality sticks of celery. The work on bolting and *Sclerotinia* was the subject of a commodity review in Report of the Glasshouse Crops Research Institute 1986-87, pp 37-40.

There is neither AFRC nor MAFF-funded work on quality defects in British celery. Indeed, there has been no public funding of research in protected celery since the demise of the ADAS/AFRC Integrated Programme of Horticultural Research and Development in 1989.

6. DESCRIPTION OF THE WORK

The main works of the project will be:

(i) To instigate an authoritative search of the scientific literature relating to quality defects in protected (and field celery),

(ii) to review previous researches on quality defects in protected celery which were carried out at both the former Glasshouse Crops Research Institute and the former Experimental Horticulture Stations of ADAS,

(iii) to liaise with British growers and visit various glasshouse nurseries (mainly in the South Coast area) in order to discuss problems of both pre- and post-harvest quality defects in early protected celery crops,

(iv) to correspond with major retailers and marketing co-operatives in order to obtain a 'customer' view of different problems and their relative importance,

(v) to conduct a preliminary assessment of the 'quality' of local samples of protected celery (Note: local producers would be invited to provide fortnightly samples of marketable sticks of celery that are either of potentially good or indifferent quality. Assessments of quality would be made at HRI Littlehampton and could include such aspects as appearance, texture, flavour and storage), and

(vi) to write and submit a report covering the above. The report will identify the main quality defects of British celery and suggest possible solutions to simple problems where the information is available. The R & D requirements needed to solve the more complex problems will also be identified and prioritized.

7. COMMENCEMENT DATE AND DURATION

Start date 01.05.93; duration five months.

The final report will be produced by 30.9.93.

8. STAFF RESPONSIBILITIES

Project leader: D W Hand (HRI, Littlehampton).

Other staff: C J W Talent (ADAS, Chichester) and G E Hobson (HRI, Littlehampton).

9. LOCATION

HRI, Littlehampton
ADAS South Coast Glasshouse and Mushroom Advisory Unit (Chichester).

Contract No: PC/84

TERMS AND CONDITIONS

The Council's standard terms and conditions of contract shall apply.

Signed for the Contractor(s)

Signature.....
Position..Commercial & Marketing Manager HRI
Date.....21/6/93.....

Signed for the Contractor(s)

Signature.....
Position.....
Date.....

Signed for the Council

Signature.....
Position.....CHIEF EXECUTIVE
Date.....21.5.93.....