EFFECTS OF POTASSIUM FERTILIZATION AND PERIDERM DAMAGE ON SHELF LIFE OF CARROTS

by

REBECCA CHEMUTAI BIEGON

B.Sc. Agric. (Hons), The University of Nairobi, Kenya, 1980

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

(Department of Plant Science)

We accept this thesis as conforming
to the required standard

UNIVERSITY OF BRITISH COLUMBIA

March, 1995

© REBECCA C. BIEGON

In presenting this thesis in partial fulfilment of the requirements for an advanced degree at the University of British Columbia, I agree that the Library shall make it freely available for reference and study. I further agree that permission for extensive copying of this thesis for scholarly purposes may be granted by the head of my department or by his or her representatives. It is understood that copying or publication of this thesis for financial gain shall not be allowed without my written permission.

Department of Plant Science

The University of British Columbia
Vancouver, Canada

Date 3/4/95

DE-6 (2/88)

Abstract

Short shelf life has caused a decline in the sale of B.C.-grown carrots from 8.1 million kgs in 1987 to 6.1 million kgs in 1990. This is due to greater postharvest water loss of B.C.-grown carrots compared to those from California and Washington. The aim of this study was to improve our understanding of the factors affecting carrot water loss by (1) establishing a procedure to measure surface area of carrot roots, (2) determining the effect of K fertilization on carrot growth, yield and water loss, and (3) determining the effects of periderm damage and interaction between periderm damage and K fertilization on water loss of carrots.

Baugerod (1993), slicing and surface replica methods for determining surface area of carrot roots were compared using eight carrot varieties on two harvests, and on size grades small, medium, and large of carrots. Surface area values using the three methods were statistically different but the variation was less than 6%. Baugerod method is applicable to carrots of different sizes and can therefore be used to determine surface area of carrots.

Carrots were fertilized with five levels of KCl and one level of K_2SO_4 on muck soil, and stored at 13^0C and two levels of relative humidity (RH) to assess the effect of rate and source of K on carrot growth, yield, and water loss. Five levels of carrot periderm damage were used to study the effect of periderm damage on water loss. The rate and source of K had no significant effects on growth and water loss. No significant effects of interaction between rate of application of KCl and periderm damage on water loss were observed. Increase in rate of KCl significantly reduced marketable yields probably due to a reduction in carrot stand. KCl significantly reduced marketable yield of carrots compared with K_2SO_4 applied at same rate. Periderm damage and low RH significantly accelerated water loss and thereby reduced the shelf life of carrots in storage.

It was concluded that there was adequate K in muck soil in Cloverdale area (B.C.) to meet carrot requirement, and that K fertilization is unnecessary. The short shelf life of B.C.-grown carrots is likely due to periderm damage and/or storing of carrots at low RH. It could be extended by minimising periderm damage and/or storing carrots at high RH to reduce water loss, hence improving their acceptability.

Table of Contents

List of Tables

List of Figures

List of Appendix

Acknowledgement

I wish to thank the Government of Kenya for granting my study leave and the arrangement for my CIDA scholarship.

My deepest gratitude goes to my research supervisor, Dr. M.K. Upadhyaya, for his guidance, patience, and support during the course of the study. I am grateful to the other members of my research committee, Drs A. Bomke and P.M.A. Toivonen, for their valuable advice and constructive criticisms.

I appreciate the assistance of Drs. G.W. Eaton and A. Kozak, and Soenarto for their assistance on statistical data analysis.

My sincere thanks go to commercial growers, Mr Ray Wang and Mr Wayne Wang, for providing the field for my study and for their assistance during this study.

My friends deserve recognition for their physical and spiritual support throughout this study. Special thanks to Joyce Maina and Jennifer Khamasi for their friendship, encouragement and readiness to help any time I needed support. The tremendous amount of assistance rendered by my colleagues in the laboratory and in particular Eliza, Preeti, Upenyu, Solomon, Mesfin, and Nancy is greatly appreciated. My sincere thanks also to the Kenyan community in University of British Columbia for their endless help in the field and laboratory work. Much thanks to my fellowship group for their prayers and spiritual encouragement.

I thank my parents; late father Wilson, and mother Rachel, for their constant encouragement and support through my early years in school without which nothing like this would ever have been possible.

I dedicate this thesis to my loving husband David, and our children Dennis, Donald, Derrick, and Ruth in appreciation of their love, encouragement, support, and endurance during my stay away from them which made the study successful.

To God be the Glory for renewing my strength every morning.

Chapter 1. General Introduction

Carrots (*Daucus carota L.*) are a major vegetable crop of the world. In 1992, Canada was the tenth largest producer of carrots in the world (FAO, 1993). It is the third most important vegetable in Canada with a total annual production of 254,900 tonnes (Nonnecke, 1989). In Canada, British Columbia (B.C.) ranks third in production after Ontario and Quebec. Carrots in B.C. are grown in the lower mainland and Vancouver Island. In 1990 about 6.1 million kgs of topped carrots worth slightly over 2.8 million dollars were produced in B.C. (Anon., 1991).

Currently, carrot varieties produced for topped fresh market in B.C. include Super Nantes, Paramount, Top-Pak, Gold-Pak, Eagle, Apache, Caro-choice and Cimmaron (Anon., 1993).

The carrot industry in B.C. faces increased competition especially from California and Washington. Retailers prefer California-grown carrots, due to their longer shelf life, compared to B.C.-grown carrots. Consequently, B.C.-grown carrots' acceptability, which is defined as the level of continued purchase or consumption by a specified population (Land, 1988), has declined. As a result, total sale of B.C.-grown carrots has declined from over 8.1 million kgs worth over 3 million dollars in 1987 to 6.1 million kgs worth over 2.8 million dollars in 1990 (Anon., 1991).

Shelf life of carrots can be defined as the time period carrots can stay on the shelf while maintaining acceptability to the consumer (Dennis, 1981). It has become an important aspect of carrot marketing and more study on the factors that influence it is necessary to arrest and reverse the declining sales of B.C.-grown carrots.

Short shelf life of B.C.-grown carrots is attributed to their greater moisture loss which results in wilting, shrinkage, and loss of firmness, crispness, and succulence, which are indicators of freshness (Ben-Yehoshua, 1987). Most vegetables lose freshness when they lose 3 to 10% of fresh weights because of moisture loss (Burton, 1982; Robinson et al., 1975). These low percentages indicate the significance of transpiration in determining the shelf life of vegetables (Ben-Yehoshua, 1987). Transpiration is influenced by commodity characteristics and environmental factors such as temperature, relative humidity, air velocity, and atmospheric pressure (Apeland and Baugerod, 1971; Apeland and Hoftun, 1974; Berg and Lentz, 1973; Sastry et al., 1978; Sastry and Buffington, 1982).

Rates of transpiration from vegetables vary due to differences in surface-to-volume ratio, and in rates of water permeation from the evaporating surface (Burton, 1982; Sastry et al., 1978). Physical characteristics are governed by genotype, and may be affected by agronomic practices. The size and shape of a vegetable affect transpiration through their effects on surface-to-volume ratio. Large commodities lose less moisture on per unit weight basis than smaller ones. Long, thin, cone-shaped carrots lose more weight than cylindrical carrots in a given environment because of their greater surface area per unit volume (Sastry et al., 1978). In order to express moisture loss per unit surface area , it is important to establish an accurate method for surface area measurement.

Vapour pressure deficit (VPD), defined as the difference in RH between produce and storage environment, is the primary factor controlling the rate of moisture movement between vegetables and storage atmosphere (Kays, 1991). The VPD of plants depends on the temperature and the amount of solutes in the tissue (Nobel, 1974; Wells, 1962). Plants with low solute concentration have high osmotic potential and lose water easily (Salisbury and Ross, 1992). Dhindsa et al. (1975) showed that potassium (K) and malate account for 50% of the osmotic potential in cotton fiber. Most of the water loss in plants occurs through the stomatal opening, and the turgor of guard cells is related particularly to the uptake of K ions (Humble and Hsiao, 1970; Humble and Raschke, 1971). The involvement of K in osmotic potential and stomatal opening indicate the importance of K in water economy of plants. Brag (1972) observed higher rates of transpiration in K deficient plants. Steingrover (1983) observed that K, organic acids and soluble sugars contribute to osmotic potential of carrots. The role of K in moisture loss characteristics of carrots is not known. It would be of interest to determine if K fertilization could improve shelf life of B.C.-grown carrots by reducing their postharvest moisture loss.

Mechanical injury is the major cause of postharvest deterioration in root crops (Kader, 1983). Surface injuries, impact bruising, and vibration bruising may occur during transportation and in packing houses. They result in localized increase in respiration at the site of injury, stress-induced ethylene production, accumulation of secondary metabolites, and decompartmentalization of enzymes and substrates (Macleod et al., 1976; Rolle and Chism, 1987). Mechanical injuries are unsightly, accelerate water loss and provide loci for fungal infection (Kader, 1985).

Carrot anatomy may be playing a role in moisture loss from carrots. The outer layer of the carrot root is covered with a periderm which regulates moisture loss (Den Outer, 1990). Esau (1940) showed that the upper portion (<2.5 cm) of the carrot is actually hypocotyl tissue. This portion of carrots has stomates which may act as avenues for moisture loss. Periderm damage accelerates moisture loss and reduces shelf life (Apeland, 1974). The level of periderm damage may be reported as ratio of damaged area to non-damaged area. Surface area influences moisture loss in carrot roots (Ben-Yehoshua, 1987; Sastry et al., 1978; Wills et al., 1989). Part of this study will focus on establishing a rapid, non-destructive, and accurate procedure to measure surface area of carrot roots .

The farmer uses fertilizer in order to maximise profits. To achieve this aim, fertilizers must be applied in adequate quantities and the balance between nutrients must be correctly adjusted. It is generally believed that carrot growers in B.C. may be applying excess K which may not have any positive effect on yield. Furthermore, even if there is a positive effect on yield, it may possibly be negated by an adverse effect on the shelf life. Excess K may cause a luxury consumption by carrots, leaching and runoff which are wasteful and may harm environment, or nutrient imbalance which may cause deficiency of other cations. The amounts of fertilizer applied should give the best production, ensure nutrient availability to the crop and minimise waste over the growing period. The research presented in this thesis would provide information useful in advising carrot growers on appropriate K fertilization. This would reduce the cost of production without necessarily affecting yield and shelf life.

Percent weight loss has been reported as an indicator of physical damage caused by various harvesting and handling systems (Abrams et al., 1978; Kushman, 1975). Mechanical damage has been reported to decrease the storability of carrots (Apeland, 1974; Tucker, 1974). Whether short shelf life of B.C.-grown carrots could be due to periderm damage is not known. Knowledge on the extent of damage that can have a significant effect on carrot shelf life can be used to improve postharvest handling methods and extend the shelf life of carrots. An understanding of the effect of K fertilization on resistance of carrots to damage can be used in establishing the appropriate fertilization rates which can be passed on to the carrot growers. The contribution of periderm damage to short shelf life of B.C.-grown carrots remains to be investigated.

Research Objectives

The overall objective of this study is to improve our understanding of factors affecting the shelf life of carrots. The specific objectives are to:

1. establish a procedure to measure surface area of carrot roots,
2. determine the influence of K fertilization on carrot root yield and water loss, and
3. determine the effects of periderm damage and interaction between periderm damage and K fertilization on water loss of carrots.

Chapter 2. Literature Review

A. Characteristics and Quality of carrots

Characteristics and Ecology

Carrot (*Daucus carota* L.) originated from middle Asia (Peirce, 1987; Salunke and Desai, 1984). It is a dicotyledonous, herbaceous, biennial vegetable of Apiaceae (umbelliferae) family (Peirce, 1987; Salunke and Desai, 1984). In the first year of growth, it forms a tight rosette composed of double compound leaves and a thickened taproot. The carrot root is composed of enlarged hypocotyl and prominent fleshy taproot with a distinct light-coloured xylem (core), and deep orange phloem to the outside (Esau, 1940). The shoot elongates during the second year to form a 2 to 3 ft high flower stalk and whitish insect-pollinated flowers. The seeds are spiny, hooked, and slightly curved.

Although carrot is a cool season crop, it can be grown in a wide range of climates. Environmental conditions during growth affect the colour and shape of carrot roots (Whitaker et al., 1970). Temperature range of 15.5°C to 21.1°C is optimum for carrot growth and development, colour and shape (Barnes, 1936; Bradley and Smittle, 1965; and Bradley et al., 1967). Supra- and sub-optimal temperatures reduce vegetative growth and result in strong flavoured, poor coloured and long and tapered roots. It can grow in a variety of soils but muck and sandy loams are the best. Deep, well drained, aerated, and loose soils free of clods and rocks with a pH of 5.5 to 7.0 are desirable for carrot root growth (Olymbios and Schwabe, 1977). Short, blunt, abruptly tapered and defective roots are produced where soils are shallow, compact and warmer than 25°C (Olymbios and Schwabe, 1977; Strandberg and White, 1979; Thompson, 1969). Roots become more cylindrical in dry soil (Barnes, 1936; Bradley et al., 1967).

Importance of carrots

Carrot is an important vegetable in our diet. It can be eaten raw or cooked in a variety of ways (baked, boiled, steamed, fried, diced, roasted, sauteed, and pickled (Nonnecke, 1989). Carrots supply dietary fibre important for roughage in digestion and in regulation of bowel movements. It has a high nutritive value, being a good source of vitamins and minerals, and breaks the monotony of basic diets by adding rich colour, aroma and savour to vegetable salads, juices, soups and desserts (Sarkar and Phan, 1979; Salunke and Desai, 1984).

Quality attributes of carrots

Aesthetic value and appearance are important in fresh market carrots and vegetables (Howarth et al., 1990). Diameter, length, shape, and external appearance are the quality grading attributes of carrots (Anon., 1980; Benjamin and Sutherland, 1989; OECD, 1976; USDA, 1965). Colour, crispness, firmness, and succulence are some of the features that consumers use as a measure of freshness and indicators of shelf life

(Ben-Yehoshua, 1987). Crisp, sweet, and deep yellow or orange carrots are considered desirable for fresh market (Ryall and Lipton, 1979). These marketing parameters determine the price and acceptability of carrots by the consumers. Unfortunately, moisture loss affects these physical features (Phan et al., 1973) hence, it is a critical factor in storage life of carrots.

B. Shelf life of vegetables

Definition of shelf life

Shelf life (synonyms: storage life, storability) can be defined as "the time period a vegetable product can stay in storage and/or retail shelf while maintaining acceptability to consumer, like produce harvested at an optimum stage for immediate consumption" (Dennis, 1981). Shewfelt (1986) defined shelf life as "the time period that a product can be expected to maintain a predetermined level of quality under specified storage conditions".

In this study, shelf life is defined as the number of days carrots can stay at specified storage conditions before they attain the maximum permissible moisture loss which is 8% of the initial root weight (Robinson et al., 1975).

Factors affecting shelf life of vegetables

Shelf life of vegetables can be influenced by variety, cultural practices including fertilization, climatic factors during development, degree of ripeness at harvest, and handling and environmental conditions after harvesting (Gorini, 1987).

Shelf life of vegetables, be they roots, leaves, flowers, immature and mature fruits, is shortened by biological (internal) deterioration due to metabolic changes associated with development, maturation and senescence, transpiration, and/or incidences of physiological and pathological disorders (Ben-Yehoshua, 1987; Dennis, 1981; Kader, 1983; Robinson et al., 1975). The rate of biological deterioration depends on various environmental (external) factors: temperature, RH, and atmospheric composition and pressure (FAO, 1981; Harvey, 1978; Rhodes, 1980; and Tindall and Proctor, 1980). The relative importance of the factors influencing postharvest deterioration varies considerably for different vegetables (Kader, 1983; Robinson et al., 1975).

Harvested vegetables, like other living plant structures, respire and transpire. Respiration causes loss of food reserve in the tissue, taste (especially sweetness), and food value to the consumer. The heat produced in respiration further affects the produce. Rate of respiration is affected by type and stage of development of harvested product, mechanical damage, and environmental factors such as temperature and oxygen and carbon dioxide concentrations (Kader, 1987). Respiration rate can be used as an index of storage life of a crop; high rate corresponding to short life, and low rate to long life (Robinson et al., 1975). Respiration rate above 100 mg $C0_2$/kg/hr reduces storage life (Scholz et al., 1963).

Moisture loss by transpiration causes wilting, shrinkage, and loss of firmness, crispness, and succulence (Ben-Yehoshua, 1987). Transpiration induces water stress which accelerates senescence of vegetables as indicated by a faster rate of membrane disintegration and leakage of cellular contents (Ben-Yehoshua et al., 1983). Transpiration rate is influenced by produce characteristics (shape, surface structure, physical and physiological conditions), and packaging (Fockens and Meffert, 1972; Kader, 1985; Sastry, 1985), and environmental factors namely: temperature, RH, air velocity, and atmospheric pressure (Kader, 1985).

Weight loss by transpiration is greater in produce with a high surface area-to-volume ratio (Burton, 1982; Wills et al., 1989). The driving force of moisture movement in vegetables is water vapour pressure deficit (WVPD) which reflects the difference between the humidity in the tissues and the humidity of the surrounding air (Kays, 1991). Low RH enhances moisture loss. However, at a given RH, water loss increases with increase in temperature. The water-holding capacity of air increases as the temperature rises; hence, air at 90% RH and 10°C contains more water by weight than air at 90% RH and 0°C (Gaffney, 1978).

Microbial attack is a common and obvious symptom of quality deterioration of vegetables. Temperature, pH, and RH, oxygen and carbon dioxide concentrations in the atmosphere, availability of nutrients, and competition from other microbes are some of the factors that affect microbial survival, growth, and pathogenicity (Brackett, 1993; Cook and Papendrick 1978). Most microorganisms grow best (or primarily) at ambient temperatures of 10 to 40°C, below and above which their growth is adversely affected. Carbon dioxide concentration of 5% suppresses microbial growth (Daniels et al., 1985), but this effect is temperature dependent being most effective at low temperatures and less effective as the temperature increases (Jay, 1986). Moisture condensation on the surface of produce enhances decay (Eckert, 1978).

C. Effects of potassium fertilization on vegetable crops

Functions of potassium in vegetables

Potassium (K) is absorbed and required in large quantities by most crops (Daliparthy et al., 1994; Evans and Sorger, 1966; Heimer et al., 1990; Mengel and Kirkby, 1987; Leonard, 1985). It is not a structural element but performs important biophysical and biochemical functions in plants (Beringer, 1980).

The major role of K in the regulation of metabolic processes is through its catalytic activation of more than 60 enzymes (Evans and Sorger, 1966; Marschner, 1983; Suelter, 1970, 1974, 1985) involved in photosynthesis and respiration (Huber, 1985), and protein synthesis (Blevins, 1985; Evans and Wildes, 1971; Mengel and Kirkby, 1987; Wyn Jones and Pollard, 1983). K improves nitrogen utilization by enhancing utilization of amino acids for protein synthesis (Barker and Bradfield, 1963; Xu et al., 1992). K is also necessary for enzymatic activities which regulate physiological processes such as water uptake, water relations in plant tissue, meristematic growth, and long distance transport through phloem and xylem (Mengel, 1985).

Potassium promotes dry matter accumulation through its action on phosphorylation, stomatal opening, enzyme activation, phloem loading and photosynthate transport from source to user points (Beringer et al., 1989; Demmig and Gimmler, 1983; Giaquinta, 1979; Lang, 1983; Liebhardt, 1968; Peoples and Koch, 1979; Wolswinkel and Ammerlaan, 1985).

It is the most abundant cation in plants (Sekhon, 1985; Suelter, 1985), and plays an important role in turgor-related processes (Zeiger, 1983) such as cell extension and stomatal movement, and as a high mobility carrier of charges. It accumulates in cell vacuole where, with sugars, it contributes to osmotic pressure, water uptake, and turgor potential (Beringer, 1980; Mengel and Arneke, 1982). K uptake into the guard cells increases turgor pressure causing the opening of the stomata (Ben-Zioni et al., 1971; Humble and Raschke, 1971; Lips et al., 1987; Raschke, 1979; Touraine et al., 1988). Lower water loss of plants grown with adequate K has been reported (Brag, 1972). K is important for pH stabilization and neutralization of negative charge of organic acids and inorganic anions such as Cl^- and SO_4^{2-} (Bennett, 1993).

Potassium is essential in meristematic growth through its involvement in maintenance of optimum osmotic potential and turgor pressure required for cell expansion, and by enhancing the effect of phytohormones involved in growth of meristematic tissues (Cocucci and Dalla Rosa, 1980; Dela Guardia and Benlloch, 1980; Dhindsa et al., 1975; Green, 1983; Jacobi et al., 1973; Mengel and Arneke, 1982).

Adequate K nutrition improves tissue stability and crop resistance to lodging, pests and diseases through thickened leaf cuticle and epidermal cell walls, stimulation of lignification and silicification, and by its influence on metabolism in plants (Beringer and Nothdurft, 1985; Perrenoud, 1990; Trolldenier and Zehler, 1976).

Deficiency symptoms of K

Potassium deficiency occurs frequently on soils which are light and sandy, acid, and lateritic (organic or peat, soils with kaolinite as the main clay mineral). It is common in heavy soils with a high fixing power, calcareous soils, and heavily cropped soils (Anderson, 1973; Forshey, 1969; Pedro, 1973; Ulrich and Ohki, 1966). K requirement of vegetable crops is high (Cummings and Wilcox, 1968; Lucas, 1968), and failure to meet their K demands may result in development of symptoms which lower their quality. Poor quality of leafy vegetables due to extensive marginal chlorosis with interveinal brown necrotic spots and rolling, cupping, curling and distortion of the midrib of younger leaves due to K deficiency have been observed (Clarkson and Hanson, 1980; Cumming and Wilcox, 1968; Evans and Sorger, 1966; Forshey, 1969; Singh and Sharma, 1988). Reduction in the length and diameter of stem internodes and of root development due to K deficiency has also been reported (Cumming and Wilcox, 1968; Singh and Sharma, 1988; Wakhloo, 1975; Wilcox, 1969). K deficiency is indicated by development of an acute rosette in beets, celery and parsnips (Hewitt, 1963), and by chlorosis and browning of leaves, spindly roots, and short growth in carrots (Ulrich and Ohki, 1966). K deficiency decreases the rate of photosynthesis and increases the rate of respiration thereby causing a decline in sugar concentration (Ozbun et al., 1975) and accumulation of nonstructural carbohydrates (Oparka and Wright, 1988a, 1988b) due to reduced protein synthesis. Also accumulation of free amino acids and NH_4^+ in leaves due to K deficiency can occur (Daliparthy et al., 1994; Smith and Garraway, 1964; Smith and Sinclair, 1967).

Plants with low levels of K are susceptible to pathogen attack due to N accumulation which favour growth of microorganisms (Locascio, 1993) which may drastically reduce the storability of vegetables. Gerloff (1976) noted that Na can partially substitute for K, and Na applications on K deficient red beets increased yields by three- to four-fold. K deficiency reduces vegetative growth and yield, and in severe situations can result in loss of older leaves and crop death (Clarkson and Hanson, 1980; Evans and Sorger, 1966).

Effects of excess K on vegetables

Excess of K may result in luxury consumption by vegetables, and reduced net uptake of other cations especially Ca and Mg (Dibb and Thompson, 1985; Mengel, 1973; Mengel and Kirkby, 1987; Tisdale et al. 1993). This luxury consumption may cause nutrient imbalances in tissues. Several studies have reported on physiological disorders of vegetables caused by excess K uptake (Forster, 1973; Maynard et al., 1963; Shear, 1975).

K may restrict or increase uptake, transport, and utilization of other nutrients

(Daliparthy et al., 1994). Nutritional balances and ratios between and among K, Ca, and Mg are important in plant nutrition (Mengel and Kirkby, 1987; Munson, 1968). Shukla and Mukhi (1979) observed antagonistic relationship between K and Ca, and K and Mg during absorption by the roots and translocation from the root to shoot. Excess of K fertilization restricts Mg absorption and effectiveness in the tissues (Ferrari and Sluijsmans, 1955; Ulrich and Ohki, 1956) which may cause Mg deficiency. Chlorosis in celery caused by Mg deficiency is due to high K and/or Ca in tissues (Johnson et al., 1957). K application increased yield and decreased Mg concentration in kale leaves in soil low in K (Bolton and Penny, 1968). High rates of K fertilization increased K/Mg ratio, and decreased Mg concentrations in potato petioles (Maier, 1986b).

Forster (1973), Geraldson (1957), Hamilton and Agle (1962) and Shear (1975) have reported blossom-end rot of tomato and pepper caused by depressed Ca uptake by excess of K. Black heart in celery (Geraldson, 1954), tip burn in lettuce and cabbage (Walker et al. (1961), and carrot cavity spot (Maynard et al., 1963) are all symptoms of Ca deficiency due to excess K nutrition. Cracked stem (brown checking) in celery is due to depressed B levels caused by excess K (Dibb and Thompson, 1985; Yamaguchi et al., 1958). Increase in K application reduced B concentrations in Brussels sprouts and cauliflower (Gupta, 1979) and raised the severity of B toxicity in corn and tomato (Reeve and Shive, 1944).

Marschner (1971) noted that K:Na relationship is important in sugar beet (*Beta vulgaris* L.) and carrots *(Daucus carota* L.) and increase in K levels reduce their beneficial response to Na application.

K influence on vegetable crop yield

Several contradictory effects of K fertilization on yield of vegetables have been reported (Dick and Shattuck, 1987; Munson, 1979; Sanchez et al., 1991). These contradictions appear to be due to differences in the native K levels at the experimental sites.

Improved K nutrition was found to increase marketable yield and total yield of tomatoes due to increased number of fruits per plant and reduced ripening disorders (Munson, 1979; Wilcox, 1964). Dick and Shattuck (1987) noted a positive yield response of tomatoes to K application in silt loam with 65 ppm of K but not on sandy loam.

Several studies have been done on the effects of K fertilization on yield of potatoes (Chapman et al., 1992; Maier, 1986a; Schippers, 1968). Schippers (1968) reported that K had no effect on dry matter yields of potatoes on sandy soils with low K levels. Chapman et al. (1992); Maier (1986a) and Maier et al. (1986) on the other hand reported significant increases in size and yield of potatoes with increasing rates of K fertilization in soils where the initial soil K status were low.

Jaworski et al. (1978) observed significant increase in marketable yield of pepper with increase in K applied with trickle irrigation on sandy loam soil. They also found increase in yield of polebeans over a range of K fertilization rates applied with trickle irrigation on sandy loam soil but the increases were only significant at the lower rates of fertilization.

Sanchez et al. (1991) reported no response of radish yield to K fertilization in histosols.

Influence of K on quality and shelf life of horticultural crops

Quality improvement of vegetables has been observed as one of the beneficial effects of K fertilization. Dick and Shattuck (1987) noted a significant reduction in blotchy ripening of tomatoes with increasing K fertilization rate on sandy loam soil with initial K levels of 46-80 ppm. Forster (1973), Picha and Hall (1981) and Winsor (1973) also observed a reduction in undesirable qualities viz: blotchy ripening, greenback (delayed maturation), irregularly shaped fruits and hollow fruits in tomatoes with increasing application of K. Application of high rates of K reduced severity of bruising in potatoes (Chapman et al., 1992; Maier et al., 1986).

There is some evidence to show that K improves the storability or shelf life of fruits and vegetables, hence has been termed quality nutrient (Bould et al., 1984; Usherwood, 1985). Kunkel (1947) and Lune and Goor (1977) observed a positive relationship between K levels and keeping quality of onion bulbs and potatoes respectively. Sanford (1968) noted improved shelf life of pineapple with K fertilization.

Overley and Overholser (1931) and Heeney and Hill (1961) noted decreased breakdown in storage and improved fruit storability, flavour, texture and colour of apples. Reeves (1967) reported that correcting inadequate K nutrition improved shelf life of peaches.

Effects of K fertilization on carrots

Root crops have high K requirement and inadequate K depresses root enlargement (Jackson and Volk, 1968). However, the effects of K fertilization on yield of carrots are contradictory. Hamilton and Bernier (1975) reported no significant effect of K application on economic yields of carrots grown on an organic soil in two consecutive years on the same experimental plot. Habben (1973) on the other hand reported that increasing K fertilization increased root weight and root-top ratio in a peat and loam soil mix low in K. Lucas (1968) reported that increase in K application up to 166 kg/ha increased carrot yield on Houghton muck soil.

Habben (1972) found that increasing K fertilization had no effect on dry matter of carrots, and a positive effect on the dietary fibre content, but the effects were small.

The effects of K fertilization on carotene content also are contradictory. Increasing amounts of K showed either no influence on carotene content (Gallagher, 1966; Habben, 1972) or increased it (Southards and Miller, 1962). Habben (1972) noted that increasing K fertilization increased both glucose and fructose contents while the glucose content was not affected in Gallagher's report (1966). Evers (1989b) and Gallagher (1966) reported no effect of K fertilization on sucrose content while Habben (1972) found that sucrose content increased with increasing K fertilization. Scharrer and Werner (1957) and Penningsfeld and Forchthammer (1961) observed that increasing levels of K increased Vitamin C content in carrots. Bishop et al. (1973) and Nilsson (1979) found that increasing K fertilization had a positive effect on K contents in carrots. Evers (1989c) noted a significant increase in root K content with fertilization as compared to unfertilized treatments.

Evers (1989d) reported a positive effect of fertilization on yield, dry matter, and dietary fibre content of carrots. Evers (1989b, c) reported that fertilization practices had a slight effect on the storability of carrots. The different fertilization practices did not affect the dry weight during storage. Nilsson (1979) reported that type or amount of fertilizer (organic or inorganic) had no effect on weight loss of carrots.

D. Storability of carrots

Shelf life of carrots is reduced by moisture loss. Excess moisture loss results in wilting, limping, softening, shrivelling, reduced crispness and juiciness, and dull and less intense colour (Berg, 1987; Berg and Lentz, 1966; Berg and Lentz, 1973; Phan et al., 1973). Burton (1982) and Robinson et al. (1975) reported 8% maximum permissible loss of fresh weight as a limit for the sale of carrots. Moisture loss is influenced by carrot characteristics (which are influenced by variety and cultural practices), storage conditions, and weather conditions during the harvesting period (Apeland, 1974; Apeland and Baugerod, 1971; Apeland and Hoftun, 1974; Berg and Lentz, 1973; Fritz and Weichmann, 1979; Phan et al., 1973; Tucker, 1974).

Root anatomy and surface damage play a major role in shelf life of carrots. Carrots are susceptible to wilting because it is covered with a very thin "skin" (periderm) which is not as protective as the epidermis and can be scratched off easily (Phan, 1987; Stoll and Weichmann, 1987). Being an underground plant part, carrot roots do not develop anatomical structures to protect against moisture loss.

Moisture loss in carrots, as in other vegetables, is affected by size and shape (Sastry et al., 1978). Long thin carrots lose weight and shrink much faster than thick cylindrical carrots under similar storage condition. Apeland and Baugerod (1971) observed that cone shaped roots lose more weight than cylindrical roots. Big carrots have a lower surface area to weight ratio and lose less moisture per unit weight.

Root damage can influence shelf life of carrots. Kader (1983) noted that mechanical injury is the major cause of postharvest deterioration of root crops. Careless handling and mechanical harvesting reduce storability of carrots by raising the level of damage (Apeland, 1974; Tucker, 1974). Apeland (1974) and Tucker (1974) observed that storage potential of machine-harvested carrots was up to 30% lower than hand-lifted carrots. Cultural practices and soil conditions influence the level of root damage in carrots. Tucker (1974) reported that big sized carrots are more prone to damage during harvesting compared to small carrots, and higher levels of damage due to lifting may occur in heavy soils compared to sandy soils where carrots are lifted with ease.

Harvesting at an optimum stage of maturity improves quality and storability of carrots (Fritz and Weichmann, 1979; Weichmann and Kappel, 1977). Young carrots are small and lose weight faster because of their high surface area to weight ratio compared to older roots. Fritz and Weichmann (1979) reported that carrots harvested at an optimum stage of maturity have a wide ratio of monosaccharides to sucrose which is good for storage.

Moisture loss in carrots is influenced by storage temperature, RH, packing method, and rate of air flow (Apeland and Baugerod, 1971; Berg, 1987; Berg and Lentz, 1966; Marriott et al., 1974; Phan et al., 1973; Umiecka, 1980). Rate of weight loss increases with increasing ambient temperature and decreasing RH (Berg, 1987; Marriott et al., 1974).

The driving force for moisture loss is the gradient of water vapour pressure (WVP) between the carrots and the storage atmosphere (Ben-Yehoshua, 1987; Kays, 1991). Berg and Lentz (1966, 1973) observed higher rates of moisture loss at lower humidities. They observed that carrots stored at high RH were crisp and juicy like fresh carrots compared to those stored at low RH. Rooke and Berg (1985) noted a negative relationship between moisture loss in carrots and RH. Berg and Lentz (1978) observed that carrot quality was maintained and weight loss was reduced in high RH storage.

Apeland and Baugerod (1971) and Lentz (1966) found that weight loss in carrots is faster where there is rapid air movement.

Marriott et al. (1974) reported that carrots packed in unlined nets lost weight faster and were less acceptable to consumers compared to carrots packed in nets lined with polyethylene film.

Since weight loss in carrots is influenced by size and shape, which affects their surface area to weight ratio, it is important to establish a quick, accurate, and non-destructive method for measuring surface area of carrots of varying sizes and shapes in order to express moisture loss on per unit area basis.

E. Measuring surface area

Importance of surface area

Surface area of whole plant or plant parts is important in plant physiological studies (Kvet and Marshall, 1971). It is used for estimating the size of assimilatory surfaces (Kvet and Marshall, 1971), calculating surface area/volume ratio (Ben-Yehoshua, 1987), assessing extent of disease infection (Maurer and Eaton, 1971) and insect damage (Malcolm et al., 1986), and estimating growth response to a specific management practice (Boynton and Harris, 1950). Leaf area is also used in estimation of rates of evapotranspiration, gaseous exchange, and receipt of solar radiation (Neumann, 1990).

Methods for measuring surface area

Direct and indirect methods, requiring destructive and non-destructive sampling, for estimating surface area have been developed over time (Apeland and Baugerod, 1971; Kvet and Marshall, 1971; Malcolm et al., 1986; Maurer and Eaton, 1971; Minvielle et al., 1981). Surface area of whole or plant parts or their peelings can be estimated using tracing/printing and square or dot counting, planimetric, and gravimetric procedures. Most of these methods have less than 10% level of inaccuracy, are tedious, time consuming and destructive (Kvet and Marshall, 1971; Malcolm et al., 1986; Maurer and Eaton, 1971). Malcolm et al. (1986) used a video image analyser and an algorithm to calculate surface area of sweet potatoes. They found an error of 7.73% compared to area using formula for a prolate spheroid.

Linear measurements have been used to estimate surface area of leaves (Kvet and Marshall, 1971), carrot roots (Apeland and Baugerod, 1971), and potato tubers (Maurer and Eaton, 1971). Apeland and Baugerod (1971) calculated the area of carrot roots based on length, greatest diameter and weight of carrot roots, while Maurer and Eaton (1971) established an equation for calculating the surface area of potato tubers using a modified equation for a prolate spheroid which is based on major and minor semi-axes. Linear measurements method is time-saving (Ackley et al., 1958), non-destructive and suitable for field use but is material specific (Kvet and Marshall, 1971).

Photoelectric leaf area measuring equipment based on the interception of light has been developed (Voisey and Mason, 1963). Voisey and Kloek (1964) used a portable area meter to estimate surface area of leaves. This method is relatively rapid (Kvet and Marshall, 1971), and has an average error of 8% (Voisey and Kloek, 1964).

Factors to consider when choosing a method to measure surface area.

The method to use to measure surface area in any particular situation depends on the morphology of the plant part used, whether the plant part is needed for subsequent experiments or not (destructive or non-destructive), sample size, level of accuracy required, and availability of technical equipment, labour, and time (Kvet and Marshall, 1971).

Chapter 3. Comparison of three methods for determining surface area of carrot roots of varying sizes

Abstract: Surface area of carrots is used in expressing postharvest moisture loss and estimating periderm damage. Baugerod (1993) method estimates carrot surface area based on size and shape. The objective of this study was to evaluate the applicability and accuracy of Baugerod method on carrots of varying size and shape. This method was compared to slicing and surface replica methods on varieties Carochoice, Top-Pak, Eagle, Paramount, Imperator Special 58, Caropride, Celloking and Top-Pak in two harvests in a growing season, and on size grades 1, 2 and 3 of carrots. The eight varieties were not different in shape but Paramount and Gold-Pak were significantly different in length from Carochoice, Eagle, Imperator Special 58, Caropride, Celloking and Top-Pak. Surface area values obtained using the three methods were statistically different ($p < 0.05$) however, the differences between Baugerod and surface replica methods were less than 5%, and between Baugerod and slicing methods were less than 9%. While using these methods on the three size grades of carrots, the differences between surface area values obtained using Baugerod and slicing methods were less than 6% on average. Results showed that Baugerod's method is applicable to carrots of different sizes with an error of less than 6% which can be tolerated in practical application

A. Introduction

Size and shape of vegetables are important parameters in grading, and in studying the effects of cultural practices on vegetables. Estimation of heat and moisture transfer in thermal processing and storage, and the amount of surface applied chemicals can be done on the basis of surface area of vegetables (Malcolm et al., 1986; Maurer and Eaton, 1971; Sastry et al., 1978; Sistler et al., 1983). Also, surface damage of agricultural products due to insects, diseases, and/or harvest and postharvest handling may be assessed on the basis of proportion of surface area damaged to the total surface area of produce.

Transpiration coefficient is expressed on per unit area or weight basis (Berg, 1987; Lentz, 1966). It is the amount of water evaporated per unit weight or surface area of a product per unit water vapour deficit per unit time (Ben-Yehoshua, 1987; Berg and Lentz, 1971; Burton, 1982; Sastry and Buffington 1982; Sastry et al., 1978). Surface area is also used in calculation of specific surface area (area per unit weight) or surface area-to-volume ratio, an important factor affecting moisture loss from vegetables (Ben-Yehoshua, 1987; Berg, 1987; Berg and Lentz, 1971; Burton, 1982; Robinson et al., 1975; Wills et al., 1989). Surface damage due to insects, diseases, and/or harvest and postharvest handling may be assessed on the basis of proportion of surface area damaged to the total surface area of carrots.

Surface area of carrots (used hereon to mean carrot roots) like most other agricultural products, cannot be determined using formulae for surface area of cones or cylinders because of their irregular shapes. The methods that may be used to determine surface area of carrots are peeling, slicing, and surface replica. In the first method, carrots are peeled and the area of the peelings determined using the planimeter or photographic techniques (Kvet and Marshall, 1971; Minvielle et al., 1981). Carrots can also be sliced into a series of small cylinders and the area of the whole root is estimated by adding areas of all slices calculated using the formula for area of a cylindrical object (Area = $2\pi rh + 2\pi r^2$). Area meter may be used to determine surface replica of carrots (as described later). All these methods are destructive and time consuming.

Baugerod established a non-destructive procedure based on height, greatest diameter and weight to determine the surface area of carrots. These parameters are controlled by genetic influence, cultural practices and environmental conditions during growth (Banga, 1962; Barnes, 1936; Dowker and Jackson, 1977; Olymbios and Schwabe; 1977; Salter et al., 1979; Umiel et al., 1972; Whitaker et al., 1970). The applicability and relative accuracy of Baugerod method on carrot roots of varying sizes and shapes however is not known.

The overall objective of this study was to establish a quick and non-destructive procedure for determining surface area of carrots. The specific objectives were to:

(1) compare three different methods for determining surface area of carrots of varying sizes and shapes, and

(2) evaluate the accuracy of Baugerod (1993) method for determining the surface area of carrots.

B. Materials and methods

Source of carrots

Eight carrot varieties (Caro-choice, Gold-Pak, Eagle, Paramount, Imperator Special 58, Caro-pride, Celloking, and Top-Pak) were planted at Totem Field at the University of British Columbia during the 1993 summer season on a silty loam soil with 5.7% organic matter and pH 5.9. Seeds of Caro-choice, Gold-Pak, Eagle, Top-Pak, Imperator Special 58, and Celloking were obtained from Stokes seeds Ltd. (St. Catharines, Ontario, Canada), while Caropride and Paramount seeds were obtained from Asgrow Seed Co. (Kalamazoo, Michigan, USA). Different varieties were used to test the applicability of the methods on carrots of different sizes and shapes. The experiment was carried out in a randomised complete block design with four blocks and 7.1 m^2 plots.

Fertilizers was manually broadcast over the plots at a rate of 70 kg N/ha, 40 kg P_2O_5/ha and 150 kg K_2O/ha, and raked in before seeding. Carrot seeds were sown at a rate of 11 kg/ha on 13th May, 1993 using a manually operated Stanhay seed spacing drill (Ashford Ltd., Ashford Kent, England) in four row beds with each row containing three lines. Weeds were controlled manually during the growing season. Carrots were irrigated uniformly on an as-needed basis by a portable overhead sprinkler system. Carrots were top dressed 56 days from sowing with 35 kg N/ha. First harvest was done on 8th September and second harvest on 16th November, 1993. At each harvest, a random sample of six carrots was manually pulled from the two centre rows of each plot, 0.5 m away from the borders. Carrots were topped, placed in labelled polyethylene bags and taken to the laboratory. They were gently washed under running cold tap water and blotted to remove surface water. They were stored until use at 2±1° C for a maximum of nine days. Carrots from each plot were labelled 1 to 6 using correcting ink "wite out" (Bic Inc., Toronto, Ontario) for identification.

Ten carrots from small. medium, and large size were randomly picked in 1994 from B.C. Coast Vegetable Co-operative (Richmond, B.C.). The samples in each grade were labelled 1 to 10.

Determination of carrot size

Length, greatest diameter, crown diameter, weight and volume of each carrot were recorded. The volume of carrots from Totem field was measured by submerging individual carrots in 200 ml of water in a 500 ml measuring cylinder and recording the volume of the displaced water.

Determination of carrot shape

The shape of carrots was determined using the Bleasdale and Thompson (1963) method. The shape (C) was calculated as:

$$C = W/\pi r^2 h \qquad (1)$$

where: C = defines the shape or cylindricality of the carrot. C is unity for a cylindrical carrot and 0.33 for a cone, W = weight of the carrot (g), which is a good estimate of carrot volume (Bleasdale and Thompson, 1963), r = half of the greatest diameter of the carrot (cm), h = length of carrot (cm), and $\pi = 3.14$.

Surface area determination

The Baugerod (1993), shrink wrap surface replica and slicing methods were used for surface area determination of carrots from the two sources as described below.

(a) Baugerod method:

It is a non-destructive method which calculates carrot surface area using carrot length, greatest diameter, and root weight. Baugerod (1993) method assumes that carrot weight in grams can be used accurately to estimate the carrot volume. This happens if specific gravity is around unity. To determine if the assumption holds true, specific gravity (g cm^{-3}) derived as weight-to-volume ratio was calculated using carrots from Totem Field.

Determination of carrot surface area

The area of each carrot was calculated as:

$$A = 4C\pi rh/(1+C) \qquad (2)$$

where: A = area of carrot (cm^2), C = shape of the carrot calculated using equation (1) above, r = half of the greatest diameter (cm), h = length of the carrot (cm), and π = 3.14.

(b) Shrink wrap surface area replica method:

Each carrot was tightly wrapped with shrink wrap (D 955; Cryovac Division, W.R. Grace and Co. Ontario, Canada) and taped in place with masking tape. For the shrink wrap to take the shape of carrot, it was blow-dried (hot air) using airjet hair dryer (Oster Corporation, Wisconsin, USA). The whole surface was then coloured black with a king size Jiffy black marker (Shachihata, Japan). On unwrapping each carrot, the area of coloured shrink wrap was recorded using LI-3000 portable area meter. LI-3100 area meter (LI-COR, Inc. Lincoln, Nebraska, USA) was used for measuring surface area of carrots collected from B.C. Coast Vegetable Cooperative.

(c) Slicing method:

Each carrot was sliced into 0.45 cm thick cylindrical discs using stainless steel vegetable slicer (M.E. Heuck Co. Cincinnati, Ohio). The peripheral surface area of each cylindrical disc was calculated using the formula:

$A = 2\pi rh$, (3)

whereas, areas of the two end discs were obtained by the formula:

$A = 2\pi rh + \pi r^2$ (4)

where: r = half of the diameter of each disc, h = thickness of each disc, and $\pi = 3.14$. Areas of all discs were then summed to obtain the total surface area of the carrot.

C. Statistical analysis

All data were subjected to analysis of variance using Proc GLM of Statistical Analysis System Institute, Inc. (1989). Size, shape and specific gravity of carrot varieties grown on Totem field were analysed as a randomised complete block design, whereas that of B.C. Coast Vegetable Co-op. carrots were analysed as a completely randomised design. Surface area data were analysed as a split-plot design with variety or grade as the main plot and method as the sub-plot. Duncan's Multiple Range Test was used to separate statistically significant means among varieties and methods.

D. Results

Size and shape of carrots

No statistically significant ($p > 0.05$) differences were observed among varieties in greatest diameter, weight, and shape in either harvests (Table 1). Shape of all varieties became more cylindrical with maturity as indicated by an increase in C value from early to late harvest. The interactions between varieties and replicates were highly significant ($p < 0.01$) for length, greatest diameter and weight during early harvest, and significant ($p < 0.05$) for only length during late harvest.

Highly significant ($p < 0.01$) differences in length among varieties were observed only during late harvest (Table 2). Considering these results, varieties can be grouped into three classes on the basis of length that is, long (Paramount), medium (Carochoice, Eagle, Imperator Special 58, Caropride, Celloking, and Top-Pak) and short (Gold-Pak).

Specific gravity

There were no statistically significant differences in specific gravity among varieties at either harvests (Table 3). The specific gravity ranged between 1.03 and 1.05 in both harvests.

Table 1. Size and shape of carrot varieties at early and late harvests from Totem field.

	Greatest diameter (cm)		Weight (g)		Shape (C Value)	
Variety	Early	Late	Early	Late	Early	Late
Carochoice	2.99	3.34	58.04	80.91	0.50	0.54
Gold-Pak	2.93	3.13	64.47	62.96	0.54	0.56
Eagle	2.85	3.14	52.58	73.42	0.54	0.57
Paramount	2.66	3.14	49.50	91.53	0.53	0.56
Imperator Special 58	3.00	3.23	64.55	80.20	0.54	0.57
Caropride	3.03	3.12	72.17	74.59	0.52	0.54
Celloking	2.70	2.91	52.29	61.57	0.54	0.54
Top-Pak	2.89	3.25	58.74	76.32	0.49	0.52
SE	0.09	0.10	5.51	6.16	0.02	0.02
Significance	NS	NS	NS	NS	NS	NS

All values are means for 24 carrots.
NS Non significant at $p < 0.05$.

Table 2. Comparison of three different methods for determining surface area (cm^2) at early and late harvests from Totem field.

	Mean area		Length (cm)	
Variety	Early	Late	Early	Late
Carochoice	96.15	123.72	16.25	16.32b
Gold-pak	102.15	101.90	16.56	14.20c
Eagle	88.58	117.34	15.14	16.53b
Paramount	93.17	141.76	17.08	20.69a
Imperator Special 58	104.30	123.72	16.50	16.55b
Caropride	112.11	119.76	17.64	17.92b
Celloking	97.59	109.59	16.86	16.80b
Top-Pak	98.09	121.29	17.12	17.58b
SE	0.97	1.04	0.63	0.54
Significance	NS	NS	NS	**
Methods				
Baugerod	103.38a	119.11b	_	_
Surface replica	98.68b	112.65c	_	_
Slicing	94.69c	127.85a	_	_
SE	0.60	0.64	_	_
Significance	**	**		

**, NS Significant and nonsignificant at $p < 0.01$ and $p < 0.05$ respectively.
Values in a column followed by the same letter are not significantly different at $p < 0.05$ using Duncan's Multiple Range Test.

Table 3. Specific gravity (g cm^{-3}) of carrot varieties at early and late harvests from Totem field.

	Harvest	
Variety	Early	Late
Carochoice	1.044	1.030
Gold-Pak	1.048	1.033
Eagle	1.033	1.027
Paramount	1.045	1.030
Imperator Special 58	1.035	1.036
Caropride	1.044	1.031
Celloking	1.044	1.035
Top-Pak	1.039	1.032
SE	0.004	0.004
Significance	NS	NS

All values are means for 24 carrots
NS Nonsignificant at $p < 0.05$.

Surface area of Totem field carrots

The surface area values using Baugerod, surface replica, and slicing methods were significantly different ($p < 0.01$) in both harvests (Table 2). Highly significant ($p < 0.01$) interaction between variety and replicate was observed at early but not late harvest. Variety by method interaction was not significant ($p < 0.05$) in both harvests indicating that the three methods ranked the same in all varieties.

Surface area values obtained using Baugerod method were the highest whereas those using slicing method were the lowest at early harvest. This relationship between the methods changed at late harvest with slicing method giving the highest values and surface replica the lowest (Table 2).

Size and surface area of carrots from B.C. Coast Vegetable Co-operative

The three size grades of carrots significantly ($p < 0.05$) differed in size (length, greatest diameter and weight) [Table 4] but not in shape.

The interaction between grade and method was highly significant ($p < 0.01$). Surface replica method gave the highest estimate of surface area on all grades whereas Baugerod method gave the lowest estimate except on grade 1 in which slicing gave the least estimate.

Table 4. Comparison of three different methods for determining surface area on three different size grades of carrots from B.C. Coast Vegetable Co-operative.

	Size			Mean area (cm^2)		
Grade	Length (cm)	Greatest Diameter (cm)	Weight (g)	Baugerod	Surface replica	Slicing
1	16.66b	2.87c	64.98b	112.50	132.40	110.20
2	18.44b	3.29b	91.42b	139.50	156.00	145.50
3	20.88a	4.86a	226.24a	233.00	273.80	257.80
SE	0.77	0.12	12.56	3.09	3.09	3.09
Sign.	**	**	**	-	-	-

All values are means for 10 carrots.
Sign. = Significance
** Significant at $p < 0.01$.
Means with the same letter in a column are not significantly different at $p < 0.05$ using Duncan's Multiple Range Test.

Percent variations of Baugerod method from surface replica and slicing methods

The average surface area values obtained using Baugerod method differed from those using surface replica method by less than 5%, and compared to slicing they differed by less than 9% on both harvests from Totem Field (Table 5). While comparing the methods using different grades of carrots, surface area values of Baugerod method differed from those of surface replica by 15% and from values using slicing method by less than 6%.

E. Discussion

The significant interaction between replicate and variety for greatest diameter and weight at early harvest, length and surface areas at both harvests, and the non significant differences in size among varieties indicate greater variation within than among varieties which may be due to the effects of the environment. There were no significant differences in specific gravity between the eight varieties of carrots in the two harvests (Table 2). The values were close to unity and agreed with the results of Bleasedale and Thompson (1963). This showed that the assumption made in Baugerod (1993, personal communication) method that weight in grams can be used as a good estimate of carrot volume, holds true.

Table 5. Percent difference of Baugerod method from surface replica and slicing methods on two harvests, and on three different grades of carrots.

	Percent differences			
	Early		Late	
Variety	Surface replica	Slicing	Surface replica	Slicing
Carochoice	9	6	3	-10
Gold-Pak	6	10	4	-9
Eagle	9	10	4	-7
Paramount	0	8	5	-6
Imperator Special 58	4	7	4	-9
Caropride	-1	11	6	0
Celloking	5	8	5	-9
Top-Pak	7	10	12	-10
Mean	4	9	5	-8
Grade				
1	-17	3	_	_
2	-12	-4	_	_
3	-18	-11	_	_
Mean	-15	-6		

Percent differences = ((Surface area values using Baugerod method - surface area values using surface replica or slicing method)/surface area values using Baugerod method) x 100.

The eight varieties and the three carrot size grades were used to test the applicability of the methods on carrots of varying sizes and shapes. The results of this study showed that there were significant differences in length among the eight varieties, and in length, greatest diameter and weight among the three grades of carrots (Table 3 and 4), and they therefore provided good materials for testing the applicability of the methods.

Surface area values obtained using the three methods differed significantly at both harvests from Totem field. This variation cannot be attributed to differences in size for there were no significant size differences among varieties at early harvest, and at late harvest the ranking of the methods was the same in all varieties despite the statistically significant differences in length. Though the surface area values using the three methods were statistically different at both harvests, the differences between area values using Baugerod and surface replica methods were less than 5%, and between Baugerod and slicing were less than 9% (Table 5) which may be tolerated on a practical basis. This shows that Baugerod method is applicable on different varieties and sizes of carrots with a level of within a 5% error.

The ranking of the surface area values obtained using the three methods differed with grade size as indicated by the significant interaction between grade and method. However, the differences between surface area values obtained using Baugerod and slicing methods were less than 6% on average (Table 5). These low percentage error of surface area values using Baugerod method compared to slicing showed that it can be used to estimate surface area of carrots of different sizes. The differences between surface area values using Baugerod and surface replica were greater on carrots from B.C. Coast Vegetable Co-operative than on carrots from Totem Field. Probably carrots from the two sources had been grown on different types of soil and therefore varied on their surface uniformity. However, the relationship between surface area values obtained using Baugerod and surface replica methods were consistent and therefore they are more accurate. Surface replica method is the most direct and therefore the best procedure for determining surface area of carrots but has the disadvantage of being laborious and somehow destructive. The accuracy of slicing method depends on the number of series of slices from each carrot and the uniformity of the carrot surface. There is a chance of cumulative error in area measurement with increase in the number of slices and this affects its reliability. It is also assumed that the lateral surface of each slice is uniform which may not be true because of the biological nature of carrots.

There were no significant variations in shape between the eight varieties in the two harvests, and between the three grades of carrots from B.C. Coast Vegetable Co-operative. However, the results showed that surface area values obtained using the three methods were comparable in carrot shapes ranging from 0.49 (Top-Pak) to 0.60 of the smallest carrots (grade 1). This indicates that Baugerod method can be used to estimate surface area of carrots within that range of shape. Bleasdale and Thompson (1963) method, used in this study to determine the shape of carrots, gives an approximate shape and may not be sensitive enough to detect minor variations. Carrots are often not radially symmetrical, they may have rounded and sloping shoulders and their maximum diameter is rarely attained at the crown.

Sample size and morphology of the study material, purpose of study, required level of accuracy, availability of resources such as labour, equipment and time are some of the factors that influence the selection of the method for determining surface area of a whole plant or plant part (Kvet and Marshall, 1971). The purpose of this study was to establish a rapid and non-destructive procedure for estimating surface area of carrots by determining the applicability and accuracy of Baugerod method on carrots of varying sizes and shapes. From the results of this study, it can be concluded that Baugerod (1993, personal communication) method is relatively rapid and non-destructive. The surface area values using this method are comparable to surface replica and slicing methods which though more direct are time consuming and destructive. This method is not carrot specific as it can be used on different varieties and/or sizes with a low percentage error. Baugerod method is used to determine the surface area of carrots with the assumption that carrots have uniform greatest diameter and length which is not true considering that carrots are biological products. This can be a source of error in estimating surface area of carrots. However, it can be used for determining surface area of carrots.

Chapter 4. Effects of potassium fertilization and periderm damage on weight loss from carrots

Abstract: A 2-year field experiment was conducted to study the effects of K fertilization on growth, yield and water loss of carrots. The interaction between periderm damage and K fertilization on carrot water loss was also assessed. Effects of five rates of KCl and one rate of K_2SO_4 were studied using randomised complete block design. Carrots were stored at 13°C and 80±5% and 35±5% RH. Five levels of damage were used in 1993, and four in 1994. The source and rate of application of K had no effects ($p < 0.05$) on marketable and unmarketable yields in 1993. However, in 1994 increase in K fertilization reduced ($p < 0.05$) the yields with significant differences observed between KCl and K_2SO_4 effects. Carrot growth and water loss were not affected by rate and source of K in the two years. Low RH significantly ($p < 0.05$) increased weight loss from carrots and consequently reduced the shelf life. Periderm damage increased the rate of weight loss from carrots but no interaction between KCl at rates of 0, 175, 275 and 375 kg K_2O/ha, and levels of periderm damage were observed.

A. Introduction

Shelf life is the number of days that a vegetable takes at specified storage conditions to reach the end of its marketable life (Dennis, 1981). It has become an important aspect of postharvest quality that wholesalers, retailers, and consumers consider in carrots. Shelf life is affected by variety, climate, cultural practices such as fertilizer application, level of maturity when harvested, and postharvest handling (Evers, 1989d; Gorini, 1987), metabolic reserves at harvest, and metabolic rate after harvest (Burton, 1982).

Postharvest deterioration of vegetables is caused by moisture loss, physiological breakdown, and microbial attack (Burton, 1978; Raghavan et al., 1980). Moisture (weight) loss due to transpiration causes wilting and shrivelling resulting in reduced saleable weight and economic value of carrots during postharvest handling and storage (Apeland and Baugerod, 1971; Berg and Lentz, 1966; Burton, 1982; Phan et al., 1973; Shirazi and Cameron, 1993). Moisture loss causes loss of crispness and undesirable changes in colour and palatability (Desai and Salunke, 1991). Such physical changes decrease the aesthetic value and hence saleability of carrots (Hardenburg et al., 1986; Hruschka, 1977; Robinson et al., 1975).

The rate of moisture loss is influenced by a carrot's physical attributes (water content, surface area:volume ratio, and surface morphology), and postharvest handling and storage conditions (Hardenburg et al., 1986; Kader, 1985; Pantastico, 1975). VPD which is the difference in humidity between tissues and surrounding air is the driving force behind moisture movement (Kays, 1991). Water content may affect the rate of water loss from carrots (Lownds et al., 1993) through its effect on vapour pressure deficit. Carrots with a higher water content would have a greater VPD than surrounding atmosphere and may lose water at a faster rate than carrots with a lower water content. Increase in surface area/volume ratio means a greater surface area per unit weight over which evaporation can take place, and indicates greater water loss (Ketsa, 1990; Sastry et al., 1978; Wills et al., 1989).

Storage conditions that enhance moisture loss, biochemical changes, and microbial attack may accelerate the postharvest deterioration of carrots. VPD is important to vegetables immediately after harvest (Grierson and Wardowski, 1978), and any factor that change it would have an effect on rate of moisture loss. Increase in temperature and decrease in RH of the storage environment, through its effects on VPD, increase the rate of postharvest moisture loss from carrots (Apeland and Baugerod, 1971; Phan et al., 1973). Increased air movement in storage has been shown to increase the rate of moisture loss from carrots (Apeland and Baugerod, 1971). Packaging produce creates an almost water saturated atmosphere thereby minimising the rate of moisture loss (Grierson and Wardowski, 1978).

Carrots contain 88 to 90% water by weight (Langer and Hill, 1991) and are stored under ambient conditions (during grading and packing, display and sale at retail markets, and at homes), both of which increase the potential for moisture loss.

Fertilization can influence rate of postharvest moisture loss from carrots through its effects on physical attributes. K has been reported to increase the size of carrots (Habben, 1973), and reduce moisture loss by plants through reduction of transpiration (Brag, 1972). It has also been shown to improve storability of potatoes and onion bulbs (Kunkel, 1947; Lune and Goor, 1977). Several authors have reported the effects of K fertilization on K, sugar, and dry matter content of carrots (Evers, 1989a; Habben, 1973; Nilsson, 1979). Evers (1989b, c) and Nilsson (1979) reported that type and amount of fertilizer had no effect on postharvest weight loss of carrots. Retailers and consumers have complained of a short shelf life of B.C.-grown carrots due to wilting and shrivelling. Carrot growers in B.C. Cloverdale area seem to be applying excess K fertilizer, and whether excess K contributes to the short shelf life, and/or has an adverse effect on yield is not known.

Carrot root surface is covered by a suberized periderm which prevents moisture loss from internal tissues (Esau, 1977; Knowles and Flore, 1983; Kolattukudy et al., 1975). Its removal may significantly affect the rate of postharvest moisture loss. Increase in surface damage of carrots has been reported to decrease carrot storability (Apeland, 1974; Tucker, 1974) due to decreased resistance to water movement. K fertilization enhances resistance of tissues to damage through lignification and silicification (Perrenoud, 1990), and may therefore reduce carrot moisture loss. The extent to which periderm damage, and interaction between periderm damage and K fertilization contribute to the short shelf life of B.C.-grown carrots is not known.

The objectives of this study were to determine:

1) the effects of K fertilization on carrot growth and yield,

2) effect of K fertilization on water loss of carrots, and

3) the interaction between periderm damage and K fertilization on water loss of carrots.

B. Materials and methods

Source of carrots

The experiments were carried out in 1993 and 1994 in Mr. Ray Wang and Mr. Wayne Wang's commercial fields near Cloverdale (B.C., Canada). It was set up in a randomised complete block design, with four replications. Six K treatments described below were used, giving a total of 24 plots each of 3 m length and 1.32 m width.

In 1993, the soil in the experimental field had pH 5.3, 64.8% organic matter (OM), and 503 ppm of K. Carrots and onions had been grown in the field in 1991 and 1992 respectively. The experiment in 1994 was carried out in a different field because of the importance of crop rotation in preventing build up of pests and diseases in carrot production. However, the soil in this field was not very different from the 1993 experimental field. It had pH 5.3, 48.9% OM, and initial K status of 693 ppm. The field was under lettuce the previous two years. In both years ammonium acetate method was used to determine the amounts of K.

In 1993, Carochoice hybrid variety was obtained from Asgrow Seed Co. (Kalamazoo, Michigan, USA). Variety Eagle planted in 1994 was obtained from Stokes Seed Ltd. (St. Catherines, Ont, Canada).

Basic fertilizer N:P:K (5-12-0) was broadcast on plots at commercially recommended rate of 900 kg/ha (BCMAFF, 1992), and incorporated by raking into the soil before seeding. KCl (0-0-60) was then applied at the rates of 0, 75, 175, 275, and 375 kg K_2O/ha, and K_2SO_4 (0-0-50) at 275 kg K_2O/ha. The recommended level of K_2O

application for carrots is 280 kg/ha (Neufeld, 1980; Nonnecke, 1989).

Planting was done on 19/5/93 using a Hestair Stanhay S870 planter with a precision seeder. Four rows and three lines for each row were seeded per bed. The same planter was used on 28/4/94 but three rows were seeded per bed. In the two years, cultivation and routine management practices were carried out by the grower. Pre-emergence weed control was done using a mixture of Linuron and Paraquat, and linuron applied for post-emergence control. Cymbush, parathion and diazinon were applied to control pests. Overhead irrigation was carried out to supplement rain water; the amount and frequency of irrigation depended on the frequency of rainfall.

Effects of K fertilization on the shoot and root growth of carrots

Random samples of five carrot plants were manually harvested from each plot at 60 and 90 days after sowing, and at the final harvest. The final harvest was done when the commercial grower felt the carrots had attained marketable size and the price was favourable. Harvesting was done 0.5 m away from the borders and from within the two middle rows and one centre row. Harvested carrots were put in polyethylene bags and taken to the laboratory at the University of B.C., 52 kms away. The samples were gently washed, when needed, to remove dirt and blotted dry with paper towels to remove excess water. Lengths and fresh weights of shoot and root, and the greatest diameter of the root were measured. Shoots and roots were dried in a ventilated oven at 60 to 70° C until their weights became stable for dry matter measurement. Roots were relatively big during the second and third harvests, and were chopped into small pieces to facilitate drying.

Effect of K fertilization on carrot yield

Carrots for yield determination were harvested as described previously. They were topped by hand, and transported in perforated polyethylene bags to the laboratory. They were gently wiped to remove soil, sorted into marketable and unmarketable (culls) roots, and weighed. Unmarketable yields included undersized, misshapen, and forked roots.

Effect of K fertilization on shelf life of carrots

Twelve carrots were randomly harvested 0.5 m away from the border from each plot, topped, gently washed and blotted dry to remove surface water. They were then divided into two lots of six carrots each. Carrots in each lot were labelled 1 to 6 for identification using correcting fluid (wite out). The length, greatest diameter, and weight of each carrot were measured. Each lot was placed in perforated (51 x 56 cm) kitchen bags (W. Ralston, Canada) and stored in incubators at 13°C, and 35±5% and 80±5% RH. A temperature of 13°C is a simulation of ambient temperature in retail food stalls. A humidifier was used to maintain high RH. Each root was weighed individually at harvest and at 2-day intervals during storage. Weight loss was determined as ((initial root wt - wt after every 2 days in storage/initial root wt) x 100).

Effect of periderm damage and K fertilization on carrot shelf life

The treatments in this experiment simulated the mechanical damage and injuries that may occur to carrots during harvesting and handling before storage. In 1993, fifty (50) carrot roots were randomly picked from each replicate of 0, 175, 275, and 375 kg K_2O/ha from KCl treatments. The roots were gently washed, blotted dry and divided into two groups of 25 roots each for assessing effects of high and low RH storage conditions. Each batch was further subdivided into five equal groups for damage treatments. Prior to applying damage treatments, the roots were stored for four days in a cold room at 2°C. There were five levels of periderm damage: 0%, 5%, 10%, 15%, and 20% of the total surface area of the carrot root was damaged. The roots were damaged by passing a nail brush four times over a 10 cm^2 section of root surface with enough pressure being applied to remove the periderm. The number of sections to be damaged was determined by dividing the required percentage level of damage by the area of damage section (10 cm^2). The damaged roots were placed in perforated kitchen bags (described earlier) and stored at 13°C and at 80±5% and 35±5 % RH incubators immediately after damage. Levels of damage were changed in 1994 to 0%, 15%, 30%, and 45%, and the experiment was carried out only at 35±5% RH because there were not enough samples for both 35±5% and 80±5% RH treatments. The weight of carrot roots was measured every second day for 18 days. Weight loss per every damage and K combination was calculated as described above. The roots were selected at random. Baugerod (1993) method was used to determine the total surface area of each root.

C. Statistical analysis

The Statistical Analysis System Institute Inc. (1989) Proc GLM was used for analysis. Trend effects of K were tested using orthogonal polynomials while KCl and K_2SO_4, both applied at 275 kg K_2O/ha, were compared using orthogonal contrast. Effects of K fertilization, and K fertilization and periderm damage on weight loss was analysed using repeated measures analysis of variance and point analysis. Each harvest and two years of experiment were analysed separately.

D. Results

Effects of K fertilization on carrot shoot growth

Rate and source of K did not influence ($p < 0.05$) shoot growth [length, weights, and dry matter (DM)] at final harvest (Tables 1 and 2). Shoot length and both fresh and dry weights increased linearly with increasing K fertilization during the first harvest in 1993 however, the effects were not maintained to maturity.

Table 1. Effect of potassium fertilization on carrot shoot growth at three harvests in 1993.

Harvest Date	K rate (kg K_2O/ha)	Shoot growth Length (cm)	Weight (g) Fresh	Dry	DM (%)	Shoot/root ratio (dry wt)
22/7/93	0	63.7	25.4	2.70	10.5	1.51
	75	62.6	26.8	2.70	10.1	1.06
	175	63.4	27.5	2.67	9.9	1.17
	275	66.5	31.3	3.06	9.9	1.26
	375	64.8	33.4	3.39	9.9	1.28
	SE	1.0	2.1	0.23	0.2	0.09
	Significance	L*	L**	L*	ns	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns
20/8/93	0	75.8	43.4	6.60	15.7	0.49
	75	71.4	35.1	5.20	14.9	0.41
	175	74.2	40.9	5.90	14.9	0.48
	275	75.9	40.8	6.20	15.8	0.60
	375	75.4	44.1	6.10	14.2	0.44
	SE	1.2	2.9	0.40	1.1	0.02
	Significance	C*	ns	ns	ns	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns
4/10/93	0	70.8	20.1	3.80	18.8	0.16
	75	69.7	18.0	3.30	18.2	0.18
	175	71.8	21.2	3.80	18.6	0.17
	275	74.3	21.0	3.60	17.3	0.18
	375	71.9	24.2	4.20	16.9	0.18
	SE	1.2	2.2	0.40	0.6	0.01
	Significance	ns	ns	ns	ns	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns

Values given are per plant and are means for 20 carrots.
**, * and ns are significant linear (L), cubic (C) at $p < 0.01$ and 0.05 and nonsignificant at $p < 0.05$ respectively.

Table 2. Effect of potassium fertilization on carrot shoot growth at three harvests in 1994.

Harvest Date	K rate (kg K_2O/ha)	Shoot growth: Length (cm)	Shoot growth: Weight (g) Fresh	Shoot growth: Weight (g) Dry	DM (%)	Shoot/root ratio (dry wt)
27/6/94	0	39.2	13.0	1.37	10.4	1.56
	75	37.7	12.4	1.31	10.5	1.53
	175	37.2	12.7	1.42	11.3	1.66
	275	36.4	12.1	1.32	11.0	1.49
	375	35.4	12.5	1.39	10.9	1.69
	SE	0.9	0.6	0.07	0.2	0.08
	Significance	ns	ns	ns	ns	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns
29/7/94	0	61.1	41.0	5.30	12.9	0.56
	75	59.9	35.5	4.50	13.0	0.55
	175	57.0	39.3	5.08	12.8	0.49
	275	57.8	39.6	5.00	12.6	0.47
	375	58.6	38.2	4.98	13.0	0.47
	SE	1.5	3.1	0.44	0.2	0.03
	Significance	ns	ns	ns	ns	L*
	KCl vs K_2SO_4	ns	ns	ns	ns	ns
5/08/94	0	62.5	38.8	5.13	13.9	0.49
	75	60.7	33.8	4.73	14.2	0.43
	175	58.6	36.8	5.12	14.0	0.41
	275	56.0	33.6	4.35	13.5	0.42
	375	60.5	39.2	5.33	14.0	0.43
	SE	1.3	2.8	0.41	0.2	0.03
	Significance	ns	ns	ns	C*	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns

Values are given per plant and are means for 20 carrots.

* and ns are significant linear (L), cubic (C) at $p < 0.05$ or nonsignificant at $p < 0.05$ respectively.

Effects of K fertilization on root growth

The increase in the rate of application of KCl, and source of K fertilization did not influence ($p < 0.05$) storage root growth (Tables 3 and 4). Dry matter (DM) did not respond to changes in rate of K fertilization. Significant responses of root length, fresh weight and greatest diameter were observed during the first and second harvest in 1993 but not at maturity.

Effects of K fertilization on carrot yield

There was no statistically significant ($p < 0.05$) effect of increase in rate of application of KCl on yield of carrots in 1993 (Table 5). Yield responses of KCl and K_2SO_4 were also not significantly different.

Highly significant ($p < 0.01$) negative linear response of yields to increase in in rate of K application were observed in 1994 (Table 5). Marketable and total yields of 275 kg K_2O/ha applied as KCl were significantly ($p < 0.01$) lower than that applied as K_2SO_4.

Table 3. Effect of potassium fertilization on carrot storage root growth at three harvests in 1993.

Harvest date	K rate (kg K_2O/ha)	Length (cm)	Weight (g) Fresh	Weight (g) Dry	Greatest diameter (cm)	DM (%)
22/7/93	0	19.1	19.2	2.0	1.87	10.5
	75	20.1	27.7	2.8	2.14	9.8
	175	18.9	24.6	2.4	2.09	9.4
	275	19.2	26.7	2.7	2.17	9.9
	375	19.1	30.0	2.9	2.23	9.8
	SE	0.7	2.3	0.2	0.07	0.2
	Significance	ns	L*	ns	L*	Q*
	KCl vs K_2SO_4	ns	ns	ns	ns	ns
20/8/93	0	19.7	91.5	9.8	3.41	10.7
	75	19.4	85.4	9.6	3.40	10.8
	175	18.5	87.9	9.3	3.42	10.9
	275	17.6	73.2	8.7	3.44	10.1
	375	18.6	100.8	10.9	3.63	11.0
	SE	0.5	4.8	0.5	0.08	0.6
	Significance	L*	ns	ns	ns	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns
4/10/93	0	20.3	130.1	12.4	3.70	9.6
	75	18.0	97.5	10.4	3.29	11.2
	175	19.5	125.4	14.3	3.66	11.4
	275	19.0	119.0	11.7	3.49	10.0
	375	20.1	136.9	14.0	3.86	10.3
	SE	0.6	10.7	1.1	0.14	0.5
	Significance	ns	ns	D*	D*	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns

Values given are per plant and are means for 20 carrots.
* and ns significant linear (L), deviations (D) at $p < 0.05$ or nonsignificant at $p < 0.05$ respectively.

Table 4. Effects of potassium fertilization on carrot storage root growth at three harvests in 1994.

Harvest Date	K rate (kg K_2O/ha)	Length (cm)	Weight (g) Fresh	Weight (g) Dry	Greatest diameter (cm)	DM (%)
27/7/94	0	14.0	10.4	0.93	1.48	8.8
	75	13.7	10.1	0.90	1.44	9.0
	175	13.7	10.6	0.94	1.50	9.0
	275	14.4	10.2	0.91	1.42	9.1
	375	13.6	9.8	0.91	1.40	8.9
	SE	0.4	0.8	0.07	0.05	0.2
	Significance	ns	ns	ns	ns	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns
29/7/94	0	18.4	85.3	9.3	3.21	11.0
	75	18.8	76.3	8.8	3.02	11.5
	175	19.4	91.6	10.3	3.32	11.3
	275	20.2	100.4	11.0	3.33	11.1
	375	19.8	98.9	10.9	3.26	11.1
	SE	0.6	6.2	0.7	0.10	0.2
	Significance	ns	ns	ns	ns	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns
5/08/94	0	19.6	102.6	11.7	3.42	11.4
	75	20.6	96.0	10.8	3.34	11.3
	175	20.8	104.0	12.3	3.45	11.7
	275	20.5	96.8	10.7	3.35	11.1
	375	20.7	113.4	13.0	3.53	11.6
	SE	0.5	5.8	0.6	0.09	0.2
	Significance	ns	ns	ns	ns	ns
	KCl vs K_2SO_4	ns	ns	ns	ns	ns

Values are per plant and are means for 20 carrots.
Ns nonsignificant at $p < 0.05$.

Table 5. Effect of potassium fertilization on carrot yield (kg/plot).

Fertilizer application (kg K_2O/ha)	Marketable		Unmarketable		Total	
	1993	1994	1993	1994	1993	1994
0	69	21	9	5	77	26
75	62	20	13	6	75	26
175	76	17	10	4	87	21
KCl 275	65	16	12	3	76	18
375	52	15	9	2	61	17
K_2SO_4 275	66	21	9	4	76	25
SE	6.5	1.3	1.9	0.7	6.6	1.4
Significance	ns	L**	ns	L**	ns	L**
KCl vs K_2SO_4	ns	**	ns	ns	ns	**

Yield is the mean of four replicates.
** and ns are significant linear (L) at $p < 0.01$ and nonsignificant at $p < 0.05$.

Effects of K and RH on weight loss of carrots

There was a statistically significantly ($p \leq 0.05$) interaction between K rate, RH and storage time on weight loss in 1993 but not in 1994. However, the trends of weight loss were consistent in both years (Fig. 1 and 2). A significant interaction between RH and storage time was observed in both years. The effects of rate of application and source of K were not significant ($p < 0.05$) and did not differ with RH. Storage time had significant linear and quadratic trend effects on weight loss in 1993 whereas in 1994 linear and cubic trend effects were significant at the end of the storage time. RH had a noticeable effect on physical appearance of carrots. Visual appearance deteriorated much faster at 35±5% than at 80±5% RH. At the former level they were wilted, flaccid, and dull, while at high RH they were turgid, crisp, and bright coloured. The rate of weight loss was significantly faster in carrots stored at low compared to high RH (Fig. 1 and Fig. 2).

The maximum permissible weight loss of carrots before they become unsaleable has been suggested to be 8% of their initial root weight (Burton, 1982; Robinson et al., 1975). In 1993, carrots at 35±5% RH had lost about 8% of their initial weight by the 12th day of storage whereas, at 80±5% RH weight loss of carrots was less than 8% of their initial weight by the 20th day in storage (Fig. 1). In 1994, the maximum permissible weight loss was attained much earlier at the 8th day of storage at 35±5% RH (Fig. 2).

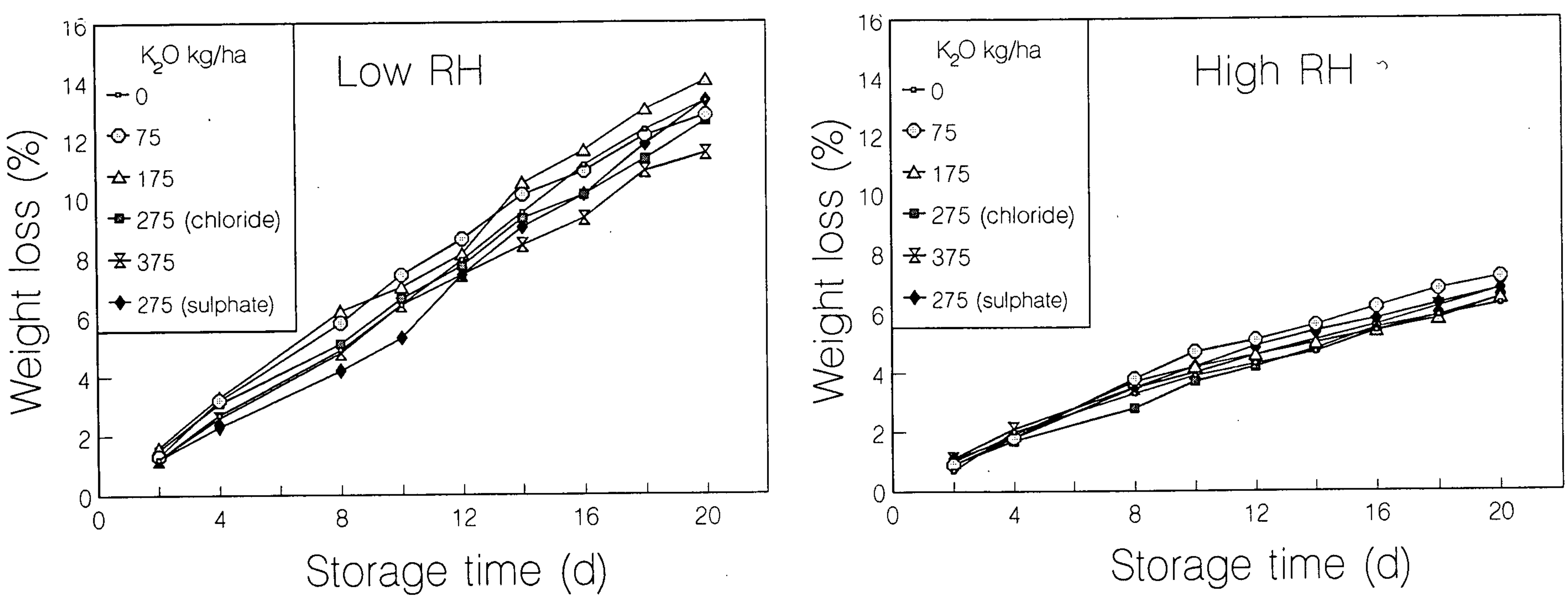

Fig. 1. Effect of K fertilization, RH and storage time on weight loss (%) of carrots stored at 13°C in 1993.

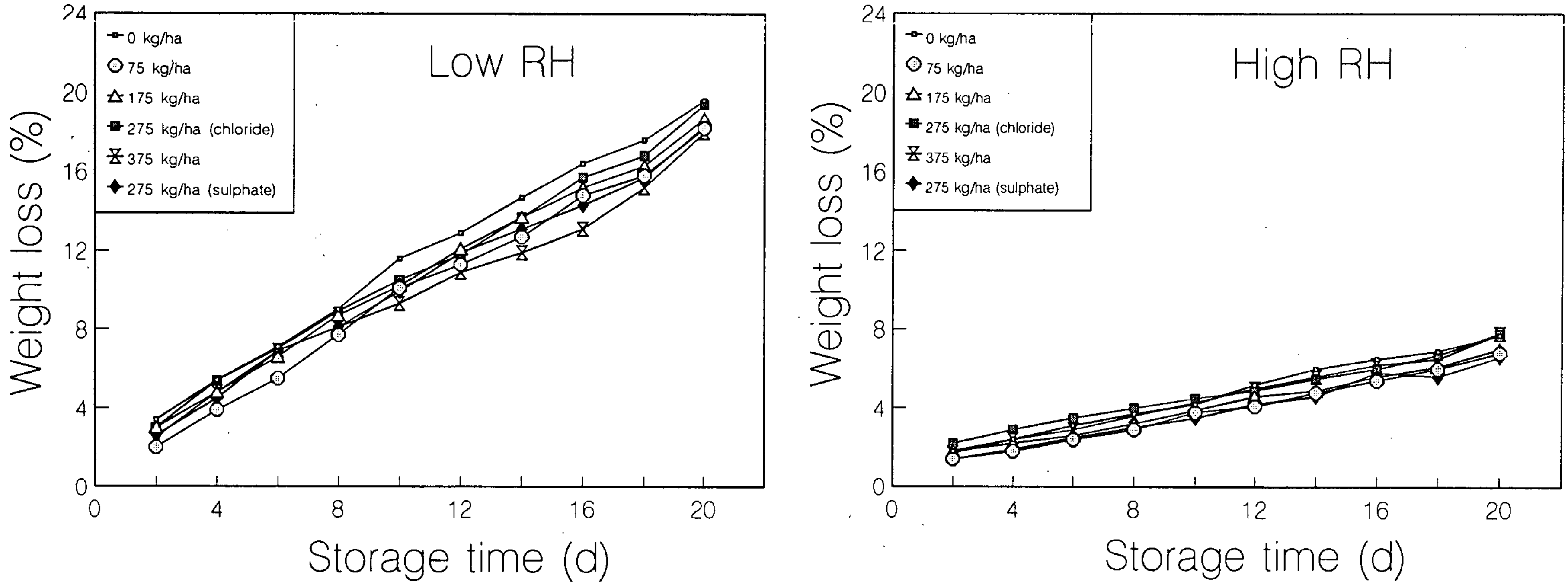

Fig. 2. Effect of K fertilization, RH and storage time on weight loss (%) of carrots stored at 13°C in 1994.

Effects of the Interaction between K fertilization and periderm damage on weight loss of carrots

There was significant ($p < 0.05$) interaction between K, periderm damage, humidity and storage time on weight loss in 1993. The interaction between K, periderm damage, and storage time, and interaction between periderm damage and time, and that between K and storage time were significant in ($p < 0.05$) both years. Also significant linear and quadratic trend effects of storage time on weight loss were observed in both years. The effects of periderm damage on weight loss were more pronounced at 35±5% than at 80±5% RH. In 1993, point analysis indicated that periderm damage significantly increased the rate of weight loss from carrots from day 6 to 12, and the only significant ($p < 0.05$) differences were in comparisons of control versus periderm damage (Fig. 3). Weight loss from carrots with 5% level of periderm damage did not differ significantly ($p < 0.05$) from those with 20%. In 1994, periderm damage did not have significant ($p < 0.05$) effects on weight loss during storage but significant ($p < 0.05$) differences were observed between control and periderm damage only on the 2nd day (Table 6).

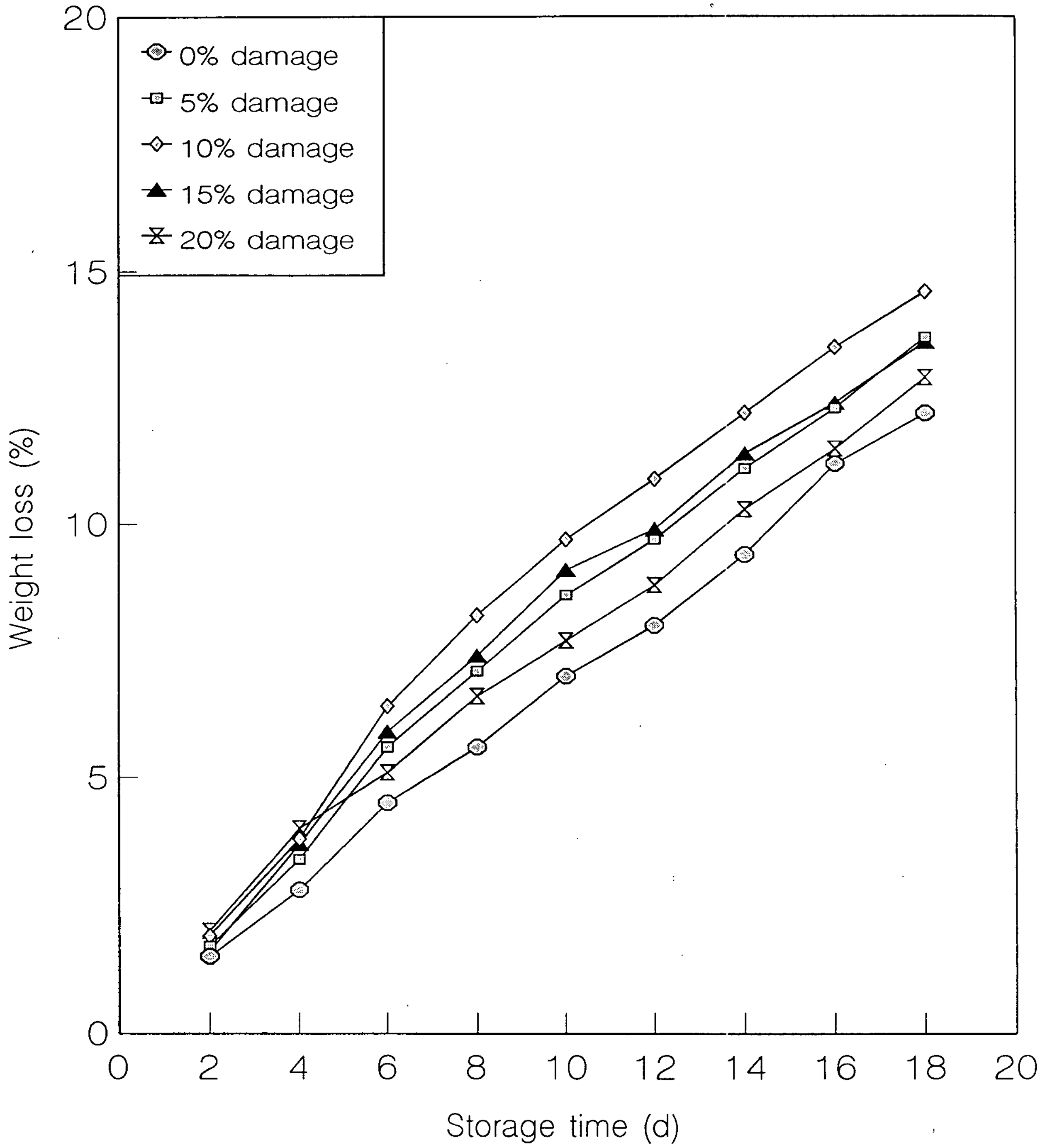

Fig. 3. Effect of periderm damage on weight loss of carrots stored at 13^0C and $35 \pm 5\%$ RH in 1993.

Table 6. Effect of level of periderm damage on weight loss (%) of carrots stored for 18 days at 13° C and 35±5% RH in 1994.

Level of damage (%)	Storage time (d)								
	2	4	6	8	10	12	14	16	18
0	2.4	4.8	7.3	8.9	11.3	12.2	14.1	15.7	18.5
15	2.9	4.7	6.6	9.2	11.1	12.9	14.9	16.6	19.2
30	3.1	5.3	7.7	10.4	12.5	14.4	17.3	19.3	21.3
45	3.1	4.8	7.3	9.0	10.9	12.6	14.8	17.3	19.9
SE	0.1	0.2	0.3	0.3	0.7	0.4	0.5	0.5	0.6
Significance	*	NS	NS	NS	NS	NS	NS	NS	NS

Values given are means for 20 carrots.

*, NS Significant and nonsignificant at $p < 0.05$ respectively.

D. Discussion

Effects of K on carrot growth

This study showed that the rate and source of K did not influence shoot and root growth (Table 1, 2, 3 and 4). Habben (1973) observed no effect of K fertilization on shoot growth but a positive effect on root growth. Vereecke and Maercke (1979) observed that K fertilization increased root weight which is contrary to the results in this study. This variation can be attributed to the differences in the amounts of K in the soil. The soil in Habben's (1973) report was a mixture of peat and loam low in background levels of K whereas in this study the soil had a background level of 503 to 693 ppm of K.

The decrease in storage root length from first to second harvest in 1993 may be due to difficulty in differentiating the storage root from the rest of the root during first harvest. Shoot DM (%) ranged from 16.9 to 18.8% and 13.5 to 14.2% during the final harvest in 1993 and 1994 respectively. Greenwood et al. (1980) reported that carrot shoots have a dry matter of 17.8% with optimum K fertilization. Hamilton and Bernier (1975) recorded a 15.1% DM in carrot leaves.

Storage root DM (%) ranged between 9.6 and 11.7% at final harvest. These results agree with those of others in literature. Hole et al. (1987) found a range of 8.4 to 12.8% among varieties. Hamilton and Bernier (1975) found a 10.6% DM in carrot roots. Greenwood et al. (1980) indicated that root DM content at optimum K fertilization is 9.3%.

Shoot-to-storage root ratio reflects assimilate distribution during growth (Hole et al., 1987). The nonsignificant differences in shoot-to-root ratio indicate that K fertilization had a uniform effect on shoot and storage root growth or, it could be that K was not the most limiting factor in dry matter distribution. Dry matter distribution in carrots is influenced by density, time and genotype (Bleasdale, 1967; Currah and Barnes, 1979; Hole et al., 1983). There was a faster increase in shoot dry weight relative to storage root dry weight during the early part of growth, and at later stages distribution changed in favour of the root. At the time of final harvest some of the older leaves had senescenced and fallen off thereby reducing the shoot/root ratio.

Carrot is a high K-demand crop (Martin and Liebhardt, 1994) and would respond to K application. The general lack of carrot growth response to K fertilization in this study indicates the presence of sufficient quantities of K in the soil. It also showed that excess application of K does not have any effect on carrot growth.

Effects of K on yield of carrots

Marketable and unmarketable yields decreased with increase in rate of K application in 1994 (Table 5). Hamilton and Bernier (1975) found no significant effect of K application on marketable yield of carrots on muck soil, and Nilsson (1979) observed no effect of type and amount of fertilizer on yield of carrots. Positive responses of carrot yield to K application are found in literature (Alt, 1987; Bishop et al. (1973). Alt (1987) classified carrots as one of the vegetables with a 25 to 70%

increase in yield with K fertilization on loamy sand soil. The response of carrot yield to K seems to depend on type and K status of the soil, and cropping pattern. Bishop et al. (1973) found that increasing K fertilization resulted in linear increases in marketable yields in five out of eight experiments in spagnum peat soil, and no response on mineral soil. Greenwood et al. (1980) observed that increasing K fertilization increased yield of unmarketable carrots on sandy loam with 69 ppm of K. Above the optimum point, the yield still increased but not significantly.

Crop yield increase with increase in rate of K application up to an optimum amount where it levels off and does not decrease (Tisdale et al., 1993). This implies therefore, that the decrease of carrot yields may not be due to the effects of K but that of the accompanying ion(s). This was shown by the significantly lower marketable yields with KCl than K_2SO_4. KCl reduced the yields because excess chloride ions are toxic (Page and Cleaver, 1983; Tinker et al., 1977), while excess sulphate ions are precipitated as calcium sulphate (Greenwood et al., 1980). The effects of chloride ions are greater in drier soils (Tinker et., 1975), and this may have contributed to the significant effects in 1994 because the growing season was relatively drier compared to 1993 (Table 7). Water usually leaches out excess ions thereby reducing the toxicity. The decrease in yields cannot be attributed to reduced size of storage roots because K fertilization had no significant effects on storage root length, weight and greatest diameter (Table 3 and 4). It may be a result of low population as K supplied as KCl has been observed to have a negative effect on seedling emergence (Tinker et al., 1977) resulting in lower plant population. Chloride in fertilizer salt is known to reduce

Table 7. Weather conditions during growing period in 1993 and 1994.

Year		April	May	June	July	Aug	Sept	Oct
		Months						
1993	Temperature (°C)	10.5	15.7	16.1	16.7	18.3	15.6	12.4
	Rainfall (mm)	145.7	101.3	80.8	39.6	18.4	7.6	77.1
1994	Temperature (°C)	11.5	14.5	15.3	19.0	18.0	-	-
	Rainfall (mm)	80.4	32.3	67.2	16.8	9.4	-	-

Source: Environment Canada, Vancouver

seed germination (Cooke, 1967; Tisdale et al., 1993). Smith and Hadley (1989) observed that carrot seedling emergence was reduced with increased KCl application. Soil salinity delays seed germination and decreases seedling emergence (Page and Cleaver, 1983), and may reduce plant population below the optimum target. Holmes et al. (1961, 1973) while working with sugar beet observed that high application of salts significantly reduced seedling emergence and plant establishment. The results of this study showed that application of excess K as KCl has a negative effect on marketable yield of carrots presumably by lowering the plant population per unit area.

Effects of RH and K fertilization on shelf life of carrots

Shelf life of vegetables is determined by postharvest weight (moisture) loss (Ben-Yehoshua et al., 1983; Lester and Burton, 1986; and Laurie et al., 1986). At low RH, the acceptable 8% weight loss was attained around the 12th day on storage. Twelve days can therefore be around the average shelf life of carrots stored at 13°C and 35±5% RH in 1993. This duration may also be taken as the minimum shelf life in retail markets and homes because storage conditions at both these locations rarely exceed 13°C and 35±5% RH. Carrots at high RH had lost less than 8% of their initial root weight by the 20th day on storage. This confirms the results of Apeland and Baugerod, 1971; Berg, 1981; Berg and Lentz (1966, 1973, 1974) who showed that shelf life of carrots can be extended by storing at high RH. Wells (1962) reported that weight loss in fruits is linearly related to VPD which is the driving force behind moisture loss. The rate of weight loss is lower at high RH because of reduced VPD between carrot surface and the surrounding air (Wills et al. 1989). The storage atmosphere at high RH is almost water saturated, and this reduces transpiration, shrinkage, and shrivelling (Hardenburg, 1971). This is the principle behind jacketed storage (Raghavan et al., 1980) and seal-packaging of horticultural produce (Ben-Yehoshua, 1985; Lownds et al., 1993).

Evers (1989c) found a negative effect of fertilization, as compared to control, on storability of carrots. Weight loss of carrots was not affected by the rate and source of K in this study. The reduction in shelf life of carrots stored at 13°C and 35±5% RH from 12 days in 1993 to 8 days in 1994 may be attributed to the relatively drier growing season in 1994 compared to the previous year (Table 7) as weather conditions have been reported to affect carrot storability (Evers, 1989c).

Effects of periderm damage on weight loss from carrots

Periderm damage increased the rate of weight loss from carrots especially at 35±5% RH. Removal of periderm from carrots decreases the surface resistance to the movement of water vapour and accelerates the exchange of water between carrots and storage environment (Kays, 1991). Storage at low RH favours water movement from carrots into the storage atmosphere because of the high VPD which is conducive to water loss (Kays, 1991). At 80±5% RH, damage may not be a worrying factor because VPD is very low and water exchange between carrots and storage atmosphere is minimal. In 1994, periderm damage significantly increased the rate of weight loss from carrots on 2nd day of storage, and thereafter the effects were not significant (Table 6). This may be explained by the healing of periderm damage through formation of wound periderm, which provides protection against moisture loss (Dyachenko, 1979; Kays, 1991; Nikolaeva et al., 1988). Davies (1977) and Lewis et al. (1981) observed healing of damaged carrot root tissues through lignification, suberization, and sometimes callus formation. This is favoured by exposure to high temperatures, high RH, and adequate aeration (Davies, 1977; Kays, 1991; Lewis et al. 1981).

K improves tissue resistance to damage (Perrenoud, 1990) but there was no significant interaction between K fertilization and periderm damage in this study. Probably, this is due to the high level of K in muck soil in Cloverdale, B.C. so that any additional K fertilization does not have any significant effect on tissues.

Practical implications

The results obtained in this study have practical implications for the production and postharvest handling of carrots. They showed that excess application of K does not have any effect on growth, shelf life and periderm damage but a negative effect on yield of carrots. They suggest that there is enough K in the Cloverdale muck soil to meet the carrot's requirement, and that the high applications of K that growers seem to be applying on carrots on muck soil is a double loss. Money is spent in purchasing and applying K fertilizer, and the added K reduce yields thereby lowering the income to the growers. Supplementary K can only be added where soil analysis indicates a deficiency. Shelf life of carrots was reduced by storage at 35±5% RH and periderm damage. This indicates the importance of postharvest handling in carrot shelf life. These results showed that periderm damage and storing at low RH, and not K fertilization, may be the more probable causes for the short shelf life of B.C.-grown carrots. Consequently, B.C.-grown carrots should be handled more carefully to minimise periderm damage, and stored at high RH to prolong their shelf life, and allow for favourable competition with those from California and Washington. This will promote the sale of B.C.-grown carrots.

Chapter 5. Conclusions and Recommendations

This study was carried out to determine the factors causing the short shelf life of B.C.-grown carrots. Considerable evidence exists that both physical characteristics and postharvest handling influence the rate of postharvest moisture loss from carrots.

Surface area-to-weight ratio is one of the inherent characteristics that influences moisture loss, and therefore it was necessary to establish a procedure to measure surface area of carrots. The results of this study showed that surface area values obtained using the non-destructive Baugerod (1993, personal communication) method differed from values given by the laborious and destructive surface replica and slicing methods with a less than 6% error. Surface area values obtained using Baugerod method varied from slicing method by less than 6% when the methods were compared using size grades of carrots of different lengths, greatest diameters and weights. Baugerod method was also relatively faster compared to surface replica and slicing methods. It is concluded from this study that Baugerod method is applicable on carrots of different sizes, and differs from the other methods by less than 6% which can be tolerated, and can therefore be used to estimate surface area of carrots.

Carrot growers seem to be applying excess K fertilizer. The impact of excess K fertilization on growth, yield, periderm damage and shelf life of carrots was assessed. Effects of periderm damage on shelf life of carrots was also studied. Excess K application had no significant effects growth and shelf life of carrots. This indicates the presence of adequate amounts of K in muck soil in Cloverdale area of B.C. to support carrot growth, and that K fertilization is unnecessary. It also rules out the application of excess K as the cause of the short shelf life of B.C.-grown carrots. KCl addition significantly reduced marketable yields per plot. As K fertilization did not influence the size of carrots, it indicates that reduced yields resulted from fewer carrots per plot and that KCl reduced plant population. A reduction in marketable yield is a reduction of the growers' income from carrots. Average yields in this study were significantly higher where K_2SO_4 was applied compared with KCl due to the toxic effects of excess Cl compared to SO_4 ions. Optimum application of Cl fertilizer or fertilizing with Cl free fertilizers is therefore recommended to minimise toxic effects of Cl, optimise carrot stand and to maximise production of carrots.

Periderm damage and storing of carrots at low RH accelerated the rate of moisture loss and reduced the shelf life of carrots. This showed that the short shelf life of B.C.-grown carrots may be more likely attributed to periderm damage and/or storing at low RH. Periderm damage is due to mechanical handling which is inevitable in commercial production of carrots. It is therefore recommended that carrots be handled more carefully to minimise periderm damage, and mechanically handled carrots be stored at high RH which has been shown in this study and elsewhere to minimise water loss and lengthen shelf life of carrots. This will improve the shelf life and acceptability of B.C.-grown carrots.

Wound healing reduces moisture loss and improve storability in carrots (Dyachenko, 1979; Nikolaeva et al., 1988), potatoes (Sukumaran et al., 1990), and sweet potatoes (St. Amand and Randle, 1991; Walter and Schadel, 1982; 1983). This may be researched further to establish the possibilities of subjecting carrots to healing treatments for a short period after harvest to harden the periderm and heal wounds which may be beneficial for carrot shelf life. If this is found to have significant and economic effects on postharvest weight loss, it may be exploited to improve the shelf life and sale of B.C.-grown carrots.

Bibliography

Abrams, C.F., E.G. Humphries, D.D. Hamann, and L.G. Wilson. 1978. Bulk harvest and handling of sweet potatoes. ASAE Trans. 21:15-19.

Ackley, W.B., P.C. Crandall, and T.S. Russell. 1958. The use of linear measurements in estimating leaf areas. Proc. Amer. Soc. Hort. Sci. 72:326-330.

Alt, D. 1987. Influence of P- and K-fertilization on yield of different vegetable species. J. Plant Nutr. 10:1429-1435.

Anderson, G.D. 1973. Potassium response of various crops in East Africa. pp. 287-309. IN: Potassium in Tropical Crops and Soils. Proc. 10th Colloq., Intern. Potash Inst., Bern, Switzerland.

Anon. 1980. Carrots. B.C. Min. of Agric., Fisheries and Food. Booklet No. 2268.

Anon. 1991. Annual statistics. B.C. Min. of Agric., Fisheries and Food. Victoria, B.C.

Apeland, J. 1974. Storage quality of carrots after different methods of harvesting. Acta Hort. 38:353-357.

Apeland, J. and H. Baugerod. 1971. Factors affecting weight loss in carrots. Acta Hort. 20:92-114.

Apeland, J. and H. Hoftun. 1974. Effects of temperature regimes on carrots during storage. Acta Hort. 38:291-309.

Banga, O. 1962. Main types of the western carotene carrot and their origin. W.E. Tjeenk Willink. Zwolle, Netherland. CITED IN: N. Umiel, A.F. Kust, and W.H. Gabelman. 1972. A technique for studying quantitatively the variation in size and shape of carrot roots. HortSci. 7:273-276.

Banga, O. 1979. Carrot. pp. 291-293. IN: N.W. Simmonds (ed.) Evolution of Crops. Longman, London.

Barker, A.V. and R. Bradfield. 1963. Effect of K and N on free amino acid contents of corn plants. Agron. J. 55:565-570.

Barnes, E.C. 1936. Effects of some environmental factors on growth and colour of carrots. Cornell Agric. Exp. Sta. Memoir 186:1-36.

Baugerod, 1993. A method to determine the surface area of carrot roots (Personal

Communication).

Bennett, W.F. 1993. Plant nutrition: Plant Nutrient Utilization and Diagnostic Plant Symptoms. pp. 1-7. IN: W.F. Bennett (ed.) Nutrient Deficiencies and Toxicities in Crop Plants. Amer. Phytopathol. Soc. St. Paul, Minnesota.

Benjamin, L.R. and R.A. Sutherland. 1989. Storage-root weight, diameter and length relationships in carrot (*Daucus carota* L.) and red beet (*Beta vulgaris* L). J. Agric. Sci. Camb. 113:73-80.

Ben-Yehoshua, S. 1987. Transpiration, water stress, and gas exchange. pp. 113-170. IN: J. Weichmann (ed.) Postharvest Physiology of Vegetables. Marcel Dekker, Inc. New York and Basel.

Ben-Yehoshua, S., B. Shapiro, Z.E. Chen, and S. Laurie. 1983. Mode of action of plastic film in extending shelf life of lemon and bell pepper fruits by alleviation of water stress. Plant Physiol. 73:87-93.

Ben-Zioni, A., Y. Vaadia, and H.S. Lips. 1971. Nitrate uptake by roots as regulated by nitrate reduction products of the shoot. Physiol. Plant. 24:288-290.

Beringer, L.R. 1980. The role of potassium in crop production. pp. 25-32. IN: Proc. of the joint Intern. seminar. Intern. Potash Inst., Bern, Switzerland and Fert. Soc. South Africa, Pretoria, SA.

Beringer, H. and F. Nothdurft. 1985. Effects of potassium on plant and cellular structures. pp. 351-368. IN: R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, SSSA, Madison. WI.

Beringer, H., K. Koch, and M.G. Lindhauer. 1989. Source:sink relationships in potato (*Solanum tuberosum*) as influenced by potassium chloride or potassium sulphate nutrition. pp. 639-642. IN: M.L. van Beusichem (ed.) Plant Nutrition - Physiology and Applications. Kluwer Academic Publishers. Dordrecht, Netherlands.

Berg, L. van den. 1981. The role of humidity, temperature, and atmospheric composition in maintaining vegetable quality during storage. pp. 95-107. IN: R. Teranishi and H. Barrera-Benitez (eds.) Quality of Selected Fruits and Vegetables of North America. Amer. Chem. Soc., Washington, D.C.

Berg, L. van den. 1987. Water vapour pressure. pp. 203-230. IN: J. Weichmann (ed.) Postharvest Physiology of Vegetables. Marcel Dekker, Inc. New York and Basel.

Berg, L. van den and C.P. Lentz. 1966. Effect of temperature, relative humidity, and atmospheric composition on changes in quality of carrots during storage. Food Technol. 20:104-107.

Berg, L. van den and C.P. Lentz. 1971. Moisture loss of vegetables under refrigerated storage conditions. Can Inst. Food Technol. J. 4:143-145.

Berg, L. van den and C.P. Lentz. 1973. High humidity storage of carrots, parsnips, rutabagas, and cabbage. J. Amer. Soc. Hort. Sci. 98:129-132.

Berg, L. van den and C.P. Lentz, 1978. High humidity storage of vegetables and fruits. HortSci. 13:565-569.

Bishop, R.F., E.W. Chipman, and C.R. MacEachern. 1973. Effect of nitrogen, phosphorus and potassium on yields and nutrient levels in carrots grown on spagnum peat and mineral soils. Comm. in Soil Sci. and Plant Analysis. 4:455-474.

Bolton, J. and A. Penny. 1968. The effects of potassium fertilizers on the yield and composition of successive crops of ryegrass, clover, sugar beet, potatoes, kale, and barley on sandy soil at Woburn. J. Agric. Sci. 70:303-311.

Bould, C., E.J. Hewitt, and P. Needham. 1984. Diagnosis of Mineral Disorders in Plants. Vol. 1, Principles. Chemical Publishing, New York.

Boynton, D. and E.W. Harris. 1950. Relationships between leaf dimensions, leaf area, and shoot length in the McIntosh apple, Elberta peach, and Italian prune. Proc. Amer. Soc. Hort. Sci. 55:16-20.

Bleasdale, J.K.A. 1967. The relationship between the weight of a plant part and total weight as affected by density. J. Hort. Sci. 42:51-58.

Bleasdale, J.K.A. and R. Thompson. 1963. An objective method of recording and comparing the shapes of carrot roots. J. Hort. Sci. 38:232-241.

Blevins, D.G. 1985. Role of potassium in protein metabolism in plants. pp. 413-424. IN: R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Brackett, R.E. 1993. Microbial quality. PP. 126-148. IN: R.L. Shewfelt and S.E. Prussia (eds.) Postharvest Handling: A Systems Approach. Academic press, Inc.

Bradley, G.A., D.A. Smittle, A.A. Kattan, and W.A. Sistrunk. 1967. Planting date, irrigation, harvest sequence and varietal effects on carrot yields and quality.

Proc. Amer. Soc. Hort. Sci. 90:223-234.

Bradley, G. and D. Smittle. 1965. Carrot quality as affected by variety, planting and harvest dates. Proc. Amer. Soc. Hort. Sci. 86:397-405.

Brag, H. 1972. The influence of potassium on the transpiration rate and stomatal opening in *Triticum aestivum* and *Pisum sativum*. Physiol. Plant. 26:250-257.

Burton, W.G. 1978. Biochemical and physiological effects of modified atmospheres and their role in quality maintenance. pp. 97-110. IN: H.O. Hultin and M. Milner (eds.) Postharvest Biology and Biotechnology. Food Nutr. Press Inc. Conn. USA.

Burton, W.G. 1982. Postharvest Physiology of Food Crops. Longman, London.

Chapman, K.S.R., L.A. Sparrow, P.R. Hardman, D.N. Wright, and J.R.A. Thorp. 1992. Potassium nutrition of Kennebec and Russet Burbark potatoes in Tasmania: Effect of soil and fertilizer potassium on yield, petiole and tuber potassium concentrations, and tuber quality. Aust. J. Exp. Agric. 32:521-527.

Clarkson, D.T. and J.B. Hanson. 1980. The mineral nutrition of higher plants. Annu. Rev. Plant Physiol. 31:239-298.

Cooke, G.W. 1967. The Control of Soil Fertility. London, Crosby Lookwood.

Cook, R.J. and R.I. Papendick. 1978. Role of water potential in microbial growth and development of plant disease with special reference to post harvest pathology. HortSci. 13:559-564.

Cocucci, M.C. and S. Dalla Rosa. 1980. Effects of canavanine on IAA- and fusicossin-stimulated cell enlargement, protein extrusion and potassium uptake in maize coleoptiles. Physiol. Plant. 48:239-242.

Cummings, G.A. and G.E. Wilcox. 1968. Effect of potassium on quality factors - fruits and vegetables. pp. 243-254. IN: V.J. Kilmer, S.E. Younts, and N.C. Brady (eds.) The Role of Potassium in Agriculture. ASA, CSSA, SSSA, Madison, WI.

Currah, I.E. and A. Barnes. 1979. Vegetable plant part relationships. I. Effects of time and population density on the shoot and storage root weights of carrot (*Daucus carota* L.). Ann. Bot. 43:475-486.

Daliparthy, J., A.V. Barker, and S.S. Mondal. 1994. Potassium fractions with other nutrients in crops: A review focusing on the tropics. J. Plant Nutr. 17:1859-1886.

Daniels, J.A., R. Krishnamurthi, and S.H. Rizvi. 1985. A review of effects of carbon dioxide on microbial growth and food quality. J. Food Prot. 48:532-537.

Davies, W.P. 1977. Infection of carrot roots by *Mycocentraspora acerina* (Hartig) Deighton. Ph.D. Thesis, University of East Anglia. CITED IN: Lewis, B.G., W.P. Davies, and B. Garrod. 1981. Wound-healing in carrot roots in relation to infection by *Mycocentraspora acerina*. Ann. Appl. Biol. 99:35-42.

Dela Guardia, M.D. and M. Benlloch. 1980. Effects of potassium and gibberellic acid on stem growth of whole sunflower plants. Physiol. Plant. 49:443-448.

Demmig, B. and H. Gimmler. 1983. Properties of the isolated intact chloroplast at cytoplasmic K^+ concentrations. I. Light-induced cation uptake into intact chloroplast is driven by an electrical potential difference. Plant Physiol. 73:169-174.

Den Outer, R.W. 1990. Discolourations of carrot (*Daucus carota* L.) during wet chilling storage. Scientia Hort. 41:201-207.

Dennis, C. 1981. The effect of storage conditions on the quality of vegetables and salad crops. pp. 329-339. IN: Goodenough, P.W. and R.K. Atkins (eds.) Quality of Stored and Processed Vegetables and Fruits. Academic Press, London.

Desai, B.B. and D.K. Salunke. 1991. Fruits and Vegetables. pp. 301-412. IN: D. K. Salunke and S.S. Deshpande (eds.) Foods of Plant Origin - Production, Technology, and Human Nutrition. An AVI Book, Van Nostrand Reinhold, New York.

Dhindsa, R.S., C.A. Beasley and I.P. Ting. 1975. Osmoregulation in cotton fiber, accumulation of potassium and malate during growth. Plant Physiol. 56:394-398.

Dibb, D.W. and W.R. Thompson. 1985. Interaction of potassium with other nutrients. pp. 515-533. IN: R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Dick, J. and V. Shattuck. 1987. Influence of potassium fertilization on blotchy ripening in processing tomatoes. Can. J. Plant Sci. 67:359-363.

Dowker, B.D. and J.C. Jackson. 1977. Variation studies in carrots as an aid to breeding V. The effects of environments within a site in the performance of carrot cultivars. J. Hort. Sci. 52:299-307.

Dyachenko, V.S. 1979. Quality of carrots after mechanised cropping. Acta Hort. 93:113-123.

Eckert, J.W. 1978. Pathological diseases of fresh fruits and vegetables. pp. 161-209. IN: H.O. Hultin and M. Milner (eds.) Postharvest Biology and Biotechnology. Food and Nutrition Press, Westport, Connecticut.

Esau, K. 1940. Developmental anatomy of the fleshy storage organ of *Daucus carota* L. Hilgardia 13:175-225.

Esau, K. 1965. Plant Anatomy. John Wiley and Sons, Inc. New York.

Esau, K. 1977. Anatomy of Seed Plants. 2nd ed. Wiley, New York.

Evans, H.J. and G.J. Sorger. 1966. Role of mineral elements with emphasis on the univalent cations. Ann. Rev. Plant Physiol. 17:46-76.

Evans, H.J. and R.A. Wildes. 1971. Potassium and its role in enzyme activation, pp. 13-39. IN: Potassium in Biochemistry and Physiology. Intern. Potash Inst., Bern, Switzerland.

Evers, A.M. 1989a. Effects of different fertilization practices on the carotene content of carrot. J. Agric. Sci. Finland. 61:7-14.

Evers, A.M. 1989b. Effects of different fertilization practices on the glucose, fructose, sucrose, taste, and texture of carrots. J. Agric. Sci. Finland. 61:113-122.

Evers, A.M.. 1989c. Effects of different fertilization practices on the quality of stored carrots. J. Agric. Sci. Finland. 61:123-134.

Evers, A.M. 1989d. The role of fertilization practices in the yield and quality of carrots. J. Agric. Sci. Finland. 61:329-360.

FAO. 1981. Food loss prevention in perishable crops. FAO Agri. Serv. Bull. 43. FAO, Rome, Italy.

FAO. 1993. FAO quarterly bulletin of statistics. FAO, Rome, Italy.

Ferrari, TH.J. and C.M.J. Sluijsmans. 1955. Mottling and magnesium deficiency in oats and their dependence on various factors. Plant and Soil 6:262-299.

Fockens, F.H. and H.F.T. Meffert. 1972. Biophysical properties of horticultural products related to loss of moisture during cooling down. J. Sci. Food Agric. 23:285-296.

Forshey, C.G. 1969. Potassium nutrition of deciduous fruits. HortSci. 4:39-41.

Forster, H. 1973. Relationship between the nutrition and the appearance of 'greenback' and 'blossom end rot' in tomato fruits. Acta Hort. 29:319-326.

Fritz, D. and J. Weichmann. 1979. Influence of the harvesting date of carrots on quality and quality preservation. Acta Hort. 93:91-100.

Gaffney, J.J. 1978. Humidity: Basic principles and measurement techniques. HortSci. 13:551-555.

Gallagher, P.A. 1966. The effect of potassium on yield and quality of carrots. pp. 257-263. IN: Proc. 8th Intern. Potash Inst. Congr. Brussels.

Geraldson, C.M. 1954. The control of blackheart of celery. Proc. Amer. Soc. Hort. Sci. 63:353-358.

Geraldson, C.M. 1957. Factors affecting calcium nutrition of celery, tomato, and pepper. SSSA Proc. 21:621-625.

Gerloff, G.C. 1976. Plant efficiencies in the use of N, P, and K. PP. 169-173. IN: J. Wright. (ed.) Plant Adaptations to Mineral Stress in Problem Soils. Cornell Univ., Ithaca, New York.

Giaquinta, R.T. 1979. Phloem loading of sucrose. Plant Physiol. 63:744-748.

Gorini, F. 1987. Market preparation methods and shelf life. pp. 489-495. IN: J. Weichmann (ed.) Postharvest Physiology of Vegetables. Marcel Dekker, Inc. New York and Basel.

Gupta, U.C. 1979. Boron nutrition of crops. Adv. Agron. 31:273-287.

Green, J. 1983. The effect of K and Ca on cotyledon expansion and ethylene evolution induced by cytokinin. Physiol. Plant. 57:57-61.

Greenwood, D.J., T.J. Cleaver, M.K. Turner, J. Hunt, K.B. Niendorf, and S.M.H. Loquens. 1980. Comparison of the effects of potassium fertilizer on the yield, potassium content and quality of 22 different vegetables and agricultural crops. J. Agric. Sci. Camb. 95:441-456.

Grierson, W. and W.F. Wardowski. 1978. Relative humidity effects on the postharvest life of fruits and vegetables. HortSci. 13:570-574.

Habben, J. 1972. Einfluss von Dungung und Standort auf die Buildung wertgebender

Inhaltsstoffe in Mohren (*Daucus carota* L.). Diss. Techn. Univ., Munchen. CITED IN: Evers, A. M. 1989b. Effects of different fertilization practices on the glucose, fructose, sucrose, taste, and texture of carrots. J. Agric. Sci. Finland. 61:113-122.

Habben, J. 1973. Quality constituents of carrots as influenced by nitrogen and potassium fertilization. Acta Hort. 29:295-305.

Hamilton, H.A. and R. Bernier. 1975. N-P-K fertilizer effects on yield, composition and residues of lettuce, carrot, and onion grown on an organic soil in Quebec. Can. J. Plant Sci. 55:453-461.

Hamilton, L.C. and W.L. Agle. 1962. The influence of nutrition on blossom end rot of pimento pepper. Proc. Amer. Soc. Hort. Sci. 80:457-461.

Hardenburg, R.F. 1971. Effect of in-package environment on keeping quality of fruits and vegetables. HortSci. 6:198-201.

Hardenburg, R.E., A.E. Watada, and C.Y. Wang. 1986. The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. USDA Handbook 66, Rev. US. Govt. Printing office, Washington, D.C.

Harvey, J.M. 1978. Reduction of losses in fresh market fruits and vegetables. Ann. Rev. Phytopathol. 16:321-342.

Heimer, Y.M., A. Golan-Goldhirsh, and S.H. Lips. 1990. Potassium deficiency in sunflower(*Helianthus annus*) is associated with changes in protein profiles: An approach to diagnosis of mineral status. pp. 785-789. IN: M.L. van Beusichem (ed.) Plant Nutrition - Physiology and Applications. Kluwer Academic Publishers. Dordrecht, Netherlands.

Heeney, H.B. and H. Hill. 1961. The use of foliage analysis to determine fertilizer requirements for apple orchards and some vegetable crops. pp. 16-27. IN: W. Ruether (ed.) Plant Analysis and Fertilizer problems. AIBS Pub. No. 8. Amer. Inst. of Biological Sciences, Washington, D.C. CITED IN: N.R. Usherwood. The role of potassium in crop quality. pp. 489-513. IN: R.D. Munson. (ed.) 1985. Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Hewitt, E.J. 1963. The essential nutrient elements: Requirements and interactions in plants. IN: F.C. Steward (ed.) Plant Physiology, a treatise. Inorg. Nutr. of plants III: 176-192.

Hole, C.C., A. Barnes, T.H. Thomas, P.A. Scott, and W.E.F. Rankin. 1983. Dry matter distribution between shoot and storage root of carrot (*Daucus carota* L.). I.

Effect of variety. Ann. Bot. 51:175-187.

Hole, C.C., G.E.L. Morris, and A.S. Cowper. 1987. Distribution of dry matter between shoot and storage root of field-grown carrots. I. Onset of differences between cultivars. J. Hort. Sci. 62:335-341.

Holmes, J.C., W.E. Gill, J.B.A. Rodger, G.R. White, and D.N. Lawley. 1961. Experiments with salts and potash on sugar beet in South-East Scotland. Exptl. Husb. 6:1-7.

Holmes, J.C., R.W. Lang, and E.A. Hunter. 1973. The effect of method and rate of application of common salt and muriate of potash on sugar beet. J. Agric. Sci. Camb. 80:239-244.

Howarth, M.S., S.W. Searcy, and G.S. Birth. 1990. Reflectance characteristics of fresh market carrots. ASAE Trans. 33:961-964.

Hsiao, T.C. 1976. Stomate ion transport. pp. 195-221. IN: U. Luttge and M.G. Pitman (eds.) Encycl. Plant Physiol. New series, Vol. 2B, Springer-Verlag, Berlin.

Huber, S.C. 1985. Role of potassium in photosynthesis and respiration. pp. 369-396. IN: R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, SSSA, Madison, WI.

Humble, G.D. and T.C. Hsiao. 1970. Light dependent influx and efflux of potassium of guard cells during stomatal opening and closing. Plant Physiol. 46:483-487.

Humble, G.D. and K. Raschke. 1971. Stomatal opening quantitatively related to potassium transport. Plant Physiol. 48:447-453.

Hruschka, H.W. 1977. Postharvest weight loss and shrivel in five fruits and five vegetables. USDA. Res. Service, Marketing Res. report No. 1059.

Jacobi, B., S. Abas, and B. Steinitz. 1973. Rubidium and potassium absorption. Physiol. Plant. 28:209-214.

Jackson, W.A. and R.J. Volk. 1968. Role of potassium in photosynthesis and respiration. pp. 109-145. IN: N.J. Kilmer, S.E. Younts, and N.C. Brand (eds.) The Role of Potassium in Agriculture. ASA, CSSA, SSSA, Madison, WI.

Jaworski, C.A., S.J. Kays, and D.A. Smittle. 1978. Effects of nitrogen and potassium fertilization in trickle irrigation on yield of pepper and polebean. HortSci. 13:477-478.

Jay, J.M. 1986. Intrinsic and extrinsic parameters of foods that affect microbial growth. pp. 33-60. IN: Modern Food Microbiology. Van Nostrand Reinhold, New York.

Johnson, K.E.E., J.F. Davis, and E.J. Beine. 1957. Control of magnesium deficiency in Utah 10B celery grown on organic soil. SSSA Proc. 21:528-532.

Kader, A.A. 1983. Postharvest quality maintenance of fruits and vegetables in developing countries. pp. 455-470. IN: M. Lieberman (ed.) Postharvest Physiology and Crop Preservation. Plenum press, New York.

Kader, A.A. 1985. Postharvest biology and technology: An overview. pp. 3-7. IN: A.A. Kader, R.F. Kasmire, F.G. Mitchell, M.S. Reid, N.F. Sommer, and J.F. Thompson (eds.) Postharvest Technology of Horticultural Crops Special Publ. 3311. Univ. of California, Div. of Agric. and Natural Resources, Davis, California.

Kader, A.A. 1987. Respiration and gas exchange of vegetables. pp. 25-43. IN: J. Weichmann (ed.) Postharvest Physiology of Vegetables. Marcel Dekker, Inc. New York and Basel.

Kays, S.J. 1991. Postharvest Physiology of Perishable Plant Products. Van Nostrand Reinhold, New York.

Ketsa, S. 1990. Effect of fruit size on weight loss and shelf life of tangerines. J. Hort. Sci. 65:485-488.

Knowles, L.O. and J.A. Flore. 1983. Quantitative and qualitative characterization of carrot root periderm during development. J. Amer. Soc. Hort. Sci. 108:923-928.

Kolattukudy, P.E., K. Kronman, and A.J. Poulose. 1975. Determination of structure and composition of suberin from roots of carrot, parsnip, rutabaga, turnip, red beet and sweet potato by combined gas - Liquid chromatography and mass spectrometry. Plant Physiol. 55:567-573.

Kunkel, R. 1947. The effect of various levels of nitrogen and potash on the keeping quality of onions. Proc. Amer. Soc. Hort. Sci. 50:361-367.

Kushman, L.J. 1975. Effect of injury and relative humidity during curing on weight and volume loss of sweet potatoes during curing and storage. HortSci. 10:275-277.

Kvet, J. and J.K. Marshall. 1971. Assessment of leaf area and other assimilating plant surfaces. pp. 517-555. IN; Z. Sestak, J. Catsky, and P. G. Jarvis (eds.) Plant

Photosynthetic Production: Manual of Methods. Dr. W. Junk N.V. Publishers, The Hague.

Land, D.G. 1988. Negative influences on acceptability and their control. pp. 475-483. IN: D.M.H. Thompson (ed.) Food Acceptability. Elsevier, New York.

Lang, A. 1983. Turgor-regulated translocation. Plant Cell Environ. 6:683-689.

Langer, R.H.M. and G.D. Hill. 1991. Agricultural Plants. 2nd edition, Cambridge Univ. Press, Great Britain.

Lauchli, A. 1986. Responses and adaptations of crops to salinity. Acta Hort. 190:243-246.

Laurie, S., B. Shapiro, and S. Ben-Yehoshua. 1986. Effects of water stress and degree of ripeness on rate of senescence of harvested bell pepper fruit. J. Amer. Soc. Hort. Sci. 111:880-885.

Lentz, C.P. 1966. Moisture loss of carrots under refrigerated storage conditions. Food Technol. 20:201-204.

Leonard, R.T. 1985. Absorption of K into root cells. pp. 327-335. IN: R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Lester, S. and B.D. Burton. 1986. Relationship of netted muskmelon fruit water loss to postharvest storage life. J. Amer. Soc. Hort. Sci. 111:727-731.

Lewis, B.G., W.P. Davies, and B. Garrod. 1981. Wound-healing in carrot roots in relation to infection by *Mycocentraspora acerina*. Ann. Appl. Biol. 99:35-42.

Liebhardt, W.C. 1968. Effect of potassium on carbohydrate metabolism and translocation. pp. 147-164. IN: N.J. Kilmer, S.E. Younts, and N.C. Brady (eds.) The Role of Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Lips, S.H., M.I.M. Soares, J.J. Kaiser, and O.A.M. Lewis. 1987. K^+ modulation of nitrogen uptake and assimilation in plants. pp. 233-239. IN: W.R. Ullrich, P.J. Aparicio, P.J. Syrett, and F. Castillo (eds.) Inorganic Nitrogen Metabolism. Springer-Verlag, Berlin.

Locascio, S.J. 1993. Cucurbits: Cucumbers, Muskmelon, and Watermelon. pp. 123-130. IN: W.F. Bennett (ed.) Nutrient Deficiencies and Toxicities in Crop Plants. Amer. Phytopathol. Soc. St. Paul, Minnesota.

Lorenz, O.A. and D.N. Maynard. 1980. Knott's handbook for vegetable growers. 2nd edition. John Wiley and Sons, New York.

Lownds, N.K., M. Banaras, and P.W. Bosland. 1993. Relationships between postharvest water loss and physical properties of pepper fruit (*Capsicum annuum* L.). HortSci. 28:1182-1184.

Lucas, R.E. 1968. Potassium nutrition of vegetable crops, pp. 489-498. IN: N.J. Kilmer, S.E. Younts, and N.C. Brady (eds.) The Role of Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Lune, P. van and B.J. van Goor. 1977. Ripening disorders of tomatoes as affected by the K/Ca ratio in the culture solution. J. Hort. Sci. 52:173-180.

Macleod, R.F., A.A. Kader, and L.L. Morris. 1976. Stimulation of ethylene and carbon dioxide production of mature green tomatoes by impact bruising. HortSci. 11:604-606.

Maier, N.A. 1986a. Potassium nutrition of irrigated potatoes in South Australia. 1. Effect on tuber yield and the prediction of tuber yield response by soil analysis. Aust. J. Exptl. Agric. 26:717-725.

Maier, N.A. 1986b. Potassium nutrition of irrigated potatoes in South Australia 2. Effect on chemical composition and the prediction of tuber yield response by plant analysis. Aust. J. Exptl. Agric. 26:727-736.

Maier, N.A., A.P. Dahlenburg and A.B. Fresham. 1986. Potassium nutrition on irrigated potatoes in South Australia. 3. Effect on specific gravity, size, and internal bruising of tubers. Aust. J. Exptl. Agric. 26:737-744.

Malcolm, E.W., J.H. Tappan, and F.E. Sistler. 1986. The size and shape of typical sweet potatoes. ASAE Trans. 29:678-682.

Marriott, J., F.J. Proctor, and N. Vakis. 1974. Effects of storage temperature and packing method on the keeping quality of cyprus carrots. Acta Hort. 38:379-387.

Martin, H.W. and W.C. Liebhardt. 1994. Tomato response to long-term potassium amd lime application on a sandy Ultisol high in non-exchangeable potassium. J. Plant Nutr. 17:1751-1768.

Marschner, H. 1971. Why can sodium replace potassium in plants, pp. 50-63. IN: Proc. 5th Colloq. Intern. Potash Inst., Berne, Switzerland.

Marschner, H. 1983. General introduction to the mineral nutrition of plants. pp. 5-60.

IN: A. Lauchli and R.L. Bieleski (eds.) Inorganic Plant Nutrition. Encycl. Plant Physiol. New series, Vol. 15A. Springer-Verlag, Berlin.

Martin, H.W. and W.C. Liebhardt. 1994. Tomato response to long-term potassium and lime application on a sandy ultisol high in non-exchangeable potassium. J. Plant Nutr. 17:1751-1768.

Maurer, A.R. and G.W. Eaton. 1971. Calculation of potato tuber surface area. Amer. Potato J. 48:82-87.

Maynard, D., N.B. Gersten, and H.F. Vernell. 1963. The cause and control of plant maturity on the calcium level and the occurrence of carrot cavity spot. Proc. Amer. Soc. Hort. Sci. 83:506-510.

Mengel, K. 1973. Cation competition in higher plants. Bull. Rech. Agron. Gemloux, pp. 168-179.

Mengel, K. 1985. Potassium movement within plants and its importance in assimilate transport. pp. 397-411. IN: R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Mengel, K. and W.W. Arneke. 1982. Effect of K on the water potential, the pressure potential, the osmotic potential, and cell elongation in leaves of *Phaseolus vulgaris*. Physiol. Plant. 54:402-408.

Mengel, K. and E.A. Kirkby. 1987. Principles of Plant Nutrition. 4th ed. Intern. Potash Inst., Berne, Switzerland.

Minvielle, D.P., F.E. Sistler, M.E. Wright, and T.R. Way. 1981. Digital analysis of the shape characteristics of agricultural products. ASAE paper No. 81-3536, ASAE, St. Joseph, MI.

Munson, R.D. 1968. Interaction of potassium and other ions. pp. 321-353. IN: V.J. Kilmer, S.E. Younts, and N.C. Brandy (eds.) The Role of Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Munson, R.D. 1979. Fertilizers improve crop quality, too. pp. 1-4. IN: Agro-knowledge 4. Potash and Phosphate Inst., Atlanta, GA.

Munson, R.D. 1980. Potassium availability and uptake. pp. 28-66. IN: Anon. 1980. Potassium for Agriculture. Potash and phosphate Inst., Atlanta, GA.

Neufeld, J.H. 1980. Soil testing methods and interpretations. British Columbia Ministry of Agriculture.

Neumann, J.A.P. 1990. Variability in the relationship between leaf area and selected stem measures in Douglas Fir. MSc Thesis. Dept. of Forest Science, Univ. of British Columbia.

Nikolaeva, M.A, T.A. Pisarenko and L.A Nelyubova. 1988. The effects of storage methods on the wound reactions of carrots. Izvestiya Vysshikh Uchebnykh Zaevedanii: Pishchevaya Jekhnologiya 2:58-61.

Nilsson, T. 1979. Yield, storage ability, quality and chemical composition of carrot, cabbage, and leek at conventional and organic fertilizing. Acta Hort. 93:209-224.

Nobel, P.S. 1974. Introduction to Biophysical Plant Physiology. H. Freeman, San Franscisco.

Nonnecke, I.L. 1989. Vegetable Production. An Avi Book, Van Nostrand Reinhold, New York.

Olymbios, C.M. and W.W. Schwabe. 1977. Effects of aeration and soil compaction on growth of the carrot. J. Hort. Sci. 52:485-500.

Oparka, K.J. and K.M. Wright. 1988a. Osmotic regulation of starch synthesis in potato tubers. Planta 174:123-126.

Oparka, K.J. and K.M. Wright. 1988b. Influence of cell turgor on sucrose partitioning in potato tuber storage tissue. Planta 175:520-526.

Organization for Economic Co-Operation and Development. 1976. Intern. Standards of Fruits and Vegetables. Paris: OECD.

Outer den, R.W. 1990. Discolourations of carrot (*Daucus carota* L.) during wet chilling storage. Scientia Hort. 41:201-207.

Overley, F.L. and E.L. Overholser. 1931. Some effects of fertilizer upon storage response of Jonathan apples. Proc. Amer. Soc. Hort. Sci. 28:572-577.

Ozbun, J.L., R.J. Volk, and W.A. Jackson. 1965. Effects of potassium deficiency on photosynthesis, respiration and the utilization of photosynthetic reductant by mature bean leaves. Crop Sci. 5:497-500.

Page, E.R. and T.J. Cleaver. 1983. Effects of nitrogen fertilizers on the emergence of vegetable seedlings. J. Sci. Food Agric. 34:13-22.

Pantastico, B. 1975. Postharvest Physiology and Utilization of Tropical and

Subtropical Fruits and Vegetables. AVI Publ. Co. Inc., Westport, CT.

Pedro, G. 1973. Pedogenesis in the humid tropics and the dynamics of K, pp. 23-49. IN: Potassium in Tropical Crops and Soils. Proc. 10th Colloq., Intern. Potash Inst., Bern, Switzerland.

Peirce, L.C. 1987. Vegetable Characteristics, Production and Marketing. John Wiley and sons, Inc., New York.

Penningsfeld, F. and L. Forchthammer. 1961. Response of the most important vegetables on a varied nutrient ratio in fertilizer application. Die Gartenbauwics. 8:347-372. CITED IN: K. Mengel and E.A. Kirkby. 1987. Principles of Plant Nutrition. 4th ed. Intern. Potash Inst., Berne, Switzerland.

Peoples, T.R. and D.W. Koch. 1979. Role of potassium in carbon dioxide assimilation in *Medicago sativa* L. Plant Physiol. 63:878-881.

Perrenoud, S. 1990. Potassium and plant health. Intern. Potash Inst., Bern, Switzerland.

Phan, C.T. 1987. Biochemical and physiological changes during the harvest period. pp. 9-22. IN: J. Weichmann (ed.) Postharvest Physiology of Vegetables. Marcel Dekker, Inc., New York and Basel.

Phan, C.T., H. Hsu, and S.K. Sarkar. 1973. Physical and chemical changes in the carrot root during storage. Can. J. Plant Sci. 53:635-641.

Picha, D.H. and C.B. Hall. 1981. Influence of potassium, cultivar, and season on tomato graywall and blotchy ripening. J. Amer. Soc. Hort. Sci. 106:704-708.

Raghavan, G.S.V., R. Bovell, and M. Chayet. 1980. Storability of fresh carrots in a simulated jacketed storage. ASAE Trans. 23:1521-1524

Raschke, K. 1979. Movement of stomate. pp. 383-441. IN: W. Haupt and M.E. Feinleib (eds.) Physiology of Movements. Encycl. Plant Physiol. New series, vol. 7. Springer-Verlag, Berlin.

Reeves, J.H. 1967. The effects of three mineral elements and two management practices upon selected chemical and physical factors in Redhaven and Elberta peaches. MSc. Thesis. North Carolina State Univ., Raleigh. CITED IN: N. R. Usherwood. 1985. The role of potassium in crop quality. pp. 489-513. IN: R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Reeve, E. and J.W. Shive. 1944. Potassium-boron and calcium-boron relationship in plant nutrition. Soil Sci. 57:1-15.

Rhodes, M.J.C. 1980. The physiological basis for the conservation of food crops. Prog. Food Nutr. Sci. 4:11-20.

Robinson, J.E., K.M. Browne and W.G. Burton. 1975. Storage characteristics of some vegetables and soft fruits. Ann. Appl. Biol. 81:399-408.

Rolle, R.S. and G.W. Chism. 1987. Physiological consequences of minimally processed fruits and vegetables. J. Food Qual. 10:157-177.

Rooke, E.A. and L. van den Berg. 1985. Equilibrium relative humidity of plant tissue. Can. Inst. Food Sci. Technol. J. 18:85-88.

Ryall, A.L. and W.J. Lipton. 1979. Handling, Transportation and Storage of Fruits and Vegetables. Vol. 1, 2nd ed. Vegetables and Melons, AVI Publishing Co. Inc. Westport, Connecticut.

Salisbury, F.B. and C.W. Ross. 1992. Plant Physiology. 4th edition. Wadsworth publ. Co., Belmont, CA.

Salter, P.J., J.E. Currah, and J.R. Fellows. 1979. The effects of plant density, spatial arrangement and time of harvest on yield and root size in carrots. J. Agric. Sci. Camb. 93:431-440.

Salunke, D.K. and B.B. Desai. 1984. Postharvest Biotechnology of Vegetables. Vol. 2., CRC Press, Inc. Boca Raton, Florida.

Sanchez, C.A., M. Lockhart, and P.S. Porter. 1991. Response of radish to phosphorus and potassium fertilization on histosols. HortSci. 26:30-32.

Sanford, W.G. 1968. Potassium builds pineapple quality. Better crops plant food 52:12-13.

Sarkar, S.K. and C.T. Phan. 1979. Naturally occurring and ethylene-induced phenolic compounds in the carrot root. J. Food protection 42:526-534.

Sastry, S.K. 1985. Moisture loss from perishable commodities. Intern. J. Refrig. on 8:343-346.

Sastry, S.K., C.D. Baird, and D.E. Buffington. 1978. Transpiration rates of certain fruits and vegetables. ASHRAE Trans. 84:237-255.

Sastry, S.K. and D.E. Buffington. 1982. Transpiration rates of stored perishable commodities. A mathematical model and experiments on tomatoes. Intern. J. Refrig. 6:84-96

Scharrer, K. and W. Werner. 1957. Dependence of ascorbic acid content on the nutrition of the plant. Z. Pflanzenernahr. Dung. Bodenk. 77:97-110. CITED IN: K. Mengel and E.A. Kirkby. 1987. Principles of Plant Nutrition. 4th ed. Intern. Potash Inst., Berne, Switzerland.

Schippers, P.A. 1968. The influence of rates of nitrogen and potassium application on the yield and specific gravity of four potato varieties. Eur. Potato J. 11:23-33.

Scholz, E.W., H.B. Johnson and W.R. Buford. 1963. Heat evaluation rates of some Texas-grown fruits and vegetables. J. Rio. Grande Valley Hort. Sci. 17:170-175.

Sekhon, G.S. 1985. Potassium in Indian agriculture. J. Indian Soc. Soil Sci. 33:754-760.

Shear, C.B. 1975. Calcium-related disorders of fruits and vegetables. HortSci. 10:361-365.

Shewfelt, R.L. 1986. Postharvest treatment for extending the shelf life of fruits and vegetables. Food Technol. 40:70-80.

Shirazi, A. and A.C. Cameron. 1993. Measuring transpiration rates of tomato and other detached fruit. HortSci. 28:1035-1038.

Shukla, U.C. and A.K. Mukhi. 1979. Sodium, potassium, and zinc relationship in corn. Agron. J. 71:235-237.

Singh, S. and C.P. Sharma. 1988. Potassium nutrition of cauliflower. J. Hort. Sci. 63:629-633.

Sistler, F.E., M.E. Wright, and R.M. Watson. 1983. Measurement of physical properties of biological products with a video analyzer. Proc. of the National Conference on Agricultural Electronics Applications (II):646-651. Chicago, IL.

Smith, S.R. and P. Hadley. 1989. Effects of organic and inorganic fertilizers on the seedling emergence of vegetable crops. J. Hort. Sci. 64:581-589.

Smith, T.A. and J.L. Garraway. 1964. N-carbamylputrescine - an intermediate in the formation of putrescine by barley. Phytochemistry 3:23-26.

Smith, T.A. and C. Sinclair. 1967. The effect of acid feeding on amine formation in barley. Ann. Bot. 31:103-111.

Southards, C.J. and C.H. Miller. 1962. A greenhouse study on the macroelement nutrition of the carrot. Proc. Amer. Soc. Hort. sci. 81:335-340.

St. Amand, P.C. and W.M. Randle. 1991. Ethylene production as possible indicator of wound healing in roots of several sweet potato cultivars. Euphytica 53:97-102.

Statistical Analysis System Institute, Inc. 1989. SAS/STAT User's guide. Version 6,Vol. 2. 4th ed., SAS Institute, Inc., Cary, NC.

Steingrover, E.E. 1983. Storage of osmotically active compounds in the tap root of *Daucus carota* L. J. Exptl. Bot. 34:548-552.

Stikeleather, L.F. and K.P. Harrel. Sweet potato damage as measured by weight loss. Paper No. 90-1614. An ASAE meeting presentation. ASAE St. Joseph, MI.

Stoll, K. and J. Weichmann. 1987. Root vegetables. pp. 541-553. IN: J. Weichmann (ed.) Postharvest Physiology of Vegetables. Marcel Dekker, Inc. New York and Basel.

Strandberg, J.O. and J.M. White. 1979. Effect of soil compaction on carrot roots. J. Amer. Soc. Hort. Sci. 104:344-349.

Stromberger, J.A., C.Y. Tsai, and D.M. Huber. 1994. Interactions of potassium with nitrogen and their influence on growth and yield potential in maize. J. Plant Nutr. 17:19-37.

Suelter, C.H. 1970. Enzymes activated by monovalent cations. Science 168:789-795.

Suelter, C.H. 1974. Monovalent cations in enzyme-catalyzed reactions. pp. 201-251. IN: Siegel (ed.) Metal Ions in Biological Systems. Vol. 3. Marcel Dekker, New York.

Suelter, C.H. 1985. Role of potassium in enzyme catalysis. pp. 337-349. IN: R.D. Munson (ed.) Potassium in Agriculture. ASA, CSSA, SSSA. Madison, WI.

Sukumaran, N.P., J.S. Jassal and S.C. Verma. 1990. Quantitative determination of suberin deposition during wound healing in potatoes (*Solanum tuberosum* L.) . J. Sci. Food Agric. 51:271-274.

Thompson, R. 1969. Some factors affecting carrot root shape and size. Euphytica 18:277-285.

Tindall, H.D. and F.J. Proctor. 1980. Loss prevention of horticultural crops in the tropics. Prog. Food and Nutr. Sci. 4:25-40.

Tinker, P.B., L. Reed, C. Legg, and S. Hoyer-Pederson. 1977. The effects of chloride in fertilizer salts on crop seed germination. J. Sci. Food Agric. 28:1045-1051.

Tisdale, S.L., W.L. Nelson, J.D. Beaton, and J.L. Havlin. 1993. Soil Fertility and Fertilizers. 5th edition. MacMillan Publishing Co. New York.

Touraine, B., N. Grignon, and C. Grignon. 1988. Charge balance in NO_3^--fed soybean. Estimation of K^+ and carboxylate recirculation. Plant Physiol. 88:605-612.

Trolldenier, G. and E. Zehler. 1976. Relationship between plant nutrition and rice diseases. pp. 85-93. IN: Fertilizer Use and Plant Health. Proc. 12th Colloq. Intern. Potash Inst., Bern, Switzerland.

Tucker, W.G. 1974. The effect of mechanical harvesting on carrot quality and storage performance. Acta Hort. 38:359-372.

Ulrich, A. and K. Okhi. 1956. Chlorine, bromine, and sodium as nutrients for sugar beet plants. Plant Physiol. 31:171-181.

Ulrich, A. and K. Ohki. 1966. Potassium. pp. 362-393. IN: H.D. Chapman (ed.) Diagnostic Criteria for Plants and Soils. University of California, Division of Agric. Sci.

Umiecka, L. 1980. The effect of different factors on the suitability of carrots for prepackaging in polyethylene bags and their storage. Acta Hort. 116:121-132.

Umiel, N., A.F. Kust, and W.H. Gabelman. 1972. A technique for studying quantitatively the variation in size and shape of carrot roots. HortSci. 7:273-276.

USDA. 1965. United States Standards for Grades of Topped Carrots. USDA Agric. Marketing Serv., Washington, D.C.

Usherwood, N.R. 1985. The role of potassium in crop quality. pp. 489-509. IN: R.D. Munson (ed.) Potassium in agriculture. ASA, CSSA, and SSSA, Madison, WI.

Vereecke, M. and D. van Maercke. 1979. Subtractive fertilization experiment on carrots in relation to soil- and leaf analysis, yield and quality. Acta Hort. 93:197-208.

Voisey, P. and W. Mason. 1963. Note on an improved device for measuring leaf areas. Can. J. Plant Sci. 43:247-251.

Voisey, P.W. and M. Kloek. 1964. A portable leaf area measuring instrument. Can J.

Plant Sci. 44:389-391.

Wakhloo, J.L. 1975. Studies on the growth, flowering, and production of female sterile flowers as affected by different levels of foliar K in *Solanum sisymbrifolium* L. J. Exptl. Bot. 26:425-450.

Walker, J.C., C.L.V. Edington, and M.U. Naynder. 1961. Tip burn of cabbage - Nature and control. Wisconsin Agr. Exp. Sta. Bull. 230.

Walter, W.M,. Jr., and W.E. Schadel. 1982. A rapid method for evaluating curing progress in sweet potatoes. J Amer. Soc. Hort. Sci. 107:1129-1133.

Walter, W.M., Jr., and W.E. Schadel. 1983. Structure and composition of normal skin (periderm) and wound tissue from cured sweet potatoes. J. Amer. Soc. Hort. Sci. 108:909-914.

Weichmann, J. and R. Kappel. 1977. Harvesting dates and storage ability of carrots. Acta Hort. 62:191-196.

Wells, A.W. 1962. Effects of storage temperature and humidity on loss of weight by fruit. USDA. Marketing Res. Rpt. 539.

Whitaker, T.W., A.F. Sherf, W.H. Lange, C.W. Nicklow, and J.D. Radewald. 1970. Carrot production in the United States. USDA-ARS Agric, Handbook. No. 375.

Wilcox, G.E. 1964. Effect of potassium on tomato growth and production. Proc. Amer. Soc. Hort. Sci. 85:484-489.

Wilcox, G.E. 1969. Potassium needs - Diagnosis and use on vegetable crops. HortSci. 4:41.

Wills, R.B.H., W.B. McGlasson, D. Graham, T.H. Lee, and E.H. Hall. 1989. Postharvest: An Introduction to the Physiology and Handling of Fruits and Vegetables. Van Nostrand Reinhold, New York.

Winsor, C.W. 1973. Nutrition. pp. 35-42. IN: H.G. Kingman (ed.) The UK tomato manual. Grower books, London.

Wolswinkel, P. and A. Ammerlaan. 1985. Effects of potassium on sucrose and amino acid release from the seed coat of developing seeds of *Pisum sativum* L. Ann. Bot. 56:35-43.

Wyn Jones, R.G. and A. Pollard. 1983. Proteins, enzymes and inorganic ions. pp. 528-

562. IN: A. Lauchli and R.L. Bieleski (eds.) Inorganic Plant Nutrition. Encycl. Plant Physiol., New series, Vol. 15B. Springer-Verlag, Berlin, Heidelberg, New York.

Xu, Q.F., C.E. Tsai, and C.Y. Tsai. 1992. Interaction of potassium with the form and amount of nitrogen nutrition on growth and nitrogen uptake of maize. J. Plant Nutr. 15:23-33.

Yamaguchi, M., F.D. Howard, and P.A. Minges. 1958. Brown checking of celery, a symptom of boron deficiency. Proc. Amer. Soc. Hort. Sci. 71:455-467.

Zeiger, E. 1983. The biology of stomatal guard cells. Annu. Rev. Plant Physiol. 34:441-475.

Appendices

Appendix 1: Analysis of variance for length at early harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	126.965	42.32180	1.59	0.2221
Variety (V)	7	93.019	13.28854	0.50	0.8249
R x V	21	559.620	26.64857	2.76	0.0002
Error	159	1536.324	9.66241		
Total	190	2316.421			

R-Square = 0.34 C.V. = 18.68

Appendix 2: Analysis of variance for greatest diameter at early harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	7.8082	2.602743	4.33	0.0159
Variety (V)	7	3.1522	0.450324	0.75	0.6340
R x V	21	12.6159	0.600758	2.93	0.0001
Error	159	32.5586	0.204771		
Total	190	55.9491			

R-Square = 0.42 C.V. = 15.68

Appendix 3: Analysis of variance for crown diameter at early harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	6.68265	2.227553	6.69	0.0001
Variety (V)	7	2.93490	0.419272	1.26	0.3163
R x V	21	6.98712	0.332720	2.63	0.0004
Error	159	20.13710	0.126648		
Total	190	36.66516			

R-Square = 0.45 C.V. = 18.78

Appendix 4: Analysis of variance for weight at early harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	18117.86	6039.288	2.70	0.0715
Variety (V)	7	9771.47	1395.925	0.62	0.7300
R x V	21	46925.72	2234.558	3.06	0.0001
Error	159	115973.60	729.393		
Total	190	190725.10			

R-Square = 0.39 C.V. = 45.66

Appendix 5: Analysis of variance for shape at early harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	0.048505	0.016167	2.07	0.1351
Variety (V)	7	0.072870	0.010410	1.33	0.2847
R x V	21	0.164191	0.007818	1.17	0.2887
Error	159	1.066803	0.006709		
Total	190	1.350517			

R-Square = 0.21 C.V. = 15.62

Appendix 6: Analysis of variance for length at late harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	44.500	14.83352	0.96	0.4280
Variety (V)	7	563.806	80.54380	5.24	0.0014
R x V	21	323.022	15.38201	2.21	0.0031
Error	160	1115.785	6.97365		
Total	191	2047.114			

R-Square = 0.45 C.V. = 15.47

Appendix 7: Analysis of variance for greatest diameter at late harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	2.11913	0.706378	2.74	0.0688
Variety (V)	7	2.55858	0.365511	1.42	0.2498
R x V	21	5.40866	0.257555	1.07	0.3906
Error	160	38.68140	0.241758		
Total	191	48.76778			

R-Square = 0.21 C.V. = 15.59

Appendix 8: Analysis of variance for crown diameter at late harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	1.42494	0.474980	2.73	0.0699
Variety (V)	7	2.48431	0.354902	2.04	0.0979
R x V	21	3.65844	0.174211	1.18	0.2785
Error	160	23.69330	0.148083		
Total	191	31.26100			

R-Square = 0.24 C.V. = 18.39

Appendix 9: Analysis of variance for weight at late harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	7002.8	2334.294	1.91	0.1587
Variety (V)	7	15950.6	2278.662	1.87	0.1270
R x V	21	25648.0	1221.336	1.34	0.1570
Error	160	145771.6	911.0727		
Total	191	194373.2			

R-Square = 0.25 C.V. = 40.15

Appendix 10: Analysis of variance for shape at late harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	0.087485	0.029161	2.70	0.0714
Variety (V)	7	0.052547	0.007506	0.70	0.6747
R x V	21	0.226414	0.010781	1.46	0.0982
Error	160	1.180500	0.007378		
Total	191	1.546947			

R-Square = 0.24 C.V. = 15.63

Appendix 11: Analysis of variance for specific gravity at early harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	0.011609	0.003869	6.82	0.0022
Variety (V)	7	0.004445	0.000635	1.12	0.3879
R x V	21	0.011912	0.000567	1.77	0.0260
Error	159	0.050983	0.000320		
Total	190	0.078996			

R-Square = 0.35 C.V. = 1.72

Appendix 12: Analysis of variance for specific gravity at late harvest.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	0.001005	0.000335	1.74	0.1897
Variety (V)	7	0.001536	0.000219	1.14	0.3772
R x V	21	0.004048	0.000192	0.62	0.9013
Error	160	0.049916	0.000311		
Total	191	0.056507			

R-Square = 0.12 C.V. = 1.71

Appendix 13. Analysis of variance for surface area of carrots at early harvest.

Source	DF	SS	MS	F Value	Pr > F
Replication (R)	3	70514.469	23504.82	2.67	0.0739
Variety (V)	7	26666.892	3809.55	0.43	0.8706
$Error_a$	21	184899.721	8804.74	127.59	0.0001
Samples S(R*V)	159	358062.951	2251.96	32.63	0.0001
Methods (M)	2	7964.291	3982.14	18.61	0.0001
V*M	14	2099.913	149.99	0.70	0.7619
$Error_b$	47	10057.370	213.98	3.10	0.0001
Error	312	21530.082	69.00		
Total	565	683833.664			

R-Square = 0.96 C.V. = 8.39

Appendix 14. Analysis of variance for surface area of carrots at late harvest.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	10800.297	3600.099	0.83	0.4944
Variety (V)	7	67252.827	9607.547	2.20	.07621
$Error_a$	21	91555.493	4359.785	56.29	0.0001
Samples S(R*V)	160	464915.666	2905.723	37.52	0.0001
Method (M)	2	22398.139	11199.069	144.60	0.0001
V*M	14	3248.931	232.066	3.00	0.0002
$Error_b$	48	9902.203	206.296	2.66	0.0001
Error	319	24706.735	77.451		
Total	574	696315.371			

R-Square = 0.96 C.V. = 7.34

Appendix 15. Surface area of carrots using three different methods at early and late harvests.

	Mean surface areas					
	Early harvest			Late harvest		
Variety	Baugerod	Surface replica	Slicing	Baugerod	Surface replica	Slicing
Carochoice	101	92	95	121	117	133
Gold-Pak	108	102	97	100	96	109
Eagle	94	86	85	116	111	124
Paramount	96	96	88	141	134	150
Imperator Sp.	108	104	100	122	117	133
Caropride	116	117	103	122	115	122
Celloking	100	95	92	108	103	118
Top-Pak	104	97	94	122	107	134

Imperator Sp. = Imperator Special 58

Appendix 16. Analysis of variance for length of three grades of carrots from B.C. Coast Vegetable Co-operative.

Source	Df	SS	MS	F Value	Pr > F
Grade (G)	2	89.76800	44.88400	7.62	0.0040
Sample (S)	9	34.92533	3.880592	0.66	0.7346
Error	18	106.0786	5.893259		
Total	29	230.7720			

R-Square = 0.54 C.V. = 13.01

Appendix 17. Analysis of variance for greatest diameter of three grades of carrots from B.C. Coast Vegetable Co-operative.

Source	Df	SS	MS	F Value	Pr > F
Grade (G)	2	21.91680	10.9584	75.50	0.0001
Sample (S)	9	0.529680	0.0588	0.41	0.9159
Error	18	2.612660	0.1451		
Total	29	25.05914			

R-Square = 0.89 C.V. = 10.37

Appendix 18. Analysis of variance for weight of three grades of carrots from B.C. Coast Vegetable Co-operative.

Source	Df	SS	MS	F Value	Pr > F
Grade (G)	2	149610.6	74805.33	47.39	0.0001
Sample (S)	9	9790.567	1087.841	0.69	0.7100
Error	18	28415.40	1578.63		
Total	29	187816.6			

R-Square = 0.84 C.V. = 31.15

Appendix 19. Analysis of variance for shape of three grades of carrots from B.C. Coast Vegetable Co-operative.

Source	Df	SS	MS	F Value	Pr > F
Grade (G)	2	0.002940	0.001470	0.17	0.8442
Sample (S)	9	0.076333	0.008481	0.99	0.4832
Error	18	0.154726	0.008595		
Total	29	0.234000			

R-Square = 0.34 C.V. = 15.71

Appendix 20. Analysis of variance for methods for determining surface area of three grades of carrots.

Source	Df	SS	MS	F Value	Pr > F
Grade (G)	2	310789.97	155394.98	50.42	0.0001
Samples G(S)	27	83215.37	3082.05	32.31	0.0001
Method (M)	2	10166.72	5083.36	53.30	0.0001
G x M	4	2659.41	664.85	6.97	0.0001
Error	54	5150.38	95.38		
Total	89	411981.86			

R-Square = 0.98 C.V. = 5.63

Appendix 21. Analysis of variance for shoot length at first harvest on 22/7/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	338.9420	112.9806	6.41	0.0052
K	5	184.8826	36.97653	2.10	0.1221
Klin	1	81.26153	81.26153	4.61	0.0485
Kqua	1	0.237453	0.237453	0.01	0.9091
Kcub	1	64.57893	64.57893	3.67	0.0748
Kdev	1	1.939124	1.939124	0.11	0.7446
KCl vs K_2SO_4	1	36.86400	36.86400	2.09	0.1686
R*K	15	264.2300	17.61533	0.93	0.5313
Error	96	1812.804	18.88337		
Total	119	2600.858			

R-Square = 0.30 C.V. = 6.76

Appendix 22. Analysis of variance for shoot fresh weight at first harvest on 22/7/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1486.292	495.4307	3.64	0.0373
K	5	1597.630	319.5260	2.35	0.0916
Klin	1	1253.458	1253.458	9.22	0.0083
Kqua	1	0.197070	0.197070	0.00	0.9701
Kcub	1	92.32231	92.32231	0.68	0.4228
Kdev	1	83.07190	83.07190	0.61	0.4465
KCl vs K_2SO_4	1	165.4048	165.4048	1.22	0.2874
R*K	15	2038.964	135.9309	1.51	0.1187
Error	95	8578.691	90.30202		
Total	118	13661.45			

R-Square = 0.37 C.V. = 31.65

Appendix 23. Analysis of variance for shoot dry weight at first harvest on 22/7/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	13.22163	4.407210	2.68	0.0846
K	5	20.67741	4.135483	2.51	0.0765
Klin	1	11.44683	11.44683	6.95	0.0187
Kqua	1	0.142683	0.142683	0.09	0.7725
Kcub	1	2.284317	2.284317	1.39	0.2573
Kdev	1	1.503722	1.503722	0.91	0.3545
KCl vs K_2SO_4	1	5.292562	5.292562	3.21	0.0932
R*K	15	24.70384	1.646923	1.47	0.1322
Error	94	105.2411	1.119587		
Total	117	164.0494			

R-Square = 0.35   C.V. = 34.72

Appendix 24. Analysis of variance for shoot dry matter at first harvest on 22/7/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	6.935875	2.311958	1.33	0.3006
K	5	9.297350	1.859470	1.07	0.4139
Klin	1	1.095784	1.095784	0.63	0.4390
Kqua	1	0.302425	0.302425	0.17	0.6821
Kcub	1	4.091479	4.091479	2.36	0.1453
Kdev	1	0.767118	0.767118	0.44	0.5160
KCl vs K_2SO_4	1	2.889498	2.889498	1.67	0.2162
R*K	15	25.99991	1.733327	1.70	0.0637
Error	92	93.62521	1.017665		
Total	115	135.7023			

R-Square = 0.31   C.V. = 9.90

Appendix 25. Analysis of variance for shoot/root ratio (dry wt) at first harvest on 22/7/93

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.429719	0.143239	0.50	0.6901
K	5	2.188747	0.437749	1.52	0.2430
Klin	1	0.049522	0.049522	0.17	0.6845
Kqua	1	0.807332	0.807332	2.80	0.1151
Kcub	1	1.111839	1.111839	3.85	0.0684
Kdev	1	0.179054	0.179054	0.62	0.4431
KCl vs K_2SO_4	1	0.002761	0.002761	0.01	0.9234
R*K	15	4.326917	0.288461	1.89	0.0335
Error	93	14.16485	0.152310		
Total	116	21.11169			

R-Square = 0.32 C.V. = 30.98

Appendix 26. Analysis of variance for root length at first harvest on 22/7/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	140.2110	46.737021	3.76	0.0339
K	5	99.41060	19.882121	1.60	0.2198
Klin	1	1.570734	1.5707343	0.13	0.7271
Kqua	1	8.914201	8.9142016	0.72	0.4102
Kcub	1	3.986419	3.9864195	0.32	0.5794
Kdev	1	32.61677	32.6167764	2.63	0.1259
KCl vs K_2SO_4	1	52.09806	52.0980625	4.20	0.0585
R*K	15	186.2778	12.418521	1.17	0.3065
Error	96	1017.032	10.594083		
Total	119	1442.931			

R-Square = 0.29 C.V. = 16.54

Appendix 27. Analysis of variance for fresh root weight at first harvest on 22/7/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	205.5566	68.5187	0.28	0.8376
K	5	2031.200	406.241	1.67	0.2020
Klin	1	1180.816	1180.81	4.86	0.0435
Kqua	1	94.23187	94.2318	0.39	0.5428
Kcub	1	79.49345	79.4934	0.33	0.5758
Kdev	1	387.3963	387.396	1.59	0.2260
KCl vs K_2SO_4	1	293.0056	293.005	1.21	0.2895
R*K	15	3645.118	243.007	2.29	0.0081
Error	96	10189.54	106.141		
Total	119	16071.42			

R-Square = 0.36   C.V. = 38.56

Appendix 28. Analysis of variance for root greatest diameter at first harvest on 22/7/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.096380	0.032126	0.17	0.9181
K	5	1.715290	0.343058	1.77	0.1806
Klin	1	1.220370	1.220370	6.28	0.0242
Kqua	1	0.115988	0.115988	0.60	0.4517
Kcub	1	0.184917	0.184917	0.95	0.3448
Kdev	1	0.190642	0.190642	0.98	0.3376
KCl vs K_2SO_4	1	0.007290	0.007290	0.04	0.8490
R*K	15	2.914530	0.194302	1.93	0.0290
Error	96	9.656920	0.100592		
Total	119	14.38312			

R-Square = 0.32   C.V. = 14.98

Appendix 29. Analysis of variance for root dry weight at first harvest on 22/7/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	2.419366	0.806455	0.29	0.8302
K	5	15.52561	3.105123	1.13	0.3885
Klin	1	8.242385	8.242385	2.99	0.1043
Kqua	1	0.375791	0.375791	0.14	0.7171
Kcub	1	0.393939	0.393939	0.14	0.7107
Kdev	1	4.291054	4.291054	1.56	0.2313
KCl vs K_2SO_4	1	2.079852	2.079852	0.75	0.3988
R*K	15	41.35513	2.757008	2.64	0.002
Error	94	98.09803	1.043596		
Total	117	157.6847			

R-Square = 0.37 C.V. = 38.88

Appendix 30. Analysis of variance for root DM at first harvest on 22/7/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	3.007403	1.002467	0.76	0.5335
K	5	13.89852	2.779704	2.11	0.1207
Klin	1	3.754122	3.754122	2.85	0.1121
Kqua	1	6.538789	6.538789	4.96	0.0417
Kcub	1	1.749960	1.749960	1.33	0.2672
Kdev	1	0.397219	0.397219	0.30	0.5911
KCl vs K_2SO_4	1	1.485327	1.485327	1.13	0.30
R*K	15	19.77053	1.318035	1.66	0.0718
Error	94	74.43043	0.791813		
Total	117	111.2432			

R-Square = 0.33 C.V. = 9.06

Appendix 31. Analysis of variance for shoot length at second harvest on 20/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	162.5550	54.18500	3.56	0.0398
K	5	289.0016	57.80033	3.80	0.0201
Klin	1	28.68012	28.68012	1.89	0.1898
Kqua	1	50.97458	50.97458	3.35	0.0870
Kcub	1	121.5369	121.5369	7.99	0.0127
Kdev	1	56.04196	56.04196	3.69	0.0741
KCl vs K_2SO_4	1	33.67225	33.67225	2.22	0.1574
R*K	15	228.0270	15.20180	0.54	0.9125
Error	96	2710.416	28.23350		
Total	119	3389.999			

R-Square = 0.20 C.V. = 7.13

Appendix 32. Analysis of variance for shoot fresh weight at second harvest on 20/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	317.7049	105.9016	0.67	0.5807
K	5	997.8515	199.5703	1.27	0.3265
Klin	1	125.6540	125.6540	0.80	0.3850
Kqua	1	334.0246	334.0246	2.13	0.1652
Kcub	1	211.2051	211.2051	1.35	0.2641
Kdev	1	332.9474	332.9474	2.12	0.1658
KCl vs K_2SO_4	1	0.128823	0.128823	0.00	0.9775
R*K	15	2353.886	156.9257	0.94	0.5287
Error	96	16108.17	167.7935		
Total	119	19777.61			

R-Square = 0.18 C.V. = 31.69

Appendix 33. Analysis of variance for shoot dry weight at second harvest on 20/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	14.85783	4.952613	1.23	0.3344
K	5	25.13998	5.027997	1.25	0.3368
Klin	1	0.215765	0.215765	0.05	0.8203
Kqua	1	6.733347	6.733347	1.67	0.2160
Kcub	1	8.309968	8.309968	2.06	0.1719
Kdev	1	6.307732	6.307732	1.56	0.2304
KCl vs K_2SO_4	1	4.147360	4.147360	1.03	0.3268
R*K	15	60.54482	4.036322	1.02	0.4437
Error	95	376.5665	3.963859		
Total	118	477.4678			

R-Square = 0.21 C.V. = 33.63

Appendix 34. Analysis of variance for shoot DM at second harvest on 22/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	40.61519	13.53839	1.66	0.21 71
K	5	7.807709	1.561542	0.19	0.9610
Klin	1	1.882302	1.882302	0.23	0.6374
Kqua	1	1.039712	1.039712	0.13	0.7257
Kcub	1	0.842902	0.842902	0.10	0.7519
Kdev	1	0.277249	0.277249	0.03	0.8560
KCl vs K_2SO_4	1	3.428664	3.428664	0.42	0.5260
R*K	15	121.9943	8.132955	0.65	0.8257
Error	86	1077.425	12.52819		
Total	109	1245.752			

R-Square = 0.13 C.V. = 25.14

Appendix 35. Analysis of variance for shoot/root ratio (dry wt) at second harvest on 22/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1.484285	0.494761	4.54	0.0187
K	5	0.826253	0.165250	1.52	0.2434
Klin	1	0.009537	0.009537	0.09	0.7714
Kqua	1	0.170520	0.170520	1.56	0.2302
Kcub	1	0.306296	0.306296	2.81	0.1144
Kdev	1	0.213466	0.213466	1.96	0.1820
KCl vs K_2SO_4	1	0.121000	0.121000	1.11	0.3087
R*K	15	1.634860	0.108990	1.53	0.1105
Error	94	6.699520	0.071271		
Total	117	10.41640			

R-Square = 0.35 C.V. = 40.07

Appendix 36. Analysis of variance for root length at second harvest on 20/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	96.50166	32.16722	3.86	0.0315
K	5	66.07466	13.21493	1.58	0.2243
Klin	1	39.93691	39.93691	4.79	0.0449
Kqua	1	15.47080	15.47080	1.85	0.1934
Kcub	1	9.168980	9.168980	1.10	0.3111
Kdev	1	0.124780	0.124780	0.01	0.9043
KCl vs K_2SO_4	1	1.089000	1.089000	0.13	0.7229
R*K	15	125.1313	8.342089	1.46	0.1365
Error	96	548.8320	5.717000		
Total	119	836.5396			

R-Square = 0.34 C.V. = 12.85

Appendix 37. Analysis of variance for root fresh weight at second harvest on 20/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	6447.026	2149.008	2.86	0.0721
K	5	4682.620	936.5240	1.25	0.3370
Klin	1	280.4601	280.4601	0.37	0.5505
Kqua	1	2907.968	2907.968	3.87	0.0680
Kcub	1	501.1728	501.1728	0.67	0.4271
Kdev	1	624.5067	624.5067	0.83	0.3765
KCl vs K_2SO_4	1	260.2432	260.2432	0.35	0.5651
R*K	15	11279.69	751.9798	1.56	0.1004
Error	93	44808.74	481.8145		
Total	116	67070.93			

R-Square = 0.33 C.V. = 24.62

Appendix 38. Analysis of variance for root greatest diameter at second harvest on 22/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.577275	0.192425	1.06	0.3939
K	5	1.130444	0.226088	1.25	0.3352
Klin	1	0.263668	0.263668	1.46	0.2460
Kqua	1	0.429783	0.429783	2.38	0.1441
Kcub	1	0.196882	0.196882	1.09	0.3134
Kdev	1	0.066362	0.066362	0.37	0.5538
KCl vs K_2SO_4	1	0.169000	0.169000	0.93	0.3491
R*K	15	2.713719	0.180914	1.38	0.1749
Error	96	12.62212	0.131480		
Total	119	17.04355			

R-Square = 0.25 C.V. = 10.55

Appendix 39. Analysis of variance for root dry weight at second harvest on 20/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	298.7158	99.57196	8.09	0.0019
K	5	72.63715	14.52743	1.18	0.3642
Klin	1	0.459177	0.459177	0.04	0.8494
Kqua	1	42.93824	42.93824	3.49	0.0815
Kcub	1	23.59380	23.59380	1.92	0.1864
Kdev	1	3.408618	3.408618	0.28	0.6064
KCl vs K_2SO_4	1	0.023522	0.023522	0.00	0.9657
R*K	15	184.6153	12.30769	2.16	0.0130
Error	94	535.0093	5.691589		
Total	117	1085.899			

R-Square = 0.50 C.V. = 24.99

Appendix 40. Analysis of variance for root DM at second harvest on 20/8/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	102.6798	34.22661	3.94	0.0294
K	5	18.22659	3.645318	0.42	0.8277
Klin	1	0.466300	0.466300	0.05	0.8199
Kqua	1	0.065456	0.065456	0.01	0.9320
Kcub	1	0.462300	0.462300	0.05	0.8206
Kdev	1	0.068346	0.068346	0.01	0.9305
KCl vs K_2SO_4	1	16.95131	16.95131	1.95	0.1826
R*K	15	130.2274	8.681830	1.06	0.4043
Error	87	712.1376	8.185490		
Total	110	967.6184			

R-Square = 0.26 C.V. = 26.39

Appendix 41. Analysis of variance for shoot length at third harvest on 4/10/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	267.6726	89.22422	1.34	0.2992
K	5	288.6346	57.72693	0.87	0.5262
Klin	1	55.02173	55.02173	0.83	0.3780
Kqua	1	1.908000	1.908000	0.03	0.8679
Kcub	1	24.68414	24.68414	0.37	0.5519
Kdev	1	14.69737	14.69737	0.22	0.6454
KCl vs K_2SO_4	1	192.2822	192.2822	2.88	0.1101
R*K	15	999.8233	66.65489	2.27	0.0087
Error	96	2820.128	29.37633		
Total	119	4376.258			

R-Square = 0.35 C.V.= 7.59

Appendix 42. Analysis of variance for shoot fresh weight at third harvest on 4/10/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	42.21910	14.07303	0.13	0.9407
K	5	403.7619	80.75238	0.75	0.6012
Klin	1	219.6104	219.6104	2.03	0.1747
Kqua	1	82.30804	82.30804	0.76	0.3969
Kcub	1	0.060265	0.060265	0.00	0.9815
Kdev	1	93.76675	93.76675	0.87	0.3666
KCl vs K_2SO_4	1	7.858822	7.858822	0.07	0.7912
R*K	15	1622.977	108.1984	1.09	0.3723
Error	96	9494.259	98.89854		
Total	119	11563.21			

R-Square = 0.17 C.V. = 47.86

Appendix 43. Analysis of variance for shoot dry weight at third harvest on 4/10/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1.460946	0.486982	0.15	0.9275
K	5	9.800805	1.960161	0.61	0.6957
Klin	1	2.985842	2.985842	0.93	0.3514
Kqua	1	3.011143	3.011143	0.93	0.3494
Kcub	1	0.032681	0.032681	0.01	0.9212
Kdev	1	3.717163	3.717163	1.15	0.3001
KCl vs K_2SO_4	1	0.024485	0.024485	0.01	0.9317
R*K	15	48.40739	3.227159	0.88	0.5894
Error	95	348.8941	3.672569		
Total	118	408.5662			

R-Square = 0.14   C.V. = 51.49

Appendix 44. Analysis of variance for shoot/root ratio (dry wt) at third harvest on 4/10/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.210071	0.070023	10.48	0.0006
K	5	0.021329	0.004265	0.64	0.6741
Klin	1	0.001328	0.001328	0.20	0.6621
Kqua	1	0.005660	0.005660	0.85	0.3720
Kcub	1	0.000073	0.000073	0.01	0.9177
Kdev	1	0.010882	0.010882	1.63	0.2214
KCl vs K_2SO_4	1	0.002556	0.002556	0.38	0.5455
R*K	15	0.100254	0.006683	0.82	0.6487
Error	87	0.705711	0.008111		
Total	110	1.045936			

R-Square = 0.32   C.V. = 28.84

Appendix 45. Analysis of variance for root length at third harvest on 4/10/93

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	35.76506	11.92168	0.71	0.5608
K	5	70.52038	14.10407	0.84	0.5417
Klin	1	0.562603	0.562603	0.03	0.8572
Kqua	1	31.60379	31.60379	1.88	0.1902
Kcub	1	6.601869	6.601869	0.39	0.5400
Kdev	1	32.02953	32.02953	1.91	0.1874
KCl vs K_2SO_4	1	0.028090	0.028090	0.00	0.9679
R*K	15	251.7770	16.78513	2.06	0.0187
Error	96	783.5067	8.161529		
Total	119	1141.569			

R-Square = 0.31 C.V. = 14.79

Appendix 46. Analysis of variance for root fresh weight at third harvest on 4/10/93

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	6375.223	2125.074	0.82	0.5044
K	5	18232.64	3646.528	1.40	0.2792
Klin	1	2639.881	2639.881	1.01	0.3297
Kqua	1	5262.805	5262.805	2.02	0.1754
Kcub	1	1911.540	1911.540	0.73	0.4048
Kdev	1	8482.396	8482.396	3.26	0.0910
KC vs lK_2SO_4	1	10.44484	10.44484	0.00	0.9503
R*K	15	39016.00	2601.066	1.13	0.3448
Error	96	221843.9	2310.874		
Total	119	285467.8			

R-Square = 0.22 C.V. = 39.56

Appendix 47. Analysis of variance for root greatest diameter at third harvest on 4/10/93.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1.442940	0.480980	1.37	0.2895
K	5	3.794340	0.758868	2.16	0.1132
Klin	1	0.570173	0.570173	1.63	0.2216
Kqua	1	1.254272	1.254272	3.58	0.0780
Kcub	1	0.113593	0.113593	0.32	0.5776
Kdev	1	1.780025	1.780025	5.08	0.0396
KCl vs K_2SO_4	1	0.083722	0.083722	0.24	0.6321
R*K	15	5.259080	0.350605	0.93	0.5299
Error	96	36.02956	0.375307		
Total	119	46.52592			

R-Square = 0.22 C.V. = 17.02

Appendix 48. Analysis of variance for root dry weight at third harvest on 4/10/93.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	368.3527	122.7842	4.15	0.0251
K	5	215.7381	43.14762	1.46	0.2613
Klin	1	22.29213	22.29213	0.75	0.3993
Kqua	1	8.934327	8.934327	0.30	0.5909
Kcub	1	6.094045	6.094045	0.21	0.6566
Kdev	1	178.7725	178.7725	6.04	0.0267
KCl vs K_2SO_4	1	1.002877	1.002877	0.03	0.8565
R*K	15	444.1872	29.61248	1.30	0.2205
Error	88	2007.069	22.80760		
Total	111	3070.344			

R-Square = 0.34 C.V = 38.85

Appendix 49. Analysis of variance for shoot length at first harvest on 27/6/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	193.3569	64.45230	1.60	0.2308
K	5	212.3274	42.46548	1.06	0.4225
Klin	1	104.2426	104.2426	2.59	0.1283
Kqua	1	3.253415	3.253415	0.08	0.7800
Kcub	1	43.07225	43.07225	1.07	0.3172
Kdev	1	1.740541	1.740541	0.04	0.8380
KCl vs K_2SO_4	1	59.78025	59.78025	1.49	0.2417
R*K	15	603.5855	40.23903	2.42	0.0049
Error	96	1593.568	16.59967		
Total	119	2602.837			

R-Square = 0.38   C.V. = 10.87

Appendix 50. Analysis of variance for shoot fresh weight at first harvest on 27/6/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	22.69078	7.563594	0.22	0.8827
K	5	11.59317	2.318635	0.07	0.9963
Klin	1	2.576337	2.576337	0.07	0.7892
Kqua	1	0.915884	0.915884	0.03	0.8732
Kcub	1	0.572058	0.572058	0.02	0.8996
Kdev	1	1.711436	1.711436	0.05	0.8274
KCl vs K_2SO_4	1	5.836960	5.836960	0.17	0.6878
R*K	15	521.6357	34.77571	4.59	0.0001
Error	96	726.7790	7.570615		
Total	119	1282.698			

R-Square = 0.43   C.V. = 21.85

Appendix 51. Analysis of variance for shoot dry weight at first harvest on 27/6/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.225260	0.075086	0.17	0.9134
K	5	0.196596	0.039319	0.09	0.9926
Klin	1	0.012990	0.012990	0.03	0.8652
Kqua	1	0.000053	0.000053	0.00	0.9913
Kcub	1	0.002307	0.002307	0.01	0.9429
Kdev	1	0.121978	0.121978	0.28	0.6045
KCl vs K_2SO_4	1	0.059290	0.059290	0.14	0.7174
R*K	15	6.536170	0.435744	3.67	0.0001
Error	96	11.40512	0.118803		
Total	119	18.36314			

R-Square = 0.37 C.V = 25.20

Appendix 52. Analysis of variance for shoot DM at first harvest on 27/6/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	5.339909	1.779969	1.16	0.3559
K	5	9.662094	1.932418	1.26	0.3293
Klin	1	3.921570	3.921570	2.57	0.1300
Kqua	1	2.619708	2.619708	1.71	0.2101
Kcub	1	0.018360	0.018360	0.01	0.9142
Kdev	1	3.036068	3.036068	1.99	0.1791
KCl vs K_2SO_4	1	0.045562	0.045562	0.03	0.8652
R*K	15	22.92049	1.528033	2.49	0.0039
Error	96	58.88968	0.613434		
Total	119	96.81217			

R-Square = 0.39 C.V. = 7.23

Appendix 53. Analysis of variance for shoot/root ratio (dry wt) at first harvest on 27/6/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1.384984	0.461661	1.69	0.2116
K	5	0.599955	0.119991	0.44	0.8141
Klin	1	0.050028	0.050028	0.18	0.6747
Kqua	1	0.075963	0.075963	0.28	0.6056
Kcub	1	0.142590	0.142590	0.52	0.4810
Kdev	1	0.323355	0.323355	1.18	0.2937
KCl vs K_2SO_4	1	0.012306	0.012306	0.05	0.8347
R*K	15	4.095375	0.273025	2.11	0.0159
Error	93	12.05203	0.129591		
Total	116	18.13330			

R-Square = 0.33 C.V. = 22.81

Appendix 54. Analysis of variance for root length at first harvest on 27/6/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	7.238666	2.412888	0.39	0.7594
K	5	16.26800	3.253600	0.53	0.7498
Klin	1	0.242856	0.242856	0.04	0.8449
Kqua	1	1.991549	1.991549	0.32	0.5771
Kcub	1	11.05624	11.05624	1.80	0.1992
Kdev	1	2.323296	2.323296	0.38	0.5474
KCl vs K_2SO_4	1	0.529000	0.529000	0.09	0.7730
R*K	15	91.94533	6.129688	1.80	0.0449
Error	96	326.2560	3.398500		
Total	119	441.7080			

R-Square = 0.26 C.V. = 13.17

Appendix 55. Analysis of variance for root fresh weight at first harvest on 27/6/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	57.33268	19.11089	0.60	0.6252
K	5	11.42663	2.285327	0.07	0.9956
Klin	1	0.916041	0.916041	0.03	0.8677
Kqua	1	3.291999	3.291999	0.10	0.7524
Kcub	1	4.027092	4.027092	0.13	0.7272
Kdev	1	1.015753	1.015753	0.03	0.8607
KCl vs K_2SO_4	1	2.157602	2.157602	0.07	0.7983
R*K	15	478.1839	31.87892	2.39	0.0056
Error	96	1281.026	13.34402		
Total	119	1827.969			

R-Square = 0.29 C.V = 35.45

Appendix 56. Analysis of variance for root greatest diameter at first harvest on 27/6/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.360557	0.120185	0.74	0.5419
K	5	0.135278	0.027055	0.17	0.9706
Klin	1	0.058461	0.058461	0.36	0.5562
Kqua	1	0.014536	0.014536	0.09	0.7682
Kcub	1	0.000910	0.000910	0.01	0.9411
Kdev	1	0.054699	0.054699	0.34	0.5690
KCl vs K_2SO_4	1	0.006250	0.006250	0.04	0.8466
R*K	15	2.420102	0.161340	3.38	0.0001
Error	94	4.491590	0.047782		
Total	117	7.405081			

R-Square = 0.39 C.V. = 15.11

Appendix 57. Analysis of variance for root dry weight at first harvest on 27/6/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.340283	0.113427	0.44	0.7262
K	5	0.050123	0.010024	0.04	0.9990
Klin	1	0.001331	0.001331	0.01	0.9435
Kqua	1	0.003930	0.003930	0.02	0.9031
Kcub	1	0.014413	0.014413	0.06	0.8158
Kdev	1	0.003947	0.003947	0.02	0.9029
KCl vs K_2SO_4	1	0.025969	0.025969	0.10	0.7547
R*K	15	3.847409	0.256493	2.53	0.0035
Error	93	9.430115	0.101399		
Total	116	13.65389			

R-Square = 0.30 C.V = 34.40

Appendix 58. Analysis of variance for root DM at first harvest on 27/6/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	4.00058871	1.33352957	2.72	0.0816
K	5	1.05711901	0.21142380	0.43	0.8202
Klin	1	0.06206057	0.06206057	0.13	0.7271
Kqua	1	0.79266408	0.79266408	1.62	0.2231
Kcub	1	0.00076609	0.00076609	0.00	0.9690
Kdev	1	0.03844884	0.03844884	0.08	0.7834
KCl vs K_2SO_4	1	0.16704545	0.16704545	0.34	0.5683
R*K	15	7.36201703	0.49080114	0.63	0.8440
Error	93	72.5599400	0.7802144		
Total	116	85.0120581			

R-Square = 0.14 C.V. = 9.82

Appendix 59. Analysis of variance for shoot length at second harvest on 29/7/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	695.8955	231.9651	6.05	0.0065
K	5	262.9187	52.58375	1.37	0.2893
Klin	1	128.3294	128.3294	3.35	0.0872
Kqua	1	112.9609	112.9609	2.95	0.1065
Kcub	1	0.963806	0.963806	0.03	0.8761
Kdev	1	16.22423	16.22423	0.42	0.5251
KCl vs K_2SO_4	1	3.721000	3.721000	0.10	0.7596
R*K	15	574.7429	38.31619	0.85	0.6182
Error	96	4315.892	44.95721		
Total	119	5849.449			

R-Square = 0.26 C.V. = 11.44

Appendix 60. Analysis of variance for shoot fresh weight at second harvest on 29/7/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	5792.730	1930.910	8.08	0.0019
K	5	351.5195	70.30392	0.29	0.9086
Klin	1	0.000354	0.000354	0.00	0.9990
Kqua	1	6.453301	6.453301	0.03	0.8716
Kcub	1	256.6890	256.6890	1.07	0.3163
Kdev	1	92.77498	92.77498	0.39	0.5425
KCl vs K_2SO_4	1	0.114490	0.114490	0.00	0.9828
R*K	15	3583.007	238.8671	1.27	0.2386
Error	95	17913.44	188.5625		
Total	118	27654.98			

R-Square = 0.35 C.V. = 35.31

Appendix 61. Analysis of variance for shoot dry weight at second harvest on 29/7/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	87.69139	29.23046	7.78	0.0023
K	5	6.517979	1.303595	0.35	0.8763
Klin	1	0.002761	0.002761	0.00	0.9787
Kqua	1	0.597569	0.597569	0.16	0.6957
Kcub	1	3.132154	3.132154	0.83	0.3757
Kdev	1	3.010763	3.010763	0.80	0.3849
KCl vs K_2SO_4	1	0.001094	0.001094	0.00	0.9866
R*K	15	56.36825	3.757883	1.01	0.4561
Error	93	347.4064	3.735553		
Total	116	500.7037			

R-Square = 0.30 C.V. = 38.87

Appendix 62. Analysis of variance for shoot/root ratio (dry weight) at second harvest on 29/7/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.419978	0.139992	7.90	0.0022
K	5	0.165295	0.033059	1.87	0.1605
Klin	1	0.106144	0.106144	5.99	0.0272
Kqua	1	0.001892	0.001892	0.11	0.7483
Kcub	1	0.000652	0.000652	0.04	0.8504
Kdev	1	0.012451	0.012451	0.70	0.4151
KCl vs K_2SO_4	1	0.043367	0.043367	2.45	0.1386
R*K	15	0.265837	0.017722	0.90	0.5618
Error	93	1.822465	0.019596		
Total	116	2.701622			

R-Square = 0.32 C.V. = 27.32

Appendix 63. Analysis of variance for shoot DM at second harvest on 29/7/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	5.346967	1.782322	2.28	0.1206
K	5	2.847506	0.569501	0.73	0.6119
Klin	1	0.441366	0.441366	0.57	0.4636
Kqua	1	0.626399	0.626399	0.80	0.3844
Kcub	1	1.690119	1.690119	2.17	0.1617
Kdev	1	0.031155	0.031155	0.04	0.8443
KCl vs K_2SO_4	1	0.024363	0.024363	0.03	0.8621
R*K	15	11.70206	0.780137	0.69	0.7888
Error	93	105.2255	1.131457		
Total	116	125.4312			

R-Square = 0.16 C.V. = 8.30

Appendix 64. Analysis of variance for root length at second harvest on 29/7/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	12.48491	4.161638	0.50	0.6911
K	5	55.68441	11.13688	1.33	0.3062
Klin	1	22.50967	22.50967	2.68	0.1225
Kqua	1	0.772992	0.772992	0.09	0.7659
Kcub	1	1.001019	1.001019	0.12	0.7348
Kdev	1	0.920353	0.920353	0.11	0.7453
KCl vs K_2SO_4	1	30.45025	30.45025	3.62	0.0764
R*K	15	126.0745	8.404972	1.12	0.3481
Error	96	719.3240	7.492958		
Total	119	913.5679			

R-Square = 0.21 C.V. = 14.27

Appendix 65. Analysis of variance for root fresh weight at second harvest on 29/7/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	9007.348	3002.449	2.18	0.1324
K	5	8276.173	1655.234	1.20	0.3541
Klin	1	4445.138	4445.138	3.23	0.0923
Kqua	1	140.6543	140.6543	0.10	0.7535
Kcub	1	584.4202	584.4202	0.43	0.5243
Kdev	1	1109.527	1109.527	0.81	0.3832
KCl vs K_2SO_4	1	2003.498	2003.498	1.46	0.2461
R*K	15	20624.00	1374.933	1.80	0.0456
Error	96	73371.82	764.2899		
Total	119	111279.3			

R-Square = 0.34 C.V. = 30.79

Appendix 66. Analysis of variance for root dry weight at second harvest on 29/7/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	87.36153	29.12051	2.07	0.1475
K	5	82.13713	16.42742	1.17	0.3702
Klin	1	49.56279	49.56279	3.52	0.0802
Kqua	1	0.298768	0.298768	0.02	0.8861
Kcub	1	1.562436	1.562436	0.11	0.7437
Kdev	1	11.01042	11.01042	0.78	0.3905
KCl vs K_2SO_4	1	19.68409	19.68409	1.40	0.2555
R*K	15	211.2010	14.08007	1.58	0.0923
Error	96	852.9830	8.885240		
Total	119	1233.682			

R-Square = 0.30 C.V. = 29.88

Appendix 67. Analysis of variance for root DM at second harvest on 29/7/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	6.403656	2.134552	1.73	0.2040
K	5	3.174156	0.634831	0.51	0.7616
Klin	1	0.400121	0.400121	0.32	0.5776
Kqua	1	0.816830	0.816830	0.66	0.4288
Kcub	1	1.362240	1.362240	1.10	0.3102
Kdev	1	0.455463	0.455463	0.37	0.5527
KCl vs K_2SO_4	1	0.162562	0.162562	0.13	0.7218
R*K	15	18.52278	1.234852	1.30	0.2100
Error	96	91.28660	0.950902		
Total	119	119.3871			

R-Square = 0.23   C.V. = 8.71

Appendix 68. Analysis of variance for root greatest diameter at second harvest on 29/794.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1.796337	0.598779	1.96	0.1636
K	5	1.279480	0.255896	0.84	0.5437
Klin	1	0.325082	0.325082	1.06	0.3188
Kqua	1	0.010632	0.010632	0.03	0.8546
Kcub	1	0.324861	0.324861	1.06	0.3189
Kdev	1	0.520064	0.520064	1.70	0.2118
KCl vs K_2SO_4	1	0.092160	0.092160	0.30	0.5910
R*K	15	4.585647	0.305709	1.58	0.0933
Error	95	18.35454	0.193205		
Total	118	26.20992			

R-Square = 0.29 C.V. = 13.60

Appendix 69. Analysis of variance for shoot length at third harvest on 5/8/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	504.3675	168.1225	2.58	0.0921
K	5	490.6192	98.12385	1.51	0.2461
Klin	1	160.9490	160.9490	2.47	0.1368
Kqua	1	232.8215	232.8215	3.58	0.0781
Kcub	1	40.09739	40.09739	0.62	0.4448
Kdev	1	3.214009	3.214009	0.05	0.8272
KCl vs K_2SO_4	1	61.70187	61.70187	0.95	0.3458
R*K	15	976.7896	65.11930	1.93	0.0293
Error	95	3206.174	33.74920		
Total	118	5196.544			

R-Square = 0.38 C.V. = 9.77

Appendix 70. Analysis of variance for shoot fresh weight at third harvest on 5/8/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	147.5041	49.16806	0.23	0.8709
K	5	729.3629	145.8725	0.70	0.6349
Klin	1	3.987366	3.987366	0.02	0.8922
Kqua	1	400.3871	400.3871	1.91	0.1873
Kcub	1	18.46285	18.46285	0.09	0.7707
Kdev	1	308.8920	308.8920	1.47	0.2436
KCl vs K_2SO_4	1	1.618155	1.618155	0.01	0.9312
R*K	15	3145.434	209.6956	1.30	0.2185
Error	94	15174.67	161.4326		
Total	117	19149.72			

R-Square = 0.20 C.V. = 35.56

Appendix 71. Analysis of variance for shoot dry weight at third harvest on 5/8/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.243639	0.081213	0.02	0.9959
K	5	14.06792	2.813584	0.71	0.6271
Klin	1	0.101933	0.101933	0.03	0.8750
Kqua	1	5.011457	5.011457	1.26	0.2794
Kcub	1	2.472970	2.472970	0.62	0.4427
Kdev	1	5.836679	5.836679	1.47	0.2445
KCl vs K_2SO_4	1	0.383527	0.383527	0.10	0.7605
R*K	15	59.67731	3.978487	1.23	0.2628
Error	92	297.0562	3.228871		
Total	115	372.4275			

R-Square = 0.20 C.V. = 36.88

Appendix 72. Analysis of variance for shoot DM at third harvest on 5/8/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	10.30494	3.434981	5.41	0.0100
K	5	6.644815	1.328963	2.09	0.1228
Klin	1	0.808678	0.808678	1.27	0.2767
Kqua	1	0.467145	0.467145	0.74	0.4044
Kcub	1	5.049800	5.049800	7.96	0.0129
Kdev	1	0.293748	0.293748	0.46	0.5066
KCl vs K_2SO_4	1	0.110006	0.110006	0.17	0.6830
R*K	15	9.518853	0.634590	0.59	0.8790
Error	90	97.55478	1.083942		
Total	113	124.0258			

R-Square = 0.21 C.V. = 7.49

Appendix 73. Analysis of variance for shoot/root ratio (dry wt) at third harvest on 5/8/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.035140	0.011713	0.47	0.7049
K	5	0.136513	0.027302	1.11	0.3983
Klin	1	0.049054	0.049054	1.99	0.1792
Kqua	1	0.058629	0.058629	2.37	0.1443
Kcub	1	0.000002	0.000002	0.00	0.9915
Kdev	1	0.005014	0.005014	0.20	0.6588
KCl vs K_2SO_4	1	0.023163	0.023163	0.94	0.3482
R*K	15	0.370564	0.024704	1.12	0.3472
Error	88	1.933225	0.021968		
Total	111	2.479591			

R-Square = 0.22 C.V. = 34.85

Appendix 74. Analysis of variance for root length at third harvest on 5/8/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	74.60648	24.86882	1.60	0.2308
K	5	27.92008	5.584017	0.36	0.8681
Klin	1	12.43650	12.43650	0.80	0.3849
Kqua	1	7.644819	7.644819	0.49	0.4936
Kcub	1	1.401921	1.401921	0.09	0.7679
Kdev	1	0.713289	0.713289	0.05	0.8332
KCl vs K_2SO_4	1	5.490969	5.490969	0.35	0.5609
R*K	15	232.8867	15.52578	2.79	0.0013
Error	95	529.3047	5.571629		
Total	118	871.8923			

R-Square = 0.39 C.V. = 11.48

Appendix 75. Analysis of variance for root fresh weight at third harvest on 5/8/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1634.881	544.9603	0.54	0.6619
K	5	4577.838	915.5676	0.91	0.5016
Klin	1	1545.832	1545.832	1.53	0.2347
Kqua	1	912.5760	912.5760	0.91	0.3565
Kcub	1	0.071480	0.071480	0.00	0.9934
Kdev	1	662.2363	662.2334	0.66	0.4304
KCl vs K_2SO_4	1	1457.331	1457.331	1.45	0.2479
R*K	15	15124.92	1008.328	1.52	0.1139
Error	96	63771.39	664.2853		
Total	119	85109.03			

R-Square = 0.25 C.V. = 24.88

Appendix 76. Analysis of variance for root greatest diameter at third harvest on 5/8/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.042649	0.014216	0.08	0.9704
K	5	0.535184	0.107036	0.59	0.7045
Klin	1	0.062501	0.062501	0.35	0.5644
Kqua	1	0.172506	0.172506	0.96	0.3431
Kcub	1	0.059616	0.059616	0.33	0.5734
Kdev	1	0.237510	0.237510	1.32	0.2686
KCl vs K_2SO_4	1	0.000000	0.000000	0.00	1.0000
R*K	15	2.699405	0.179960	1.18	0.2989
Error	96	14.61616	0.152251		
Total	119	17.89339			

R-Square = 0.18 C.V. = 11.45

Appendix 77. Analysis of variance for root dry weight at third harvest on 5/8/94

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	24.00640	8.002160	0.55	0.6532
K	5	82.21616	16.44323	1.14	0.3828
Klin	1	18.45675	18.45675	1.28	0.2760
Kqua	1	9.806125	9.806125	0.68	0.4228
Kcub	1	0.625255	0.625255	0.04	0.8380
Kdev	1	24.72385	24.72385	1.71	0.2104
KCl vs K_2SO_4	1	28.07300	28.07300	1.94	0.1835
R*K	15	216.6079	14.44052	1.76	0.0529
Error	92	755.1078	8.207694		
Total	115	1079.496			

R-Square = 0.30 C.V. = 24.24

Appendix 78. Analysis of variance for root DM at third harvest on 5/8/94.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	0.858565	0.286188	0.27	0.8474
K	5	4.357066	0.871413	0.82	0.5564
Klin	1	0.033771	0.033771	0.03	0.8612
Kqua	1	0.039778	0.039778	0.04	0.8495
Kcub	1	1.312946	1.312946	1.23	0.2849
Kdev	1	2.498796	2.498796	2.34	0.1468
KCl vs K_2SO_4	1	0.306250	0.306250	0.29	0.6001
R*K	15	16.01105	1.067403	1.38	0.1732
Error	92	71.09009	0.772718		
Total	115	92.63930			

R-Square = 0.23 C.V. = 7.71

Appendix 79. Analysis of variance for marketable yield in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	181.6967	60.56559	0.36	0.7810
K	5	1305.217	261.0435	1.56	0.2302
K lin	1	335.1946	335.1946	2.01	0.1771
K qua	1	521.7021	521.7021	3.12	0.0975
K cub	1	115.2856	115.2856	0.69	0.4192
K dev	1	332.3191	332.3191	1.99	0.1788
KCl vs K_2SO_4	1	2.820312	2.820312	0.02	0.8983
Error	15	2505.821	167.0547		
Total	23	3992.735			

R-Square = 0.37 C.V. = 19.87

Appendix 80. Analysis of variance for unmarketable yield in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	39.52661	13.17553	0.88	0.4734
K	5	62.68498	12.53699	0.84	0.5433
K lin	1	2.026291	2.026291	0.14	0.7180
K qua	1	18.62171	18.62171	1.24	0.2822
K cub	1	11.60378	11.60378	0.78	0.3925
K dev	1	22.10311	22.10311	1.48	0.2430
KCl vs K_2SO_4	1	8.673612	8.673612	0.58	0.4583
Error	15	224.4933	14.96622		
Total	23	326.7049			

R-Square = 0.31 C.V. = 37.67

Appendix 81. Analysis of variance for total yield in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	243.3165	81.10550	0.46	0.7142
K	5	1362.719	272.5439	1.55	0.2347
K lin	1	389.3413	389.3413	2.21	0.1579
K qua	1	737.0179	737.0179	4.18	0.0588
K cub	1	53.76062	53.76062	0.31	0.5889
K dev	1	182.9551	182.9551	1.04	0.3244
KCl vs K_2SO_4	1	1.584200	1.584200	0.01	0.9257
Error	15	2643.675	176.2450		
Total	23	4249.711			

R-Square = 0.37 C.V. = 17.63

Appendix 82. Analysis of variance for marketable yield in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	6.224908	2.074969	0.32	0.8124
K	5	179.2036	35.84072	5.49	0.0046
K lin	1	83.28595	83.28595	12.75	0.0028
K qua	1	0.479291	0.479291	0.07	0.7902
K cub	1	11.72353	11.72353	1.80	0.2002
K dev	1	17.05803	17.05803	2.61	0.1269
KCl vs K_2SO_4	1	66.36096	66.36096	10.16	0.0061
Error	15	97.96081	6.530721		
Total	23	283.389331			

R-Square = 0.65 C.V. = 13.87

Appendix 83. Analysis of variance for unmarketable yield in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	19.13857	6.379525	3.06	0.0604
K	5	26.64213	5.328426	2.56	0.0726
K lin	1	18.90953	18.90953	9.08	0.0087
K qua	1	0.835321	0.835321	0.40	0.5361
K cub	1	2.082901	2.082901	1.00	0.3332
K dev	1	2.545966	2.545966	1.22	0.2863
KCl vs K_2SO_4	1	2.300298	2.300298	1.10	0.3099
Error	15	31.24196	2.082797		
Total	23	77.02267			

R-Square = 0.59 C.V. = 37.45

Appendix 84. Analysis of variance for total yield 1994 in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	37.15581	12.38527	1.63	0.2251
K	5	314.5986	62.91972	8.27	0.0006
K lin	1	181.5777	181.5777	23.86	0.0002
K qua	1	2.580019	2.580019	0.34	0.5691
K cub	1	3.924731	3.924731	0.52	0.4837
K dev	1	32.78390	32.78390	4.31	0.0556
KCl vs K_2SO_4	1	93.36563	93.36563	12.27	0.0032
Error	15	114.1618	7.610790		
Total	23	465.9162			

R-Square = 0.75 C.V. = 12.38

Appendix 85. Repeated Measures Analysis of Variance for weight loss of carrots in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	799.2860	266.428	4.81	0.0001
K	5	194.4033	38.8806	0.70	0.2025
R*K	18	830.6287	55.3752	2.08	0.0113
Humidity (H)	1	7110.111	7110.11	130.50	0.0001
K*H	5	165.7945	33.1589	0.61	0.2873
R*H(K)	8	980.1029	54.4501	2.05	0.0083
Error	238	6322.635	26.5657		
Time	8	19832.39	2479.04	2253.12	0.0001
Time*R	24	116.9535	4.87306	4.430	0.0001
Time*K	40	98.47913	2.46197	2.240	0.0001
Time*R*K	120	338.3997	2.81999	2.560	0.0001
Time*H	8	2514.320	314.290	285.650	0.0001
Time*K*H	40	102.6902	2.56725	2.330	0.0001
Time*R*H(K)	144	378.3275	2.62727	2.390	0.0001
Error (Time)	1904	2094.921	1.10027		

Appendix 86. Analysis of variance for weight loss from carrots on the 2nd day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate(R)	3	5.559529	1.853176	4.13	0.0070
K	5	2.626515	0.525303	1.17	0.3240
Klin	1	0.513155	0.513155	0.50	0.4908
Kqua	1	1.654744	1.654744	1.61	0.2240
Kcub	1	0.054367	0.054367	0.05	0.8213
Kdev	1	0.299637	0.299637	0.29	0.5973
KCl vs K_2SO_4	1	0.103359	0.103359	0.10	0.7556
R*K	15	15.42677	1.028451	2.29	0.0047
Humidity (H)	1	9.790312	9.790312	21.83	0.0001
K*H	5	3.094054	0.618810	1.38	0.2326
R*H(K)	18	21.66475	1.203597	2.68	0.0004
Error	240	107.6594	0.448581		
Total	287	165.8213			

R-Square = 0.35 C.V. = 57.69

Appendix 87. Analysis of variance for weight loss from carrots on the 4th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	38.48310	12.82770	5.19	0.0117
K	5	8.707962	1.741592	0.70	0.6286
Klin	1	1.079812	1.079812	0.44	0.5186
Kqua	1	0.714300	0.714300	0.29	0.5987
Kcub	1	2.699942	2.699942	1.09	0.3124
Kdev	1	1.482278	1.482278	0.60	0.4506
KCl vs K_2SO_4	1	2.740504	2.740504	1.11	0.3089
R*K	15	37.05944	2.470629	1.98	0.0174
Humidity (H)	1	66.72050	66.72050	17.26	0.0006
K*H	5	14.92251	2.984503	0.77	0.5821
R*H(K)	18	69.56636	3.864797	3.09	0.0001
Error	240	299.7203	1.248835		
Total	287	535.1802			

R-Square = 0.43 C.V.= 46.95

Appendix 88. Analysis of variance for weight loss from carrots on the 8th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	96.80761	32.26920	7.96	0.0021
K	5	44.31035	8.862070	2.19	0.1104
Klin	1	5.967053	5.967053	1.47	0.2437
Kqua	1	8.477891	8.477891	2.09	0.1687
Kcub	1	25.21666	25.21666	6.22	0.0248
Kdev	1	4.656232	4.656232	1.15	0.3007
KCl vs K_2SO_4	1	0.147267	0.147267	0.04	0.8514
R*K	15	60.79018	4.052679	1.65	0.0609
Humidity (H)	1	210.8431	210.8431	30.57	0.0001
K*H	5	29.82664	5.965329	0.86	0.5234
R*H(K)	18	124.1661	6.898117	2.82	0.0002
Error	240	587.7651	2.449022		
Total	287	1154.5094			

R-Square = 0.49 C.V. = 36.26

Appendix 89. Analysis of variance for weight loss from carrots at 10th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	117.6340	39.21135	5.69	0.0083
K	5	42.21974	8.443949	1.23	0.3453
Klin	1	7.034230	7.034230	1.02	0.3284
Kqua	1	3.376276	3.376276	0.49	0.4947
Kcub	1	28.72808	28.72808	4.17	0.0592
Kdev	1	0.607818	0.607818	0.09	0.7706
KCl vs K_2SO_4	1	2.666667	2.666667	0.39	0.5433
R*K	15	103.3915	6.892772	2.06	0.0127
Humidity (H)	1	404.3220	404.3220	44.23	0.0001
K*H	5	36.02138	7.204277	0.79	0.5717
R*H(K)	18	164.5477	9.141541	2.73	0.0003
Error	240	804.2784	3.351160		
Total	287	1672.414			

R-Square = 0.51 C.V. = 34.26

Appendix 90. Analysis of variance for weight loss from carrots on the 12th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	220.8604	73.62016	7.88	0.0022
K	5	28.05159	5.610320	0.60	0.7007
Klin	1	7.072083	7.072083	0.76	0.3981
Kqua	1	4.761092	4.761092	0.51	0.4864
Kcub	1	10.21659	10.21659	1.09	0.3124
Kdev	1	3.332953	3.332953	0.36	0.5593
KCl vs K_2SO_4	1	2.829067	2.829067	0.30	0.5903
R*K	15	140.2186	9.347908	2.43	0.0026
Humidity (H)	1	752.4290	752.4290	103.19	0.0001
K*H	5	18.19748	3.639496	0.50	0.7729
R*H(K)	18	131.2513	7.291741	1.90	0.0169
Error	240	922.8906	3.845380		
Total	287	2213.899			

R-Square = 0.58 C.V. = 31.33

Appendix 91. Analysis of variance for weight loss from carrots on the 14th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	127.5407	42.51359	4.31	0.0222
K	5	43.62286	8.724570	0.88	0.5156
Klin	1	12.56023	12.56023	1.27	0.2770
Kqua	1	20.16093	20.16093	2.04	0.1735
Kcub	1	10.50098	10.50098	1.06	0.3187
Kdev	1	0.005650	0.005650	0.00	0.9812
KCl vs K_2SO_4	1	0.455470	0.455470	0.05	0.8328
R*K	15	148.0697	9.871300	2.02	0.0145
Humidity (H)	1	1356.501	1356.501	140.55	0.0001
K*H	5	33.00971	6.601900	0.6	0.6415
R*H(K)	18	173.7298	9.651660	1.98	0.0115
Error	238	1160.198	4.874780		
Total	285	3038.008			

R-Square = 0.61 C.V. = 30.25

Appendix 92. Analysis of variance for weight loss from carrots on the 16th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	137.1023	45.70077	3.82	0.0323
K	5	42.53703	8.507407	0.71	0.6238
Klin	1	29.24243	29.24243	2.45	0.1386
Kqua	1	10.14075	10.14075	0.85	0.3715
Kcub	1	2.817240	2.817240	0.24	0.6343
Kdev	1	0.290520	0.290520	0.02	0.8782
KCl vs K_2SO_4	1	0.096760	0.096760	0.01	0.9295
R*K	15	179.2212	11.94808	2.18	0.0078
Humidity (H)	1	1698.675	1698.675	145.1	0.0001
K*H	5	52.35900	10.47190	0.89	0.5054
R*H(K)	18	210.6892	11.70496	2.13	0.0057
Error	238	1307.417	5.49335		
Total	285	3618.832			

R-Square = 0.63 C.V. = 28.95

Appendix 93. Analysis of variance for weight loss from carrots on the 18th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	86.16674	28.72224	2.00	0.1580
K	5	34.52933	6.905867	0.48	0.7860
Klin	1	17.16984	17.16984	1.19	0.2920
Kqua	1	8.863170	8.863170	0.62	0.4449
Kcub	1	4.823170	4.823170	0.34	0.5713
Kdev	1	0.374280	0.374280	0.03	0.8741
KCl vs K_2SO_4	1	3.195010	3.195010	0.22	0.6443
R*K	15	215.9355	14.39570	2.20	0.0071
Humidity (H)	1	2342.178	2342.178	204.3	0.0001
K*H	5	47.38043	9.476090	0.83	0.5472
R*H(K)	18	206.3879	11.46600	1.75	0.0323
Error	238	1559.401	6.552110		
Total	285	4482.449			

R-Square = 0.65 C.V. = 28.24

Appendix 94. Analysis of variance for weight loss from carrots on the 20th day of storage in 1993.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	71.20677	23.73559	1.35	0.2971
K	5	38.09852	7.619705	0.43	0.8194
Klin	1	13.95290	13.95290	0.79	0.3878
Kqua	1	17.08457	17.08457	0.97	0.3407
Kcub	1	0.010650	0.010650	0.00	0.9807
Kdev	1	1.086630	1.086630	0.06	0.8073
KCl vs K_2SO_4	1	5.891140	5.891140	0.33	0.5719
R*K	15	264.5922	17.63948	2.47	0.0022
Humidity (H)	1	2758.140	2758.140	192.2	0.0001
K*H	5	53.74115	10.74823	0.75	0.5974
R*H(K)	18	258.2682	14.34823	2.01	0.0101
Error	238	1699.901	7.142440		
Total	285	5137.533			

R-Square = 0.66 C.V. = 27.16

Appendix 95. Repeated measures analysis of variance for weight loss of carrots in 1994

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	3556.701	1185.567	9.09	0.0001
K	5	451.153	90.230	0.37	0.0640
R*K	15	1955.523	130.368	3.06	0.0002
Humidity (H)	1	28884.751	28884.751	199.95	0.0001
K*H	5	187.526	37.5053	0.25	0.4948
R*H(K)	18	2600.252	144.458	3.39	0.0001
Error	237	10094.881	42.5944		
Time	9	31236. 30	3470.7003	1054.73	0.0001
Time*R	27	234.640	8.69040	2.64	0.0001
Time*K	45	202.052	4.49004	1.36	0.0547
Time*R*K	135	890.808	6.59858	2.01	0.0001
Time*H	9	7099.394	788.82160	239.72	0.0001
Time*K*H	45	151.778	3.37284	1.02	0.4269
Time*R*H(K)	162	1041.934	6.43169	1.95	0.0001
Error (Time)	2133	7018.886	3.29061		

Appendix 96. Analysis of variance for weight loss from carrots on the 2nd day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	115.8744	38.62483	9.18	0.0011
K	5	27.94694	5.589390	1.33	0.3049
Klin	1	0.132353	0.132353	0.03	0.8616
Kqua	1	0.313369	0.313369	0.07	0.7886
Kcub	1	10.37764	10.37764	2.47	0.1371
Kdev	1	9.993322	9.993322	2.38	0.1441
KCl vs K_2SO_4	1	7.757751	7.757751	1.84	0.1946
R*K	15	63.10443	4.206962	2.83	0.0004
Humidity (H)	1	76.71587	76.71587	17.90	0.0005
K*H	5	8.134829	1.626965	0.38	0.8561
R*H(K)	18	77.12923	4.284958	2.88	0.0001
Error	237	352.4133	1.486976		
Total	284	730.0293			

R-Square = 0.51 C.V. = 54.59

Appendix 97. Analysis of variance for weight loss from carrots on the 4th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	277.9037	92.63457	8.69	0.0014
K	5	50.87053	10.17410	0.95	0.4752
Klin	1	0.629034	0.629034	0.06	0.8113
Kqua	1	3.812750	3.812750	0.36	0.5586
Kcub	1	19.42226	19.42226	1.82	0.1970
Kdev	1	5.887254	5.887254	0.55	0.4688
KCl vs K_2SO_4	1	21.63150	21.63150	2.03	0.1747
R*K	15	159.8281	10.65521	4.50	0.0001
Humidity (H)	1	473.7536	473.7536	38.5	0.0001
K*H	5	4.522604	0.904521	0.07	0.9955
R*H(K)	18	221.7093	12.31718	5.21	0.0001
Error	239	565.3176	2.365350		
Total	286	1754.334			

R-Square = 0.67 C.V. = 43.32

Appendix 98. Analysis of variance for weight loss from carrots on the 6th day of storage in 1994

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	421.8045	140.6015	12.24	0.0003
K	5	45.44315	9.088632	0.79	0.5723
Klin	1	3.678400	3.678400	0.32	0.5799
Kqua	1	5.088660	5.088660	0.44	0.5158
Kcub	1	27.04533	27.04533	2.35	0.1458
Kdev	1	3.125380	3.125380	0.27	0.6096
KCl vs K_2SO_4	1	7.134050	7.134050	0.62	0.4430
R*K	15	172.3243	11.48829	3.14	0.0001
Humidity (H)	1	1082.226	1082.226	89.42	0.0001
K*H	5	11.58343	2.316690	0.19	0.9620
R*H(K)	18	217.8413	12.10230	3.31	0.0001
Error	239	874.9042	3.660690		
Total	286	2826.917			

R-Square = 0.69   C.V. = 40.12

Appendix 99. Analysis of variance for weight loss of carrots on the 8th day of storage in 1994

Source	DF	SS	M S	F Value	Pr > F
Replicate (R)	3	335.4316	111.8105	9.51	0.0009
K	5	44.72602	8.945200	0.76	0.5919
Klin	1	0.101740	0.101740	0.01	0.9271
Kqua	1	1.905490	1.905490	0.16	0.6930
Kcub	1	15.91507	15.91507	1.35	0.2629
Kdev	1	5.298750	5.298750	0.45	0.5123
KCl vs K_2SO_4	1	21.83134	21.83134	1.86	0.1932
R*K	15	176.4058	11.76039	3.08	0.0001
Humidity (H)	1	1810.281	1810.281	164.20	0.0001
K*H	5	8.511390	1.702280	0.15	0.9759
R*H(K)	18	198.4428	11.02460	2.89	0.0001
Error	239	912.9095	3.819710		
Total	286	3486.568			

R-Square = 0.73   C.V. = 32.98

Appendix 100. Analysis of variance for weight loss of carrots on the 10th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	389.8230	129.9410	2.96	0.0661
K	5	96.82464	19.36493	0.44	0.8131
Klin	1	61.26521	61.26521	1.40	0.2559
Kqua	1	0.465220	0.465220	0.01	0.9194
Kcub	1	3.916020	3.916020	0.09	0.7693
Kdev	1	16.81167	16.81167	0.38	0.5454
KCl vs K_2SO_4	1	14.90738	14.90738	0.34	0.5688
R*K	15	658.7427	43.91618	1.90	0.0236
Humidity (H)	1	2391.637	2391.637	92.34	0.0001
K*H	5	95.25743	19.05149	0.74	0.6064
R*H(K)	18	466.2165	25.90092	1.12	0.3311
Error	239	912.9095	3.819710		
Total	286	3486.568			

R-Square = 0.42 C.V. = 65.05

Appendix 101. Analysis of variance for weight loss from carrots on the 12th day of storage in 1994

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	478.7188	159.5729	9.03	0.0012
K	5	48.19496	9.638992	0.55	0.7395
Klin	1	12.41626	12.41626	0.70	0.4151
Kqua	1	3.033790	3.033790	0.17	0.6845
Kcub	1	20.65829	20.65829	1.17	0.2968
Kdev	1	9.844380	9.844380	0.56	0.4671
KCl vs K_2SO_4	1	2.473630	2.473630	0.14	0.7136
R*K	15	265.1719	17.67813	3.48	0.0001
Humidity (H)	1	3685.082	3685.082	179.48	0.0001
K*H	5	27.10086	5.420170	0.26	0.9269
R*H(K)	18	369.5781	20.53212	4.05	0.0001

R-Square = 0.80 C.V. = 27.24

Appendix 102. Analysis of variance for weight loss from carrots on the 14th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	474.1649	158.0549	7.96	0.0021
K	5	88.80406	17.76081	0.89	0.5092
Klin	1	27.85815	27.85815	1.40	0.2546
Kqua	1	5.791900	5.791900	0.29	0.5970
Kcub	1	31.85286	31.85286	1.60	0.2246
Kdev	1	11.09417	11.09417	0.56	0.4663
KCl vs K_2SO_4	1	12.42001	12.42001	0.63	0.4413
R*K	15	297.7471	19.84981	3.22	0.0001
Humidity (H)	1	4658.597	4658.597	186.6	0.0001
K*H	5	49.22783	9.845570	0.39	0.8462
R*H(K)	18	449.2720	24.95956	4.05	0.0001
Error	239	1472.883	6.162690		
Total	286	7487.568			

R-Square = 0.80 C.V. = 26.68

Appendix 103. Analysis of variance for weight loss from carrots on the 16th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	521.8420	173.9473	7.51	0.0027
K	5	93.36364	18.67272	0.81	0.5630
Klin	1	44.30778	44.30778	1.91	0.1870
Kqua	1	0.425820	0.425820	0.02	0.8940
Kcub	1	32.32566	32.32566	1.40	0.2559
Kdev	1	2.091520	2.091520	0.09	0.7680
KCl vs K_2SO_4	1	13.96900	13.96900	0.60	0.4496
R*K	15	347.5787	23.17192	2.79	0.0005
Humidity (H)	1	5857.992	5857.992	192.6	0.0001
K*H	5	84.35943	16.87189	0.55	0.7329
R*H(K)	18	547.3707	30.40948	3.67	0.0001
Error	239	1982.012	8.292940		
Total	286	9431.336			

R-Square = 0.78 C.V = 27.55

Appendix 104. Analysis of variance for weight loss from carrots on the 18th day of storage in 1994

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	509.9876	169.9958	6.77	0.0042
K	5	84.70853	16.94170	0.68	0.6488
Klin	1	27.39494	27.39494	1.09	0.3127
Kqua	1	5.619200	5.619200	0.22	0.6429
Kcub	1	20.02402	20.02402	0.80	0.3858
Kdev	1	3.884000	3.884000	0.15	0.6996
KCl vs K_2SO_4	1	27.79954	27.79954	1.11	0.3093
R*K	15	376.4617	25.09745	3.28	0.0001
Humidity (H)	1	7098.562	7098.562	241.8	0.0001
K*H	5	27.79646	5.559290	0.19	0.9628
R*H(K)	18	528.4278	29.35710	3.83	0.0001
Error	239	1831.206	7.661950		
Total	286	10453.58			

R-Square = 0.82 C.V. = 24.51

Appendix 105. Analysis of variance for weight loss from carrots on the 20th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	472.3145	157.4381	6.88	0.0039
K	5	62.70103	12.54020	0.55	0.7376
Klin	1	2.179360	2.179360	0.10	0.7619
Kqua	1	7.804600	7.804600	90.3	0.5679
Kcub	1	18.68523	18.68523	0.82	0.3805
Kdev	1	3.073790	3.073790	0.13	0.7191
KCl vs K_2SO_4	1	31.27025	31.27025	1.37	0.2607
R*K	15	343.2999	22.88667	2.25	0.0056
Humidity (H)	1	9394.398	9394.398	297.6	0.0001
K*H	5	22.40628	4.481260	0.14	0.9800
R*H(K)	18	568.1427	31.56348	3.10	0.0001
Error	239	2430.366	10.16890		
Total	286	13286.38			

R-Square = 0.81 C.V. = 24.48

Appendix 106. Repeated measures analysis of variance for weight loss of carrots in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	11770.880	3923.626	26.59	0.0001
K	3	96.5043	32.168	0.28	0.5399
R*K	9	1327.9820	147.554	3.31	0.0006
Damage (D)	4	1033.7791	258.444	1.36	0.0732
K*D	12	3089.8374	257.486	1.36	0.5636
R*D(K)	48	9095.8288	189.496	4.25	0.0001
Humidity (H)	1	16589.6738	16589.673	87.08	0.0001
K*H	3	343.7972	114.599	0.60	0.6540
D*H	4	331.2040	82.801	0.43	0.1170
K*D*H	12	915.6483	76.304	0.40	0.0614
R*H(K*D)	31	5905.7315	190.507	4.27	0.0001
Error	519	23162.2762	44.628		
Time	8	39993.6446	4999.205	2309.92	0.0001
Time*R	24	2309.4284	96.226	44.46	0.0001
Time*K	24	95.4675	3.977	1.84	0.0076
Time*R*K	72	517.3139	7.184	3.32	0.0001
Time*D	32	266.2280	8.319	3.84	0.0001
Time*K*D	96	962.8829	10.0300	4.63	0.0001
Time*R*D(K)	384	2516.9850	6.5546	3.03	0.0001
Time*H	8	2985.3014	373.1626	172.42	0.0001
Time*K*H	24	102.65043	4.2771	1.98	0.0031
Time*D*H	32	132.66892	4.1459	1.92	0.0015
Time*K*D*H	96	332.56023	3.4641	1.60	0.0002
Time*R*H(K*D)	248	1818.41414	7.3323	3.39	0.0001
Error (TIME)	4152	8985.90172	2.1642		

Appendix 107. Analysis of variance for weight loss of carrots on the 2nd day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	395.1127	131.7042	30.46	0.0001
K	3	8.413454	2.804484	0.65	0.6033
R*K	9	38.91466	4.323850	4.00	0.0001
Damage (D)	4	27.18175	6.795440	1.16	0.3415
K*D	12	46.76189	3.896825	0.66	0.7766
R*D(K)	48	281.8876	5.872660	5.43	0.0001
Humidity (H)	1	38.64155	38.64155	10.10	0.0030
K*H	3	20.92057	6.973525	1.82	0.1603
D*H	4	6.373056	1.593264	0.42	0.7955
K*D*H	12	40.87494	3.406245	0.89	0.5640
R*H(K*D)	36	137.6739	3.824280	3.54	0.0001
Error	541	585.0157	1.081400		
Total	676	1715.296			

R-Square = 0.65   C.V. = 72.25

Appendix 108. Analysis of variance for weight loss from carrots on the 4th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	558.3010	186.1003	24.61	0.0001
K	3	10.51797	3.505991	0.46	0.7146
R*K	9	68.04477	7.560530	3.64	0.0002
Damage (D)	4	59.25708	14.81427	1.73	0.1590
K*D	12	92.42148	7.701790	0.90	0.5542
R*D(K)	48	411.1685	8.566010	4.12	0.0001
Humidity (H)	1	610.4171	610.4171	68.9	0.0001
K*H	3	90.25038	30.08346	3.40	0.0237
D*H	4	13.99048	3.497622	0.39	0.8114
K*D*H	12	38.55703	3.213086	0.36	0.9713
R*H(K*D)	58	513.6448	8.855950	4.26	0.0001
Error	630	1310.003	2.079400		
Total	787	3800.688			

R-Square = 0.65   C.V. = 54.74

Appendix 109. Analysis of variance for weight loss from carrots on the 6th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	503.9160	167.9720	14.51	0.0009
K	3	23.91725	7.972419	0.69	0.5815
R*K	9	104.2154	11.57950	3.28	0.0006
Damage (D)	4	145.3053	36.32634	2.57	0.0499
K*D	12	218.2664	18.18887	1.28	0.2582
R*D(K)	48	679.4306	14.15480	4.01	0.0001
Humidity (H)	1	1946.393	1946.393	168.5	0.0001
K*H	3	47.77142	15.92380	1.38	0.2586
D*H	4	55.59841	13.89960	1.20	0.3195
K*D*H	12	170.2697	14.18914	1.23	0.2872
R*H(K*D)	57	658.5152	11.55290	3.27	0.0001
Error	626	2209.222	3.529100		
Total	782	6602.590			

R-Square = 0.66 C.V. = 46.73

Appendix 110. Analysis of variance for weight loss from carrots on the 8th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	888.7899	296.2633	34.85	0.0001
K	3	14.98888	4.996294	0.59	0.6382
Klin	1	1.965570	1.965570	0.23	0.6421
Kqua	1	1.152520	1.152520	0.14	0.7212
Kdev	1	11.82259	11.82259	1.39	0.2685
R*K	9	76.51540	8.501700	1.92	0.0467
Damage (D)	4	220.2614	55.06536	2.94	0.0297
Control vs rest of D	1	192.4126	192.4126	10.3	0.0024
5% D vs rest	1	3.928468	3.928468	0.21	0.6489
10% vs rest	1	14.04179	14.04179	0.75	0.3907
15% vs 20% D	1	9.611490	9.611490	0.51	0.4771
K*D	12	290.1493	24.17911	1.29	0.2542
R*D(K)	48	898.3546	18.71570	4.22	0.0001
Humidity (H)	1	3190.449	3190.449	172.8	0.0001
K*H	3	80.85222	26.95074	1.46	0.2345
D*H	4	117.5863	29.39657	1.59	0.1880
K*D*H	12	166.4328	13.86940	0.75	0.6962
R*H(K*D)	60	1107.605	18.46010	4.17	0.0001
Error	638	2826.975	4.431000		
Total	797	9879.357			

R-Square = 0.71 C.V. = 42.00

Appendix 111. Analysis of variance for weight loss from carrots on the 10th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1374.877	458.2924	30.20	0.0001
K	3	33.39452	11.13151	0.73	0.5578
Klin	1	10.59598	10.59598	0.70	0.4250
Kqua	1	5.219390	5.219390	0.34	0.5720
Kdev	1	17.42974	17.42974	1.15	0.3118
R*K	9	136.5889	15.17650	2.50	0.0081
D	4	275.9517	68.98793	2.87	0.0327
Control vs rest of D	1	214.9784	214.9784	8.95	0.0044
5% vs rest	1	2.437853	2.437853	0.10	0.7514
10% vs rest	1	25.36201	25.36201	1.06	0.3093
15% vs 20%	1	32.76849	32.76849	1.36	0.2486
K*D	12	387.6884	32.30737	1.34	0.2257
R*D(K)	48	1153.095	24.02280	3.96	0.0001
Humidity (H)	1	4320.118	4320.118	186.1	0.0001
K*H	3	104.5988	34.86628	1.50	0.2232
D*H	4	141.4563	35.36407	1.52	0.2068
K*D*H	12	210.4124	17.53437	0.76	0.6923
R*H(K*D)	60	1392.841	23.21400	3.83	0.0001
Error	638	3866.822	6.060900		
Total	797	13410.80			

R-Square = 0.71 C.V. = 40.34

Appendix 112. Analysis of variance for weight loss from carrots on the 12th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1614.860	538.2867	34.9	0.0001
K	3	40.93426	13.64475	0.89	0.4846
Klin	1	18.79693	18.79693	1.22	0.2980
Kqua	1	6.298420	6.298420	0.41	0.5385
Kdev	1	15.64337	15.64337	1.02	0.3400
R*K	9	138.6684	15.40760	2.07	0.0305
Damage (D)	4	336.2227	84.05568	3.05	0.0255
Control vs rest	1	260.3610	260.3610	9.45	0.0035
5% vs rest	1	2.031209	2.031209	0.07	0.7872
10% vs rest	1	45.04907	45.04907	1.63	0.2072
15% vs 20%	1	28.33317	28.33317	1.03	0.3157
K*D	12	457.8846	38.15705	1.38	0.2060
R*D(K)	48	1322.652	27.55530	3.69	0.0001
Humidity (H)	1	4968.884	4968.884	188.2	0.0001
K*H	3	132.2121	44.07070	1.67	0.1833
D*H	4	139.6210	34.90526	1.32	0.2722
K*D*H	12	206.8534	17.23779	0.65	0.7883
R*H(K*D)	60	1584.426	26.40710	3.54	0.0001
Error	638	4757.875	7.457000		
Total	797	15717.42			

R-Square = 0.69 C.V. = 39.14

Appendix 113. Analysis of variance for weight loss from carrots on the 14th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	2183.647	727.8826	44.6	0.0001
K	3	47.31555	15.77185	0.97	0.4497
Klin	1	14.99328	14.99328	0.92	0.3627
Kqua	1	19.95105	19.95105	1.22	0.2974
Kdev	1	12.18300	12.18300	0.75	0.4099
R*K	9	146.7988	16.31100	2.07	0.0301
Damage (D)	4	348.0803	87.02008	2.56	0.0504
Control vs rest	1	278.8288	278.8288	8.20	0.0062
5% vs rest	1	0.194155	0.194155	0.01	0.9401
10% vs rest	1	39.14266	39.14266	1.15	0.2886
15% vs 20%	1	29.46465	29.46465	0.87	0.3565
K*D	12	595.7797	49.64831	1.46	0.1726
R*D(K)	48	1631.503	33.98970	4.31	0.0001
Humidity (H)	1	6632.660	6632.660	202.6	0.0001
K*H	3	114.3563	38.11878	1.16	0.3308
D*H	4	107.7173	26.92933	0.82	0.5159
K*D*H	12	212.9277	17.74398	0.54	0.8782
R*H(K*D)	60	1964.025	32.73380	4.16	0.0001
Error	638	5026.077	7.878000		
Total	797	19026.28			

R-Square = 0.73 C.V. = 35.10

Appendix 114. Analysis of variance for weight loss from carrots on the 16th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	2592.563	864.1878	35.0	0.0001
K	3	85.95965	28.65321	1.16	0.3769
Klin	1	47.32201	47.32201	1.92	0.1995
Kqua	1	20.83230	20.83230	0.84	0.3821
Kdev	1	17.42308	17.42308	0.71	0.4225
R*K	9	222.0772	24.67520	2.25	0.0176
Damage (D)	4	265.3240	66.33102	1.72	0.1607
Control vs rest	1	177.0531	177.0531	4.59	0.0372
5% vs rest	1	0.127276	0.127276	0.00	0.9544
10% vs rest	1	65.28228	65.28228	1.69	0.1993
15% vs 20%	1	22.57606	22.57606	0.59	0.4478
K*D	12	769.3431	64.11193	1.66	0.1056
R*D(K)	48	1849.523	38.53170	3.52	0.0001
Humidity (H)	1	8264.948	8264.948	208.5	0.0001
K*H	3	47.15230	15.71743	0.40	0.7560
D*H	4	83.54625	20.88656	0.53	0.7164
K*D*H	12	288.8484	24.07071	0.61	0.8276
R*H(K*D)	60	2378.552	39.64250	3.62	0.0001
Error	638	6992.492	10.96000		
Total	797	23856.82			

R-Square = 0.70 C.V. = 36.84

Appendix 115. Analysis of variance for weight loss from carrots on the 18th day of storage in 1993.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	3008.131	1002.710	33.8	0.0001
K	3	99.20559	33.06853	1.11	0.3931
Klin	1	55.78567	55.78567	1.88	0.2035
Kqua	1	12.19786	12.19786	0.41	0.5374
Kdev	1	30.74894	30.74894	1.04	0.3352
R*K	9	267.0087	29.66760	2.54	0.0071
Damage (D)	4	321.9605	80.49013	1.96	0.1162
Control vs rest	1	246.0127	246.0127	5.98	0.0182
5% vs rest	1	0.070809	0.070809	0.00	0.9671
10% vs rest	1	55.38121	55.38121	1.35	0.2516
15% vs 20%	1	20.12251	20.12251	0.49	0.4876
K*D	12	748.6602	62.38835	1.52	0.1510
R*D(K)	48	1974.210	41.12940	3.53	0.0001
Humidity (H)	1	9712.246	9712.246	206.7	0.0001
K*H	3	53.09145	17.69715	0.38	0.7702
D*H	4	47.51001	11.87750	0.25	0.9069
K*D*H	12	306.2224	25.51853	0.54	0.8775
R*H(K*D)	60	2819.486	46.99140	4.03	0.0001
Error	638	7443.944	11.66800		
Total	797	26821.10			

R-Square = 0.72   C.V. = 34.42

Appendix 116. Repeated Measures Analysis of Variance for weight loss of carrots in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	6718.4763	2239.4921	4.08	0.0001
K	3	1385.6038	461.8679	0.80	0.3221
R*K	9	4926.5301	547.3922	8.14	0.0001
Damage (D)	3	1117.5632	372.5211	1.64	0.4311
K*D	9	1266.6059	140.7340	0.54	0.6311
R*D(K)	36	9275.7063	257.6585	3.83	0.0001
Error	232	15605.1613	67.2636		
Time	8	73548.8824	9193.610	1282.4	0.0001
Time*R	24	2456.5862	102.3577	14.28	0.0001
Time*K	24	546.14410	22.75600	3.17	0.0001
Time*R*K	72	1434.7167	19.9266	2.78	0.0001
Time*D	24	559.3437	23.3059	3.25	0.0001
Time*K*D	72	1257.6426	17.4672	2.44	0.0001
Time*R*D(K)	288	5253.5144	18.2413	2.54	0.0001
Error(Time)	1856	13304.997	7.1686		

Appendix 117. Analysis of variance for weight loss from carrots on the 2nd day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	205.5212	68.50707	12.7	0.0014
K	3	1.876030	0.625343	0.12	0.9487
Klin	1	0.304120	0.304120	0.06	0.8178
Kqua	1	1.382187	1.382187	0.26	0.6253
Kdev	1	0.392150	0.392150	0.07	0.7937
$Error_a$	9	48.65451	5.406057	3.89	0.0001
Damage (D)	3	27.71071	9.236904	2.37	0.0867
Control vs D	1	25.74054	25.74054	6.60	0.0145
15% D vs rest	1	1.981755	1.981755	0.51	0.4804
30% vs 45% D	1	0.014051	0.014051	0.00	0.9525
K*D	9	36.47603	4.052892	1.04	0.4287
$Error_b$	36	140.3061	3.897393	2.80	0.0001
Error	23	324.1303	1.391117		
Total	296	801.4616			

R-Square = 0.59   C.V. = 40.89

Appendix 118. Analysis of variance for weight loss from carrots on the 4th day of storage in 1994.

Source	Df	SS	MS	F value	Pr > F
Replicate (R)	3	610.7421	203.5807	5.58	0.0193
K	3	49.62325	16.54108	0.45	0.7211
Klin	1	5.135754	5.135754	0.14	0.7161
Kqua	1	10.46900	10.46900	0.29	0.6051
Kdev	1	34.05160	34.05160	0.93	0.3591
$Error_a$	9	328.1469	36.46076	12.4	0.0001
Damage (D)	3	14.23782	4.745943	0.33	0.8058
Control vs D	1	1.078197	1.078197	0.07	0.7868
15% D vs rest	1	4.846985	4.846985	0.33	0.5669
35% vs 45% D	1	8.135003	8.135003	0.56	0.4589
K*D	9	67.01278	7.445865	0.51	0.8553
$Error_b$	36	522.5077	14.51410	4.92	0.0001
Error	233	687.3840	2.950150		
Total	296	2304.416			

R-Square = 0.70   C.V. = 34.93

Appendix 119. Analysis of variance for weight loss from carrots on the 6th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1190.567	396.8559	4.10	0.0434
K	3	185.2687	61.75624	0.64	0.6095
Klin	1	23.11341	23.11341	0.24	0.6369
Kqua	1	46.43919	46.43919	0.48	0.5061
Kdev	1	114.9905	114.9905	1.19	0.3042
$Error_a$	9	871.6578	96.85087	16.1	0.0001
Damage (D)	3	43.52537	14.50845	0.55	0.6518
Control vs D	1	0.219005	0.219005	0.01	0.9279
15% vs rest	1	35.16289	35.16289	1.33	0.2561
30% VS 45%	1	7.796251	7.796251	0.30	0.5902
K*D	9	126.6022	14.06691	0.53	0.8409
$Error_b$	36	950.5904	26.40529	4.38	0.0001
Error	233	1406.090	6.034730		
Total	296	4846.313			

R-Square = 0.70   C.V. = 33.98

Appendix 120. Analysis of variance for weight loss from carrots on the 8th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	920.5839	306.8613	3.17	0.0783
K	3	225.9930	75.33102	0.78	0.5357
Klin	1	9.873826	9.873826	0.10	0.7569
Kqua	1	144.6786	144.6786	1.49	0.2529
Kdev	1	73.60626	73.60626	0.76	0.4062
$Error_a$	9	872.4117	96.93464	11.7	0.0001
Damage (D)	3	101.5600	33.85333	0.84	0.4815
Control vs rest	1	19.21124	19.21124	0.48	0.4946
15% vs rest	1	12.74198	12.74198	0.32	0.5777
30% vs 45% D	1	68.43526	68.43526	1.70	0.2011
K*D	9	292.4787	32.49763	0.81	0.6142
$Error_b$	36	1452.787	40.35522	4.88	0.0001
Error	233	1927.429	8.272230		
Total	296	5747.583			

R-Square = 0.66   C.V. = 30.92

Appendix 121. Analysis of variance for weight loss from carrots on the 10th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1318.1007	439.3669	5.98	0.0158
K	3	85.739080	28.57969	0.39	0.7636
Klin	1	6.8345675	6.834567	0.09	0.7672
Kqua	1	73.884334	73.88433	1.01	0.3420
Kdev	1	0.6422729	0.642272	0.01	0.9275
$Error_a$	9	660.73110	73.41457	2.26	0.0193
Damage (D)	3	107.86661	35.95553	0.45	0.7167
Control vs D	1	2.1473441	2.147344	0.03	0.8702
15% D vs rest	1	18.746595	18.74659	0.24	0.6299
35% vs 45% D	1	85.897990	85.89799	1.08	0.3051
KxD	9	514.67634	57.18626	0.72	0.6867
$Error_b$	36	2856.3679	79.34355	2.44	0.0001
Error	233	7574.7367	32.50960		
Total	296	13106.876			

R-Square = 0.42 C.V.= 49.85

Appendix 122. Analysis of variance for weight loss from carrots on the 12th day of storage in 1994.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	1155.815	385.2717	4.07	0.0442
K	3	275.2377	91.74590	0.97	0.4491
Klin	1	3.843886	3.843886	0.04	0.8449
Kqua	1	192.0793	192.0793	2.03	0.1882
Kdev	1	86.33942	86.33942	0.91	0.3647
$Error_a$	9	852.7375	94.74861	7.81	0.0001
Damage (D)	3	196.8329	65.61098	1.23	0.3118
Control vs D	1	60.76988	60.76988	1.14	0.2923
15% vs rest	1	21.08542	21.08542	0.40	0.5330
35% vs 45% D	1	112.7123	112.7123	2.12	0.1542
K*D	9	473.4789	52.60877	0.99	0.4660
$Error_b$	36	1915.231	53.20087	4.39	0.0001
Error	233	2826.285	12.12998		
Total	296	7543.455			

R-Square = 0.62 C.V. = 26.90

Appendix 123. Analysis of variance for weight loss from carrots on the 14th day of storage in 1994.

Source	Df	SS	MS	F Value	Pr > F
Replicate (R)	3	1249.653	416.5511	4.34	0.0377
K	3	374.5973	124.8657	1.30	0.3331
Klin	1	15.16225	15.16225	0.16	0.7004
Kqua	1	162.0666	162.0666	1.69	0.2263
Kdev	1	205.0914	205.0914	2.13	0.1780
$Error_a$	9	864.6286	96.06985	5.15	0.0001
Damage	3	434.6872	144.8957	2.51	0.0739
Control vs D	1	145.3514	145.3514	2.52	0.1211
15% vs rest	1	60.39791	60.39791	1.05	0.3129
30% vs 45% D	1	226.1448	226.1448	3.92	0.0553
K*D	9	303.5609	33.72899	0.58	0.8005
$Error_b$	36	2075.762	57.66007	3.10	0.0001
Error	232	4317.904	18.61166		
Total	295	9484.112			

R-Square = 0.54 C.V. = 28.50

Appendix 124. Analysis of variance for weight loss from carrots on the 16th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1656.757	552.2523	5.76	0.0176
K	3	377.4115	125.8038	1.31	0.3292
Klin	1	45.89238	45.89238	0.48	0.5063
Kqua	1	72.64611	72.64611	0.76	0.4065
Kdev	1	257.7879	257.7879	2.69	0.1353
$Error_a$	9	862.2232	95.80258	4.62	0.0001
Damage (D)	3	504.4314	168.1438	2.75	0.0566
Control vs D	1	218.7220	218.7220	3.58	0.0665
15% vs rest	1	144.5434	144.5434	2.37	0.1327
30% vs 45% D	1	138.5700	138.5700	2.27	0.1407
K*D	9	244.2078	27.13420	0.44	0.9013
$Error_b$	36	2198.427	61.06743	2.94	0.0001
Error	232	4810.913	20.73670		
Total	295	10642.44			

R-Square = 0.54 C.V. = 26.64

Appendix 125. Analysis of variance for weight loss from carrots on the 18th day of storage in 1994.

Source	DF	SS	MS	F Value	Pr > F
Replicate (R)	3	1065.452	355.1508	3.79	0.0524
K	3	415.7143	138.5714	1.48	0.2852
Klin	1	58.37872	58.37872	0.62	0.4504
Kqua	1	4.921058	4.921058	0.05	0.8240
Kdev	1	345.7270	345.7270	3.69	0.0871
$Error_b$	9	844.1962	93.79958	4.03	0.0001
Damage (D)	3	321.5612	107.1870	1.61	0.2036
Control vs D	1	150.6112	150.6112	2.26	0.1411
15% vs rest	1	93.37863	93.37863	1.40	0.2438
30% vs 45% D	1	76.06254	76.06254	1.14	0.2920
K*D	9	354.1452	39.34947	0.59	0.7951
$Error_b$	36	2393.873	66.49647	2.85	0.0001
Error	232	5404.048	23.29331		
Total	295	10933.74			

R-Square = 0.50 C.V. = 24.67