Preharvest and postharvest factors affecting yield and quality of witloof chicory (Cichorium intybus L.) /

PREHARVEST AND POSTHARVEST FACTORS AFFECTING YIELD AND QUALITY OF WITLOOF CHICORY (*Cichorium intybus* L.)

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ABSTRACT

PREHARVEST AND POSTHARVEST FACTORS AFFECTING YIELD AND QUALITY OF WITLOOF CHICORY.

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Key words: Belgian endive, cultural practices, 'Daliva', 'Faro', dry matter, soluble carbohydrates, vegetable forcing

The effects of plant population, maturity, cultivar, thinning, and storage duration on growth, yield, and quality of witloof chicory (*Cichorium intybus* L.) roots and chicons were studied. 'Daliva' plants were grown at 22 and 44 plants m^{-2} and harvested after 100, 120, and 140 days from planting in the maturity-population study, while 'Daliva' and 'Faro' plants were grown at 22, 29, and 44 plants m^{-2} and harvested after 120 days from planting in the cultivar-population study. Samples of field treatment combinations were forced hydroponically following 40, 80, 120, and 160 days of storage. Size, weight, dry matter, and soluble sugars of roots increased with increasing maturity. Yield of numbers of forceable roots harvested at 120 or 140 days was 265,000 and 190,000 ha^{-1} for the high and low populations, respectively in the maturity-population study. Yields of number of forceable roots for the cultivar-population study were 265,000, 225,000 and 165,000 ha^{-1} for the high, medium and low populations, respectively. Thinning had no effect on root yield, but did enhance crown diameters of roots. Roots grown for 100 days produced few or no marketable chicons. Yield of chicons in the maturity study from roots grown for ≥ 120 days at either population peaked when forced after 80 days storage and decreased later in storage suggesting that yield and quality of chicons is partially dependent on levels of carbohydrates and soluble sugars in roots at the time of forcing. 'Daliva' produced high yields of chicons early in storage, but decreased over time, while yields from 'Faro' were consistent at all storage periods. Greater consistency of marketability, size, and quality of chicons was obtained from roots grown at the low plant population, but higher yield of roots from the high population resulted in a 17% yield increase of chicons in the maturity-population study, while the low and intermediate plant population produced the largest yield of chicons in the cultivar-population study. Results suggest that optimum production of high yields of chicons in Massachusetts is obtained with the use of early and late cultivars, grown at plant populations of 220,000 to 290,000 ha^{-1} for a minimum of 120 days.

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CHAPTER I

INTRODUCTION

A. Botanical Description

Witloof chicory (*Cichorium intybus* L.), also known as Belgian endive, is a perennial vegetable, grown as a biennial, that is extensively cultivated in France, the Netherlands, and Belgium. Native to the Mediterranean region of Europe and a member of the cichorium tribe of the compositae family, witloof chicory produces a taproot and a rosette of leaves in the first season (Fernald, 1970). The plant develops a floral meristem in the second year that gives rise to a tall spike supporting clusters of 4 to 6 axillary, nearly stemless blue composite infloresences (Leteinturier, 1983). Wild strains of chicory can be seen flowering in the late summer along roadsides in New England.

Chicory has been used, in the wild state "from time immemorial" for salads and medicinally (Vilmorin-Andrieux, 1885). First record of cultivation was in 1616 in Germany. Common uses were green leaves for salads, and roots (of the Magdenburg type) used as a coffee substitute (Ryder, 1979). Forcing of the roots to produce chicons (firm heads of etiolated leaves) began in the mid 1800's in Belgium. Forced chicory is known as witloof chicory, translated means "white-leaf" chicory. Witloof chicory has become a staple vegetable crop in Belgium and France, where 9,300 hectares and 14,460 hectares are cultivated, respectively (Ryder, 1979).

There is increased interest in expanding the witloof chicory industry in North America. Current United States imports of witloof chicory are valued at $6 millon annually, suggesting it is a crop with an established market with opportunities for increased expansion (U.S. Dept. Commerce, 1987).

B. Production

1. Field Stage

Witloof chicory is grown on a wide range of soil types. The most desirable soils are silt loams that are free of stones, with low nitrogen content (Leteinturier, 1983; Timmerman, 1980). Excessive soil nitrogen is undesirable because it causes production of excessive leaf growth at the expense of the accumulation of dry matter in the taproot. Chicory is best grown in soils with a pH of 5.5 to 7.0 (Machet, 1986). It is desirable to grow the crop in rotation with crops that leave low residues of soil nitrogen. Typically, small grains are rotated with chicory because of their low nitrogen requirements. European guidelines suggest witloof be planted once every four years on a given area. Rotation with carrots, onions, lettuce, and potatoes should be avoided to ensure that inoculum of *Sclerotinia sclerotiorum* and *Rhizoctonia solani* do not reach injurious levels (Leteinturier, 1983).

The crop is seeded in late spring and harvested in the fall. In the northeastern U.S., planting should not begin earlier than the last week of May and can extend to the beginning of July. Chicory can withstand hard frosts in the fall, but early seeding which would result in cool weather in early development can lead to bolting (Corey et al., 1989; Hill, 1985). The crop is generally precision seeded in 38 cm row spacings on the flat or in double-rows on raised beds spaced at 76 cm. European production recommendations suggest drilling 600,000 seeds per hectare, and thinning to plant populations of 200,000 to 250,000 plants per hectare. Weed control practices include use of stale seedbed method of seeding, premergant herbicides, such as chlorprophame and propyzamide, and cultivation for early season weed control. Use of non-selective, translocated herbicides, such as glyphosate, applied with a wick applicator is effective for late season weed control. The roots reach maturity in the range of 120 to 165 days, depending on the climate and cultivar (Timmerman, 1980). Yields of roots obtained in Europe with these guidelines range from 18 to 30 MT per hectare (Cochet and Marle 1985). After harvest the roots are placed into cold storage at 0° C to 2° C and 95% relative humidity (Anon., 1985). A minimum vernalization of 10 to 30 days, depending on cultivar, is required before the roots are ready for forcing chicons (Huyskes, 1962).

Fiala and Jolivet (1980) suggest that the main obstacle to production of consistent quality chicons is the inability to determine optimum maturity of the roots. Root crown diameter and percent dry matter can be used to estimate maturities in the field. Crown diameters of 3.0 to 5.0 cm and percent dry matter of 22 to 24% are common European recommendations (Leteinturier, 1983). Attempts to correlate seasonal trends in carbon dioxide exchange of leaves with maturity of roots have been unsuccessful (Huygens et al., 1983). Studies with cultivars used for a coffee substitute showed increases in higher molecular weight oligofructosans, reducing sugars, and root yield with increasing maturity (Bhatia et al., 1974; Chubey and Dorrell, 1978). Suitability for forcing after storage is dependent on the physiological condition of the root (Fiala and Jolivet, 1980).

2. Storage

During the first two weeks in cold storage, the vegetative bud differentiates to a floral meristem which then elongates during the forcing process. The storage carbohydrate, inulin, slowly breaks down leading to an increase in the soluble sugar fraction, a process necessary for growth and development of chicons during the forcing stage. Carbohydrate composition of the roots at harvest and the subsequent breakdown of inulin to oligofructosans during storage has been studied to establish indicators for optimum forcing time for roots of various cultivars (Rutherford and Weston, 1968; Jolivet and Fiala, 1980). The rate of breakdown varies during storage, with most changes occurring within 6 to 8 weeks, and can be correlated with chicon quality (Rutherford, 1977; Rutherford and Phillips, 1975). Ethanol soluble carbohydrates, sucrose, fructose, glucose and oligofructosans up to 10 units increase greatly during the first month and a half of storage (Fiala and Jolivet, 1980). The quality of chicons produced after storage is affected by the change in inulin and soluble sugar concentrations, and varies among cultivars (Fiala and Jolivet, 1980; Huyskes, 1962). Reduced quality of chicons after long storage periods (more than 18 weeks) before forcing has been noted and correlated with increasing length of the central axis (Rutherford, 1977).

This suggests that forcing results depend upon the physiological state of the root. The physiological condition of the root is dependent on the cultivar, which in turn is dependent on environmental conditions during growth and development in the field, storage conditions, and storage duration. Generally, it is desirable to produce a range of cultivars that are suitable for early, intermediate, and late forcing to maximize yield and quality over the complete production cycle.

3. Forcing

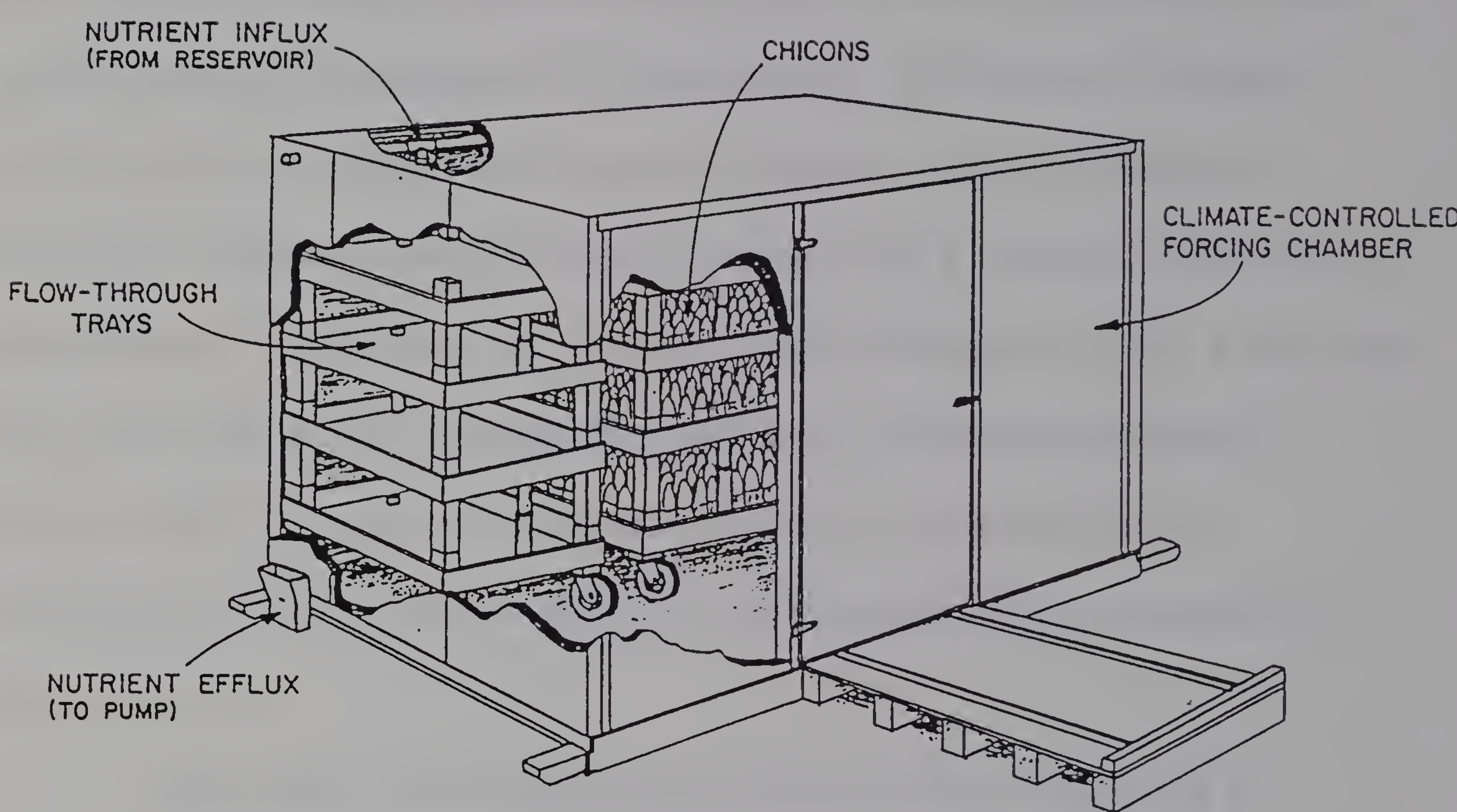
The forcing stage of production is where the marketable product, the chicon, is produced. There are three methods of forcing presently used, hydroponic without cover and in soil, with or without cover. Traditionally, soil forcing with cover has been the method of choice, but with the development of hybrid cultivars, hydroponic methods have become the dominant method of commercial production. Many small scale producers in Europe are still using the soil forcing, because of the higher quality chicons produced. The extra labor expense of cleaning chicons that have been forced in a system with soil cover has caused producers to convert to hydroponic systems.

The hydroponic method produces a harvestable crop in 20 to 30 days when forced at temperatures in the range of 13° to 22° C. Specific temperature is dependent on the cultivar, maturity, and storage period. Typically, temperatures are reduced as roots are stored for longer periods, and the forcing solution temperature is maintained 1° to 2° C warmer than the air temperature (Van Kruistum, 1981).

Hydroponic production is dependent on the use of a temperature and humidity controlled facility. Typical forcing systems consist of a nutrient reservoir with stacked watertight trays 1 m^{-2} and 10 to 15 cm deep constructed of wood or steel (Corey and Whitney, 1988). The roots are placed upright in the trays, with the nutrient solution pumped to the top tray and gravity fed to the lower trays, via telescoping PVC pipes. The solution then flows, or is pumped to a reservoir, and recirculated to the top container. The protruding tubes, generally measuring 4 cm in diameter, are adjustable so the nutrient solution can be maintained at a constant depth (usually 5 cm) before it flows into the lower tray (Figure 1.1).

The addition of nutrients to the forcing solution has been shown to increase chicon weight (Lips, 1976). Typical solutions include the addition of $Ca(NO_3)_2$, $MgSO_4$, and KNO_3 (Brunner, 1983). Nutrient levels are monitored by testing solution conductivity and adjusted with the addition of fertilizers. An upward drift in pH is common due to the uptake of anions such as NO_3^-, and the resultant efflux of hydroxyl ions. Solution pH is monitored and kept in the range of 6.0 to 7.0 with periodic additions of sulfuric acid. Treatment of roots with ethylene prior to forcing has resulted in increased chicon yields (De Proft et al., 1986). Improved quality and yields of chicons has been noted with the use mechanical pressure on the chicons during forcing (Corey and Tan, 1990).

Figure 1.1 Schematic diagram of a hydroponic forcing chamber. Taken from Witloof chicory: a new vegetable crop in the United States. In: Advances in New Crops (Corey et al. 1990).

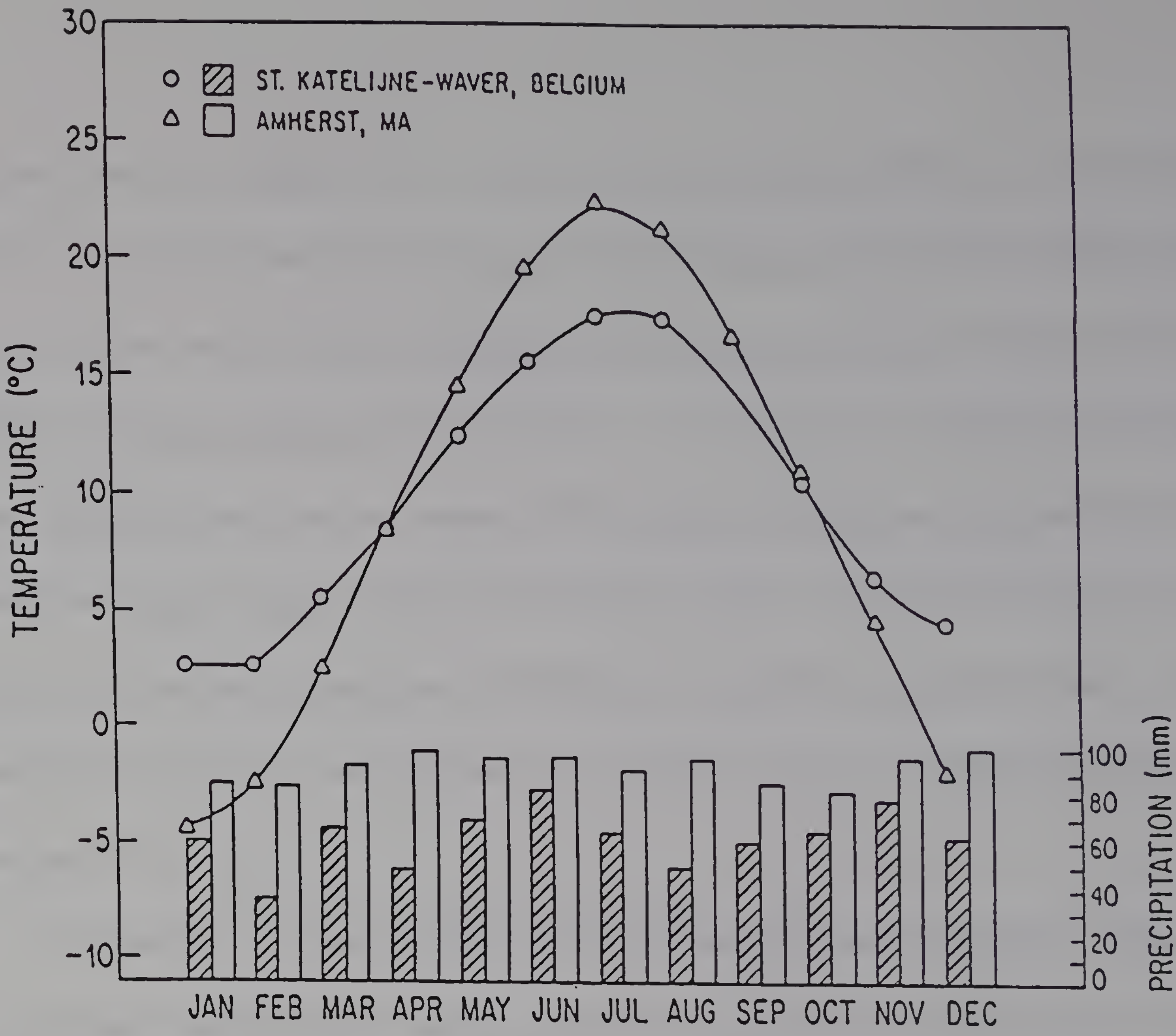

NUTRIENT INFLUX
(FROM RESERVOIR)
CHICONS
CLIMATE-CONTROLLED
FORCING CHAMBER
FLOW-THROUGH
TRAYS
NUTRIENT EFFLUX
(TO PUMP)

C. Climatic Requirements

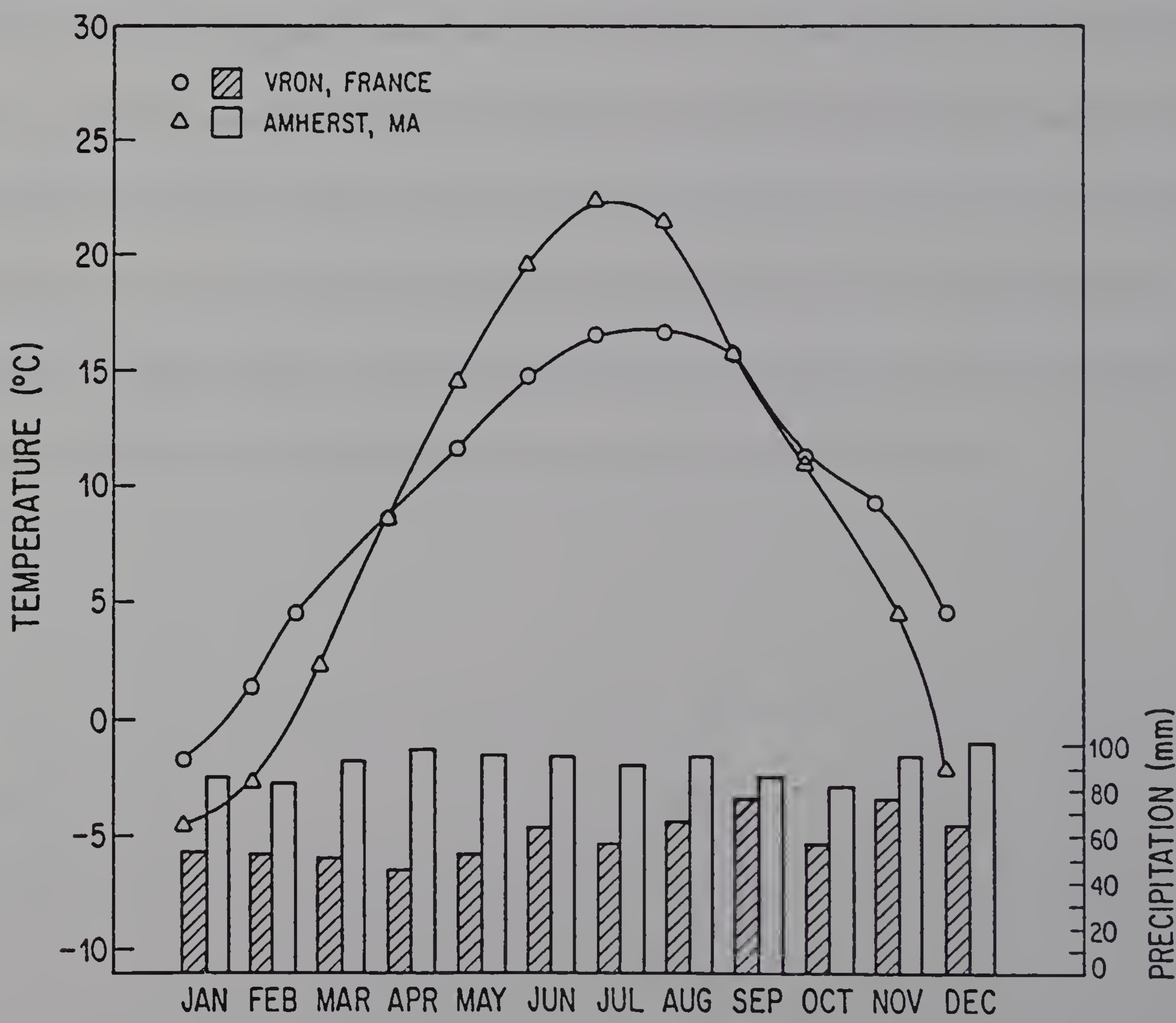
The principal production areas of witloof chicory are the coastal regions of France, the Netherlands, and Belgium. The climate of those regions is characterized by long cool summers and moderate winters. Climatic differences between Massachusetts and European production areas are considerable (Figure 1.2) with most noticeable differences being higher summer temperatures and greater amounts of precipitation in Massachusetts. Differences in latitude, Massachusetts 42.5 degrees and Belgium 51 degrees, results in increased daylength in Belgium during the growing season, with a maximum difference of approximately 75 minutes at the summer solstice (Wernstedt, 1972). It has been shown that plant growth, development, and yield is dependent on climate (Watson, 1963). Because of the climatic differences, growth rate and development of chicory will likely differ in Massachusetts when compared to European areas.

Plant species with varying native habitats respond differently to temperature changes. Plants often respond positively to increased temperatures, resulting in increased rate of carbon dioxide fixation, thus an increase in the net assimilation rate. Excessively warm temperatures can result in injury to the photosynthetic components of a plant, depending upon the species, which greatly reduces the net photosynthetic rate (Berry and Björkman, 1980). The maximum variation of 8° C between Massachusetts and European production areas suggests that chicory plants could develop more quickly than in European production areas, without encountering injurious temperatures. Potential differences in

Figure 1.2 Climate comparisons, based on 30 year average data, between Amherst, MA and witloof production regions in Belgium and France.



ST. KATELIJNE-WAVER, BELGIUM
AMHERST, MA
TEMPERATURE (°C)
PRECIPITATION (mm)
30
25
20
15
10
5
0
-5
-10
100
80
60
40
20
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC



VRON, FRANCE
AMHERST, MA
TEMPERATURE (°C)
PRECIPITATION (mm)
30
25
20
15
10
5
0
-5
-10
100
80
60
40
20
0
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

growth rate also suggests the testing of increased populations. It has been shown with many crops that the above-ground and below-ground dry weight produced from a given area remains relatively constant as population increases (Donald, 1963). If this is true for witloof chicory, roots produced at high populations will have reduced levels of dry matter. The potential increase in growth rate could result in larger weight yield of roots from a given area, which theoretically could result in roots with adequate carbohydrates to produce quality chicons. The main question is at what plant population is optimum yield of marketable chicons produced?

Research on determining optimum combinations of cultivar, plant populations, maturity, and storage period is essential for establishing witloof chicory production guidelines for the Northeast. European recommendations for plant population and maturity (as noted in the field production section) are used as guides in testing various cultivar, plant population, maturity, and storage period combinations in the research projects presented herein. Comparisons to European yields aids in evaluating production programs and the suitability of the regional climate of Massachusetts for growing witloof chicory.

CHAPTER II

CULTIVAR-POPULATION STUDY

A. Materials and Methods

1. Cultural Practices

The experimental design was a split-split-split plot with randomized complete blocks (4 replications). The field layout is shown in Figure 2.1. Cultivar, was the whole plot factor with unthinned plant populations (A, B, and C) the subplot factor, and thinned populations (A - 44, B - 29, and C - 22 plants m^{-2}) the sub-subplot factor. 'Daliva' and 'Faro' were the cultivars used. Root storage period before forcing (40, 80, 120, and 160 days) was the sub-sub-subplot factor. Field sub-sub-plots consisted of four, 12.2 m long rows, spaced at 38 cm. Plots were 1.8 m on center.

The field experiment was conducted at the University of Massachusetts research farm in South Deerfield, Massachusetts in 1988. Experimental field plots were grown on a Hadley very fine sandy loam soil (0 to 3 % slope); a common alluvial soil in the Connecticut river valley.

The field was plowed, disk-harrowed and meeker-harrowed before planting. Superphosphate and muriate of potash were broadcast and incorporated to supply 48 kg P ha^{-1} and 93 kg K ha^{-1}. The experiment was planted on July 14 with a four-row, tractor-mounted Stanhay precision planter (model S870). Each belt was punched with 45, #8.5 holes. The hole size was determined by a Stanhay distributor (Lee Shuknecht & Sons Inc., Elba, NY), and consisted of evaluating hole size to achieve the best % of singulation. The A choke plate was used on the seeders and the A, B, and C pulley settings were used on the seeder drive shafts for the 3 population treatments, with A delivering the highest population, B delivering an intermediate population and C planting the lowest population (Stanhay, 1976). The field plots received 6 cm of rain the day after planting. Some washing of the seedbed occurred, which resulted in poor stands of 'Faro'. The plots were irrigated as needed throughout growth. Weed control consisted of hand cultivation. Desired thinned populations were obtained by hand thinning two weeks after emergence. The number of plants needed in 2 m of row was calculated and plots were thinned accordingly.

2. Field Stage

Roots were harvested 120 (Nov. 12) days after planting. Shoots were removed one day before harvest. Hedge shears were used to cut the tops to approximately 7.5 cm above the crown. The roots were hand dug with spades and placed into wooden crates. The harvest sample size was 6.1 m and consisted of 3.05 m of inside row and 3.05 m of outside row (Appendix A). Total number of roots harvested, total root weight, number of forceable roots (defined as having crown diameter ≥ than 2.0 cm and minimal branching), total weight of forceable roots, and crown diameter (determined on a 12-root subsample) were measured. The forceable roots were placed into cold storage at 2^{0} C ± 2^{0} and 95% relative humidity. A harvest index was calculated by dividing the total weight of forceable roots by the total plant weight (roots and shoots of a 12 plant subsample).

Figure 2.1 Experimental design and plot plan for the cultivar-population study. The diagram is not to scale.

N

Cultivar	Pulley Setting	Thinned Population
D=Daliva	A = high pop.	A = 438,000 pl/ha
F=Faro--	B = mid pop.	B = 292,000 pl/ha
TH = Thinned	C = low pop.	C = 219,000 pl/ha
NT = not thinned		

13 m

F-B-TH	NT	D-A-TH	NT
F-C-TH	NT	D-B-NT	TH
F-A-NT	TH	D-C-NT	TH
D-C-TH	NT	F-A-TH	NT
D-B-TH	NT	F-C-TH	NT
D-A-TH	NT	F-B-NT	TH

1.8 m

road

Block III — Block IV

Block I — Block II

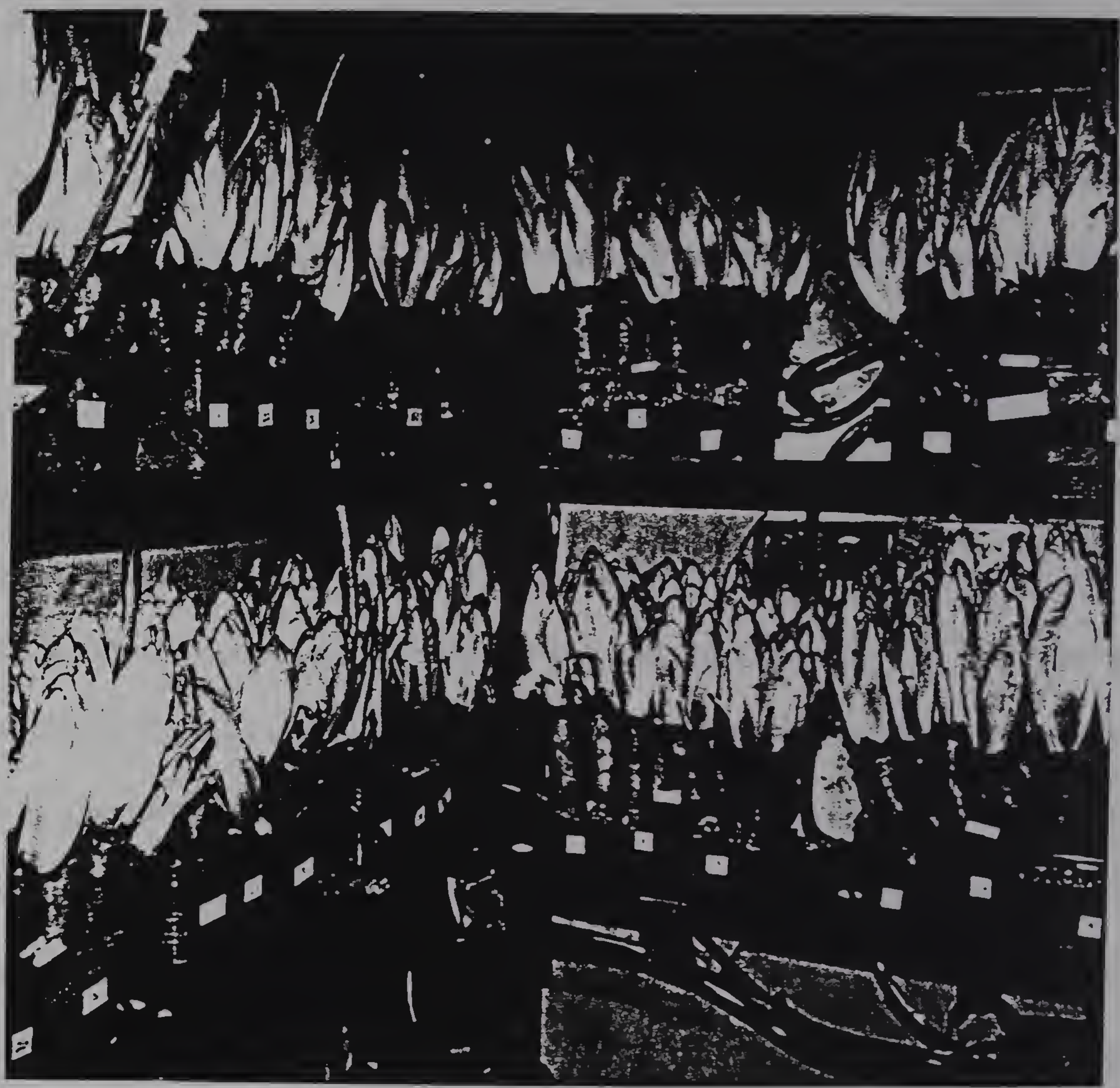
F-B-NT	TH	F-C-TH	NT
F-A-TH	NT	F-A-NT	TH
F-C-TH	NT	F-B-TH	NT
D-C-NT	TH	D-A-TH	NT
D-B-TH	NT	D-C-NT	TH
D-A-TH	NT	D-B-NT	TH

3. Forcing

The roots were forced hydroponically in the dark in a walk-in cooler. The system consisted of a 180 L reservoir and 33 forcing containers each measuring 25 cm wide x 14 cm deep x 10 cm high. The forcing solution was pumped from the reservoir with a submersible pump (rated at 0.015 hp with a capacity of 777 L per hour at an elevation of 0.3 m) to the main-line where the solution flowed by gravity through 3 containers on each of the 11 sub-lines and back to the reservoir. A portion of the system is shown in Figure 2.2. The solution flowed at a rate of 75 ml/minute ± 10 ml, and was aerated in the reservoir with a gas dispersion tube connected to a compressor (0.04 hp). Additional aeration occurred as the solution flowed into each container.

The forcing solution consisted of 2.7 mM $Ca(NO_3)_2$, 2.6 mM $MgSO_4$, and 8.7 mM KNO_3 prepared from tap water (De Proft et al., 1986). The electrical conductivity of the solution was measured periodically with an Electromark conductivity analyzer (model 422) and kept within the range of 1.8 to 2.2 mmhos. Solution pH was held between 6.0 and 7.5. Upward drift of pH was adjusted by periodic addition of H_2SO_4. The air temperature of the forcing facility was held at 15 C for the first two forcings and lowered to 12 C for the last two forcings. The change in forcing temperature was made based on European recommendations of reduced forcing temperatures for roots that have been in storage for long periods. Roots from each field treatment were forced after storage periods of 40, 80, 120, and 160 days. Twelve roots of each treatment and replication were selected randomly from storage. The roots were cut to a length

Figure 2.2 Experimental-scale hydroponic forcing facility designed for forcing roots with various field and storage treatment combinations.



of 15 cm and the remaining shoots were trimmed to 2.5 cm. The roots were placed upright in a forcing container (each container held 2 field treatments) and harvested after 27 days. Treatments forced after 120 and 160 days of storage were harvested after 31 days, due to the lower forcing temperature used, which results in slower chicon development. Each chicon was weighed, trimmed, graded, and reweighed. Criteria for marketability consisted of a 60 g minimum weight and a tight well-closed chicon. Average weight of a marketable chicon was calculated by dividing the total marketable trimmed weight by the number of marketable chicons. Replications with no marketable chicons were included in the calculations, which caused some average chicon weights to be below the 60 g minimum. A marketable yield ratio of the chicons was determined by dividing the total marketable weight by the total untrimmed weight. Subtracted from one, this ratio indicates the percentage weight loss due to trimming. A Marketable Yield Index (MYI) was calculated by dividing the total marketable weight of chicons by the initial weight of roots that were forced. Analyses of variance, regression, and correlation procedures were conducted using the Statistical Analysis System (SAS, 1989). Analyses of variance of all experiments are presented in Appendix C (Tables A.2 - A.8) Levels of significance used were 5% for main effects and 10% for interactions.

B. Results and Discussion

1. Population-Thinning

The experiment received large amounts of rain the day after planting, resulting in erosion of sections of the field plots. This caused difficulty in obtaining desired plant populations in thinned plots because of inadequate plant stands, especially in the 'Faro' plots. The actual number of plants harvested from the thinned and unthinned plots of both cultivars is presented in table 2.1.

Table 2.1 Actual population of roots harvested from field plot area of 1 m^2 for thinned and unthinned treatments of cultivars Daliva and Faro. S. Deerfield, MA 1988.

Cultivar	Seeder Pulley Setting	Desired Plant Population	Actual Unthinned Population	Actual Thinned Population
'Daliva'	A	44[a]	47	39
	B	29[b]	33	30
	C	22[c]	27	21
'Faro'	A	44[a]	22	23
	B	29[b]	21	23
	C	22[c]	22	17

a = 438,000 plants ha^{-1}
b = 292,000 plants ha^{-1}
c = 219,000 plants ha^{-1}

The 'Faro' plots had similar actual plant populations for all the population thinning treatment combinations, resulting in poor information on the affect of population on root growth. The plots did result in populations that equaled the low population treatment. The actual population of the 'Daliva' plots were similar to the desired populations, giving good information on the effect of population on root growth. While the data from the 'Faro' plots does not represent effects of varying population, it does provide meaningful information on looking at cultivar effects on growth and yield of roots at the low population treatment.

2. Field Stage

There was a significant linear increase in yield of 'Daliva' roots with increasing plant population, the high population yielding 33% more forceable roots than the low population (Figure 2.3 A). While the high population had higher yields, it produced the largest number of unusable roots (Figure 2.3 B). This represents wasted seed, increased handling and therefore increased production costs. There were no significant differences in yield among the populations in the 'Faro' plots, which is attributable to poor population establishment (Figure 2.3 A). Thinning had no effect on yield of forceable roots for either cultivar.

There was a significant linear trend of the effect of plant population on crown diameter of 'Daliva' roots. As plant population increased, root crown diameter decreased. There was no main effect of thinning on crown diameter of roots, but there was an interaction effect of cultivar and thinning at the 10% level of significance (Figure 2.4). It appears the spacing between plants in the thinned 'Daliva' plots was more uniform than the unthinned plots resulting in larger

Figure 2.3 Effects of plant population on (A) yield of forceable roots and (B) % of roots forceable of 'Daliva' and 'Faro' plants. Points represent means of 4 replications and vertical bars represent 1 SD. L**, L*, and NS denotes significant linear regression at the 1% level, significant linear regression at the 5% level and no significant regression, respectively.

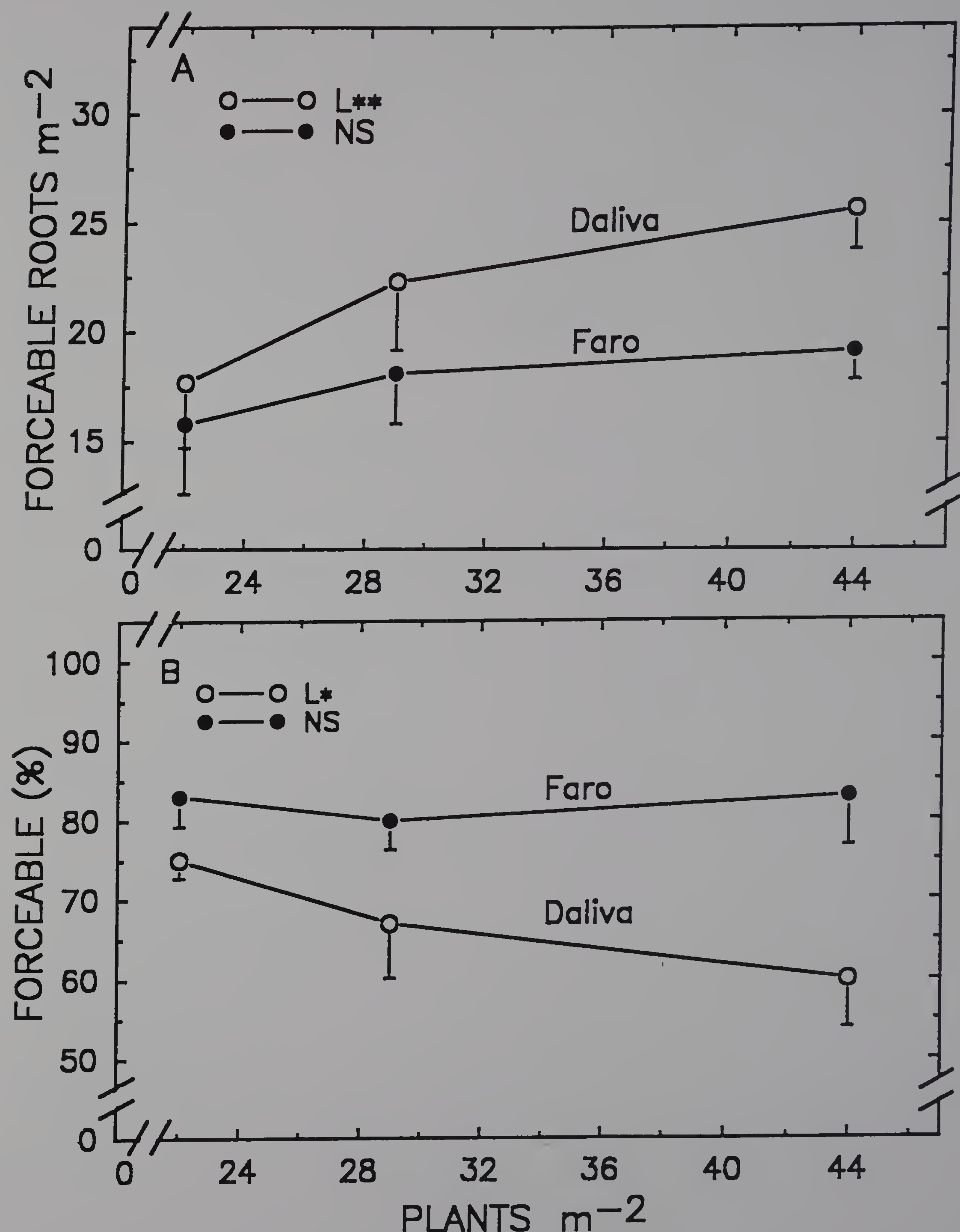
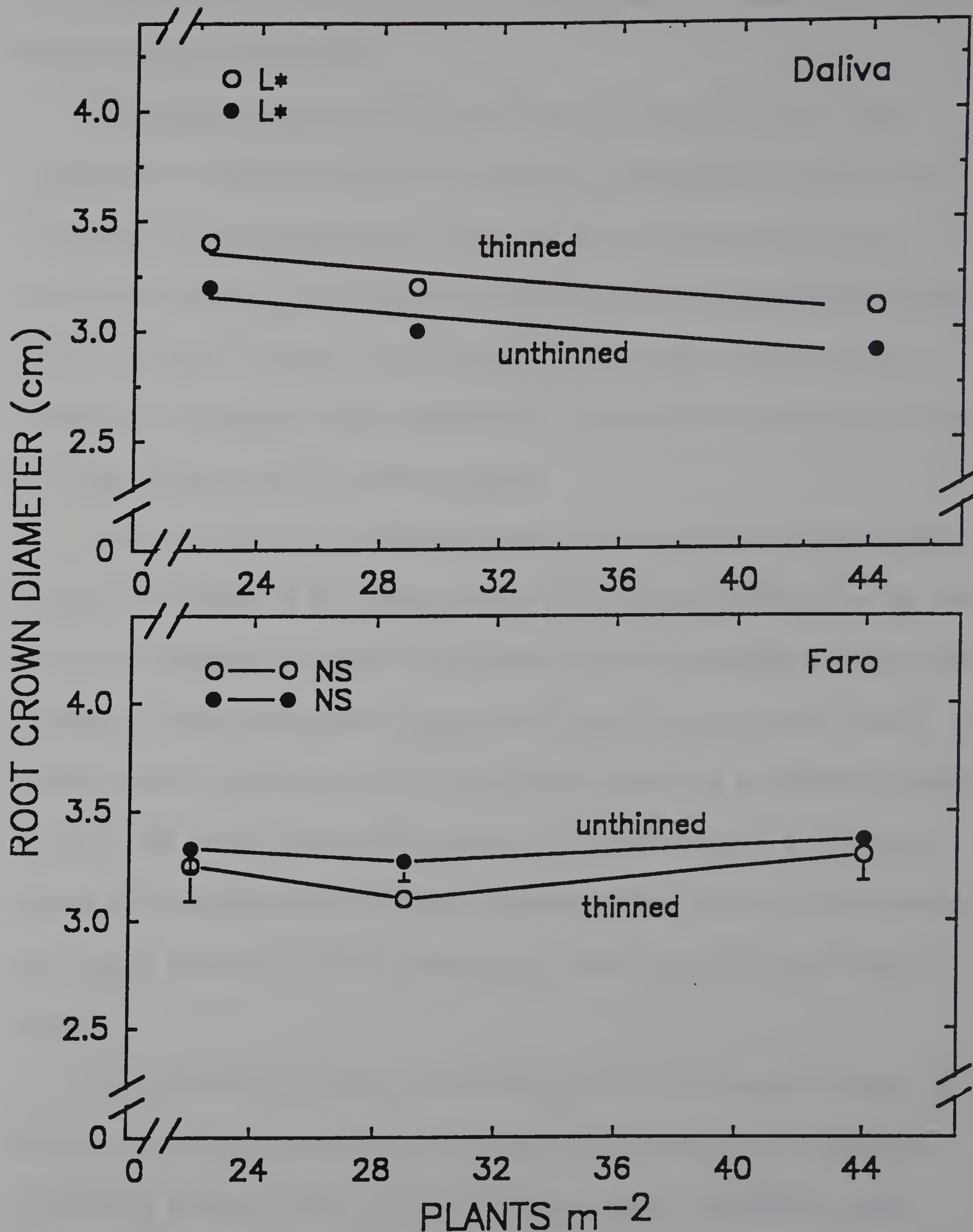

A
L**
NS
FORCEABLE ROOTS m^{-2}
30
25
20
15
0
Daliva
Faro
0
24
28
32
36
40
44
B
L*
NS
FORCEABLE (%)
100
90
80
70
60
50
0
Faro
Daliva
0
24
28
32
36
40
44
PLANTS m^{-2}

Figure 2.4 Effects of plant population and thinning on crown diameter of roots of 'Daliva' and 'Faro' plants. Points represent means of 4 replications. L* and NS denotes significant linear regression at the 5% level and no significant regression, respectively.


ROOT CROWN DIAMETER (cm)
Daliva
L*
L*
thinned
unthinned
Faro
NS
NS
unthinned
thinned
4.0
3.5
3.0
2.5
0
0
24
28
32
36
40
44
PLANTS m−2

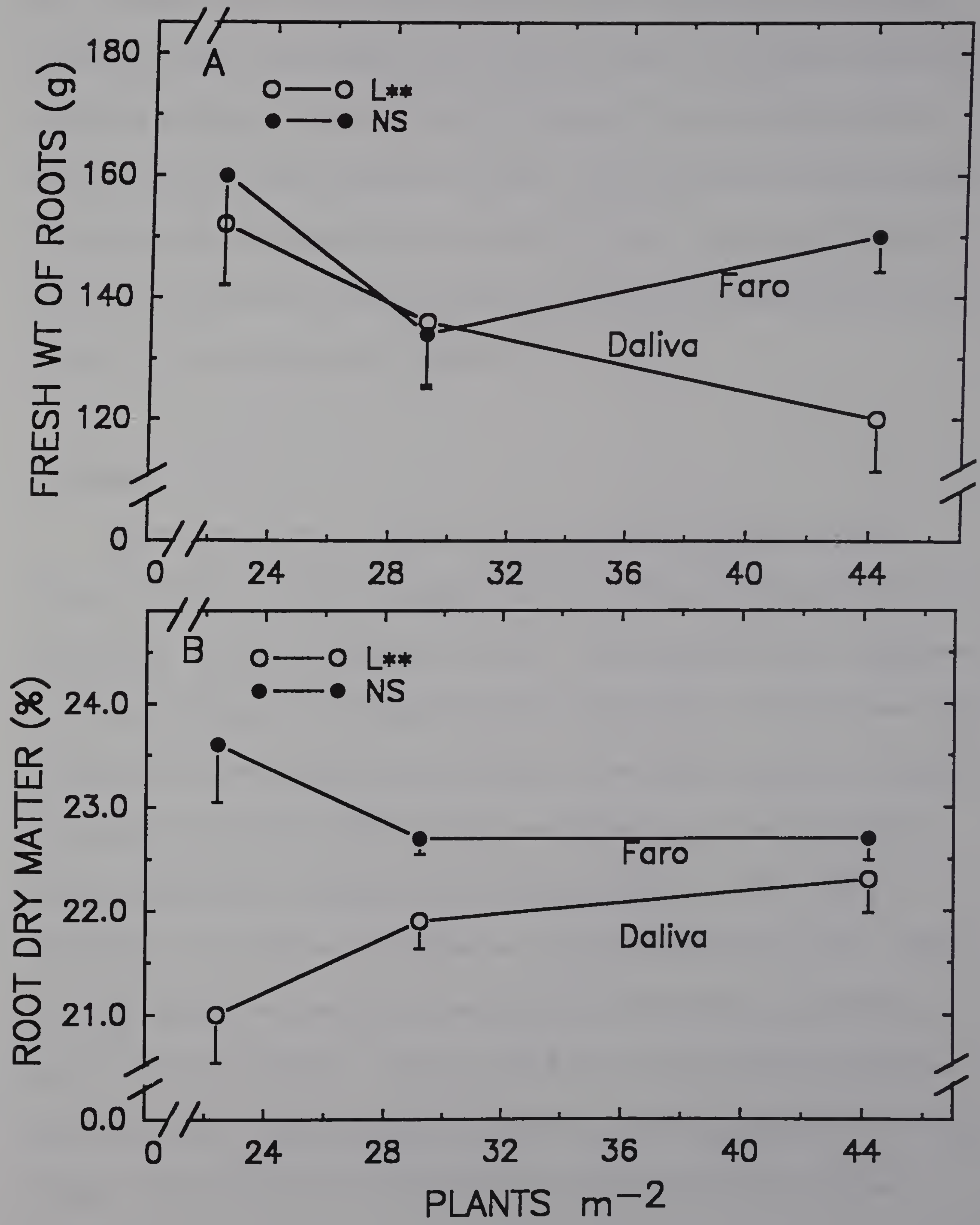
crown diameters. The data suggests crowding of plants occurred in the unthinned plots, attributable to the inability of the Stanhay seeder to place naked seeds with exact precision (Appendix B).

There was an inverse linear relationship of weight of roots to plant population for 'Daliva', with the low population producing the heaviest roots. 'Faro' plots, which had populations similar to that of the low population treatment in 'Daliva' plots, had similar fresh weight of roots as 'Daliva' (Figure 2.5 A). The lack of effect of plant population on weight of roots of 'Faro' is attributed to inadequate stand establishment. There was no effect of thinning on the fresh weight of roots for either cultivar.

Percent dry matter of 'Daliva' roots increased slightly with higher plant populations (Figure 2.5 B). While there was a signifigant difference at the 10% level, the differences are minor. Increased size of roots produced at lower plant densities is likely attributable to larger leaf surface area, and thus a greater photosynthetic capability. At the low population there was a significant difference in the % dry matter between the cultivars . The difference in % dry matter affects total carbohydrates of the roots, suggesting that 'Faro' roots may tend to have larger amounts of stored carbohydrates, which may be of importance in forcing.

Field results show that the fewer the plants per unit area, the larger the roots produced from those plants. The harvest index indicates that biomass partitioning between leaves and roots remains constant regardless of plant population (Figure 2.6). Increased size of roots obtained at the low

Figure 2.5 Effect of plant population on (A) fresh weight of roots and (B) % dry matter of roots of 'Daliva' and 'Faro' plants. Points represent means of 4 replications and vertical bars represent 1 SD. L** and NS denotes significant linear regression at the 1% level and no significant regression, respectively.


A
L**
NS
FRESH WT OF ROOTS (g)
180
160
140
120
0
Faro
Daliva
0
24
28
32
36
40
44
B
L**
NS
ROOT DRY MATTER (%)
24.0
23.0
22.0
21.0
0.0
Faro
Daliva
0
24
28
32
36
40
44
PLANTS m−2

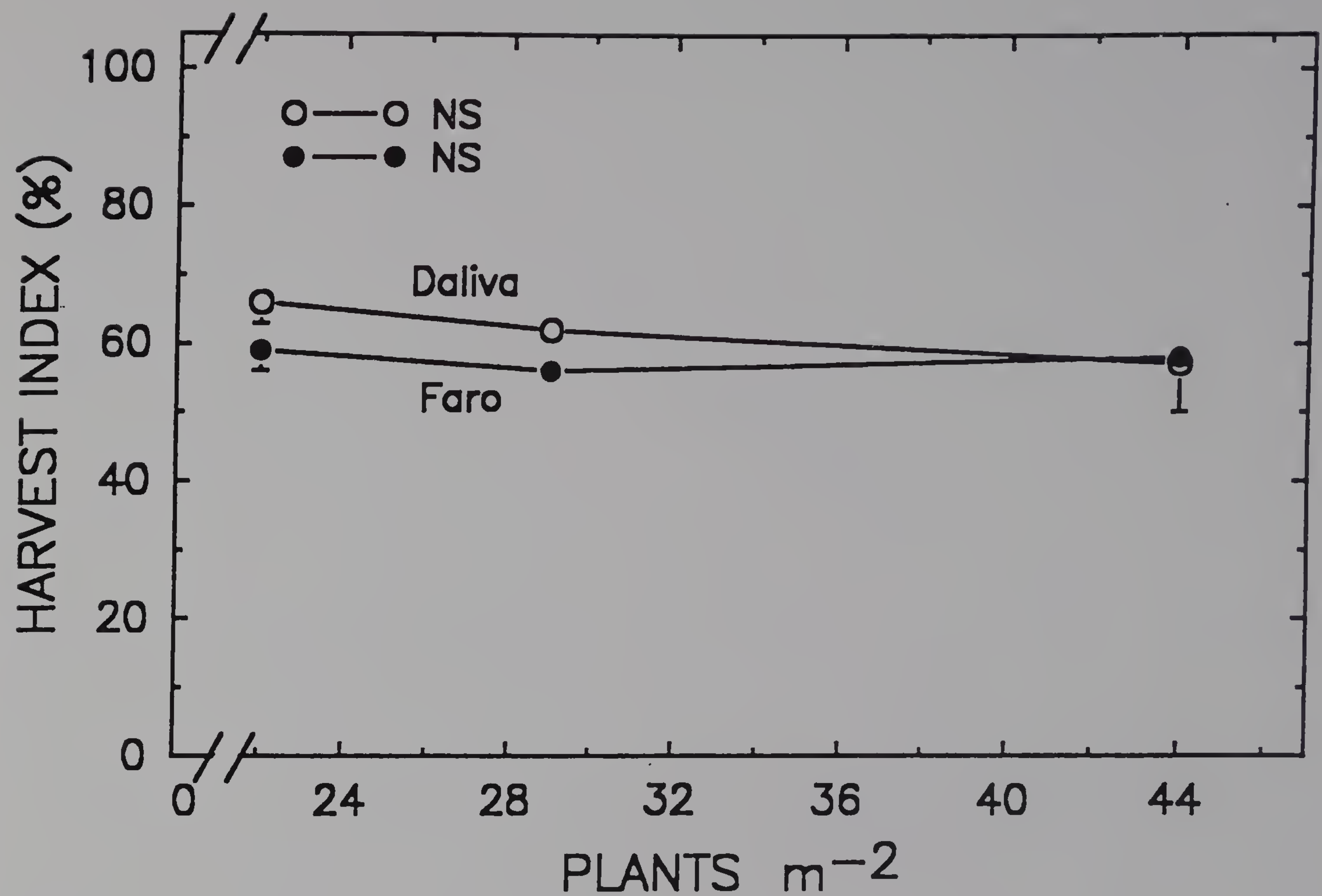
population resulted from increased overall growth, not from a change in carbohydrate partitioning. Thinning had minimal affect on root size and root yield. Greater yields of forceable roots from higher populations are desirable, unless the smaller roots produce poor results in forcing. If a larger minimum size is used for grading of roots as forceable, such as 2.5 cm, the trend of yield of forceable roots to plant population is altered. The differences in yield becomes less between the three populations, because the roots produced at 44 plants m^{-2} had a higher proportion of roots with crown diameters between 2.0 and 2.5 cm than the two lower populations (Figure 2.7).

3. Forcing

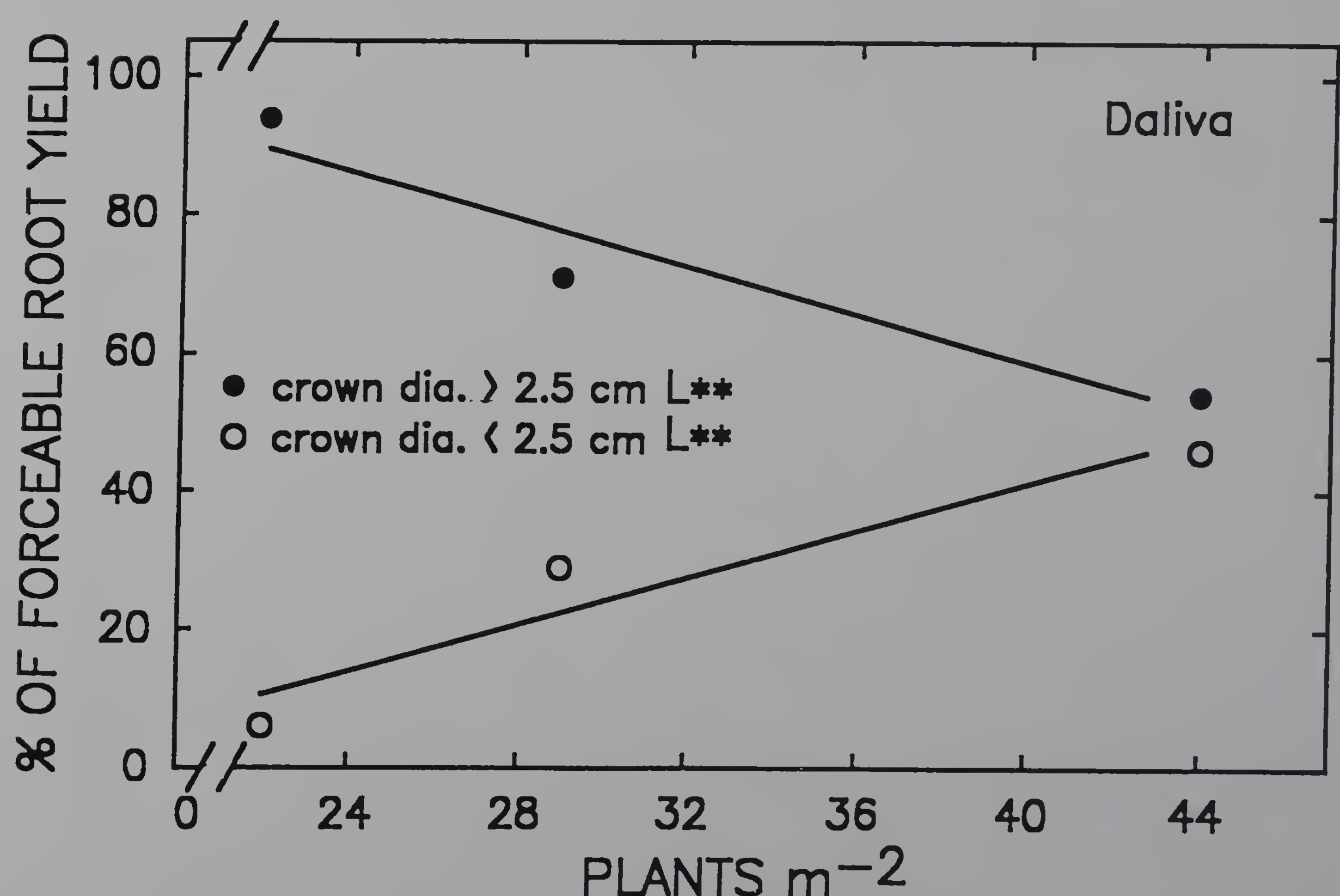
There were significant effects of storage period on forcing responses between cultivars . 'Daliva' had higher yields of marketable chicons than 'Faro' when forced after 40 and 80 days of storage. When storage period is lengthened to 120 and 160 days 'Faro' outyielded 'Daliva' (Figure 2.8). The differences were much less when forcing after 80 and 120 days. The results confirm the European information that cultivars differ in their vernalization requirements and thus respond differently to varying periods of storage (Huyskes, 1963). 'Faro' is classified as a late cultivar and 'Daliva' as a early to mid cultivar (Anon., 1985). The data suggests that successful production of witloof chicory is dependent on the use of several cultivars. A grower must use early, mid and late cultivars in order to produce a high percentage of marketable chicons throughout the forcing season. The classification of cultivars from Nunhems Zaden seed company

Figure 2.6 Effect of plant population on harvest index (root d.w./total plant d.w.) of 'Daliva' and 'Faro' plants. Points represent means of 4 replications and vertical bars represent 1 SD. NS denotes no significant regression.

Figure 2.7 Distribution of size of roots produced from 'Daliva' and 'Faro' plants. Points represent means of 4 replications. L** denotes significant linear regression at the 1% level.

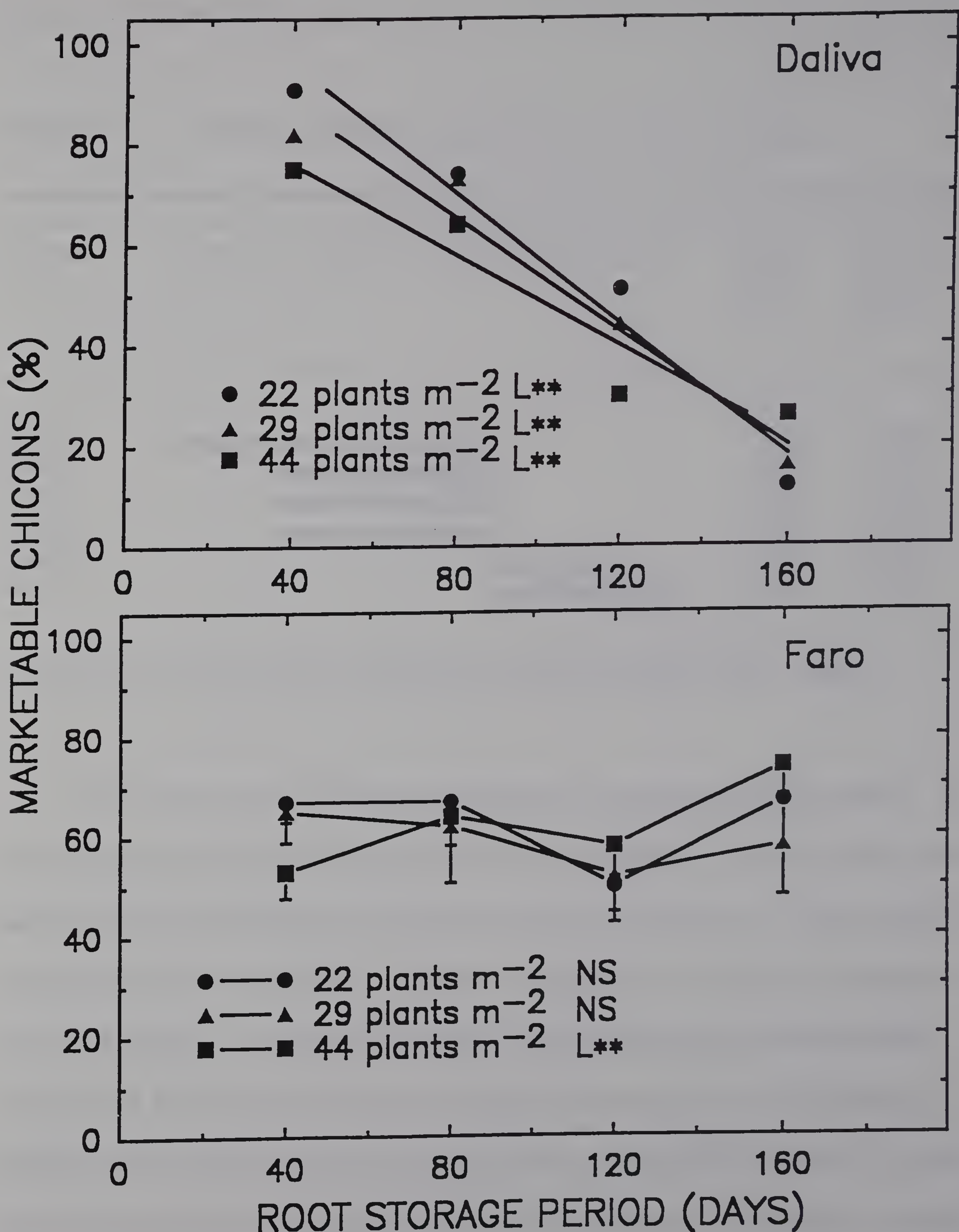


100
80
60
40
20
0
HARVEST INDEX (%)
NS
NS
Daliva
Faro
0
24
28
32
36
40
44
PLANTS m−2



100
80
60
40
20
0
% OF FORCEABLE ROOT YIELD
Daliva
crown dia. > 2.5 cm L**
crown dia. < 2.5 cm L**
0
24
28
32
36
40
44
PLANTS m−2

Figure 2.8 Effects of plant population and storage period of roots on the yield of % marketable chicons produced from 'Daliva' and 'Faro' roots. Points represent means of 4 replications and vertical bars represent 1 SD. L** and NS denotes significant linear regression at the 1% level and no significant regression respectively.



Daliva
22 plants m^{-2} L**
29 plants m^{-2} L**
44 plants m^{-2} L**
Faro
22 plants m^{-2} NS
29 plants m^{-2} NS
44 plants m^{-2} L**
MARKETABLE CHICONS (%)
ROOT STORAGE PERIOD (DAYS)
0
20
40
60
80
100
0
40
80
120
160

of the Netherlands (Table 2.2) appears to also apply for production of witloof chicory in Massachusetts.

Table 2.2 Forcing period of F1 hybrid witloof chicory cultivars.

Cultivar	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Soil temp °C	Air temp °C
Daliva									18-22	17-19
Cerol									16-20	14-15
Mitiva									16-20	14-16
Zoom									16-20	14-16
Landova									16-18	13-15
Faro									16-18	13-15

Adapted from The growing and forcing of chicory witloof. (Anon., 1985).

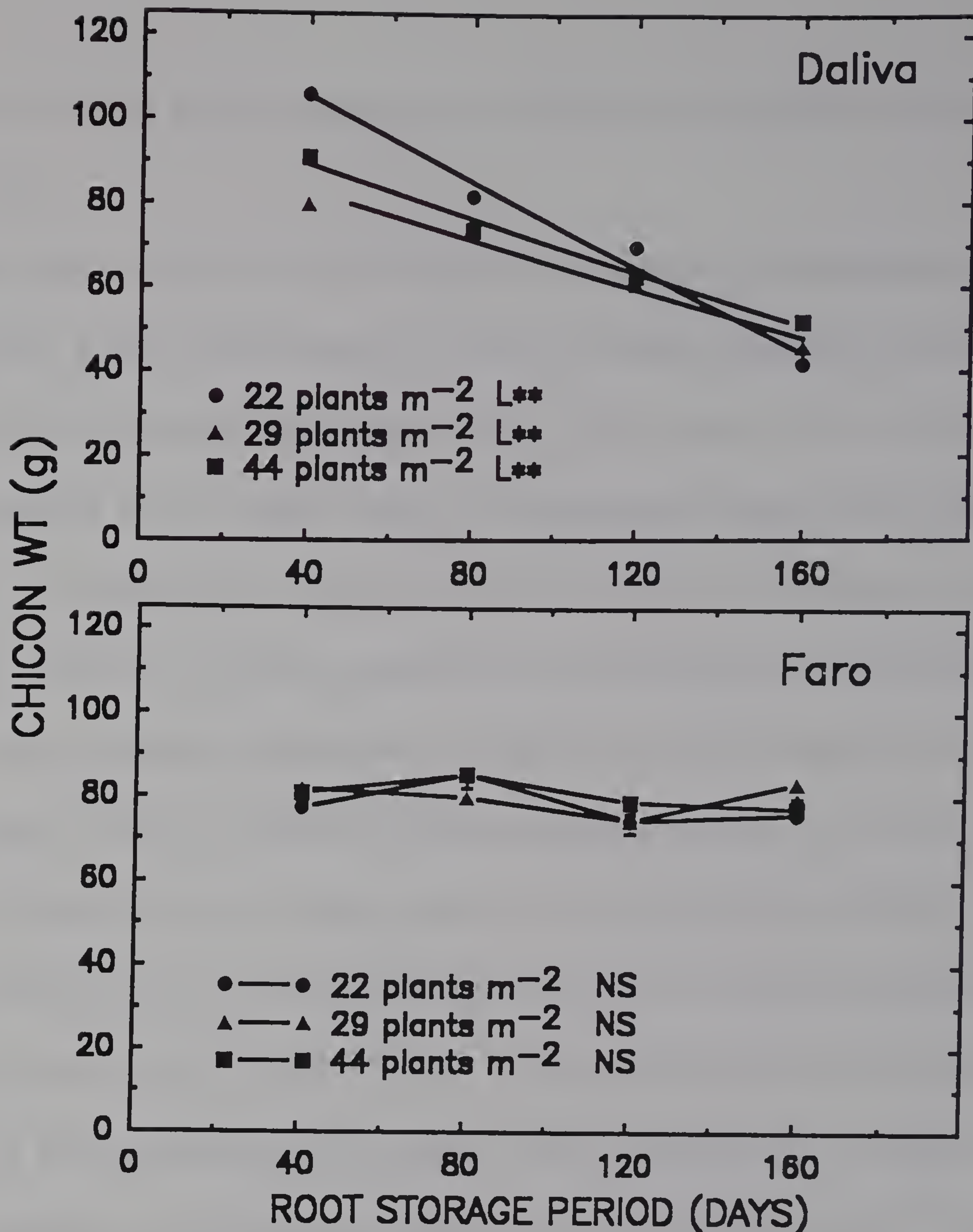
The roots from the different population treatments produced similar chicon yield trends at all storage periods for both cultivars. 'Daliva' chicons were heaviest at the first forcing, and decreased linearly in weight to < 20 g at the last forcing for all three populations. 'Daliva' roots grown at 22 plant m^{-2} produced the largest chicons, resulting in the highest yields of marketable chicons when forced after 40, 80, and 120 days of storage, while roots grown at 44 plants m^{-2} produced the smallest chicons and lowest yields of marketable chicons. The 160 day forcing produced inadequate yields for all populations. The chicons produced from 'Faro' roots increased in marketability with longer storage periods and averaged from 75 to 85 g for all four forcings (Figure 2.9). 'Faro' chicons tended to be loose and open at the first two forcings. Because of the poor establishment of plant populations for 'Faro', it is not possible to provide conclusions on the effects of population on yield and quality of chicons

Thinning of plants in the field had a significant effect on chicon weight at the 5% level, and there was also a significant interaction of cultivar and thinning treatment on chicon weight. Roots from thinned plants of 'Daliva' produced larger chicons at the latter two forcings than chicons produced from roots that were not thinned (Fig. 2.10). Thinned plants of 'Daliva' produced roots with larger crown diameters than unthinned plants. This suggests that the crown diameter of the roots forced affects the eventual size of the chicons produced, especially after long storage periods. Comparing total dry matter of individual 'Daliva' roots shows that roots grown at 22 plants m^{-2} have 32 g, roots grown at 29 plants m^{-2} have 30 g, while roots grown at 44 plants m^{-2} have 27 g. The larger roots have more total carbohydrates, suggesting that carbohydrate reserves at the time of forcing plays a role in the yield and quality of forced chicons. There was no difference between thinned and unthinned roots of 'Faro' on chicon weight (Figure 2.10).

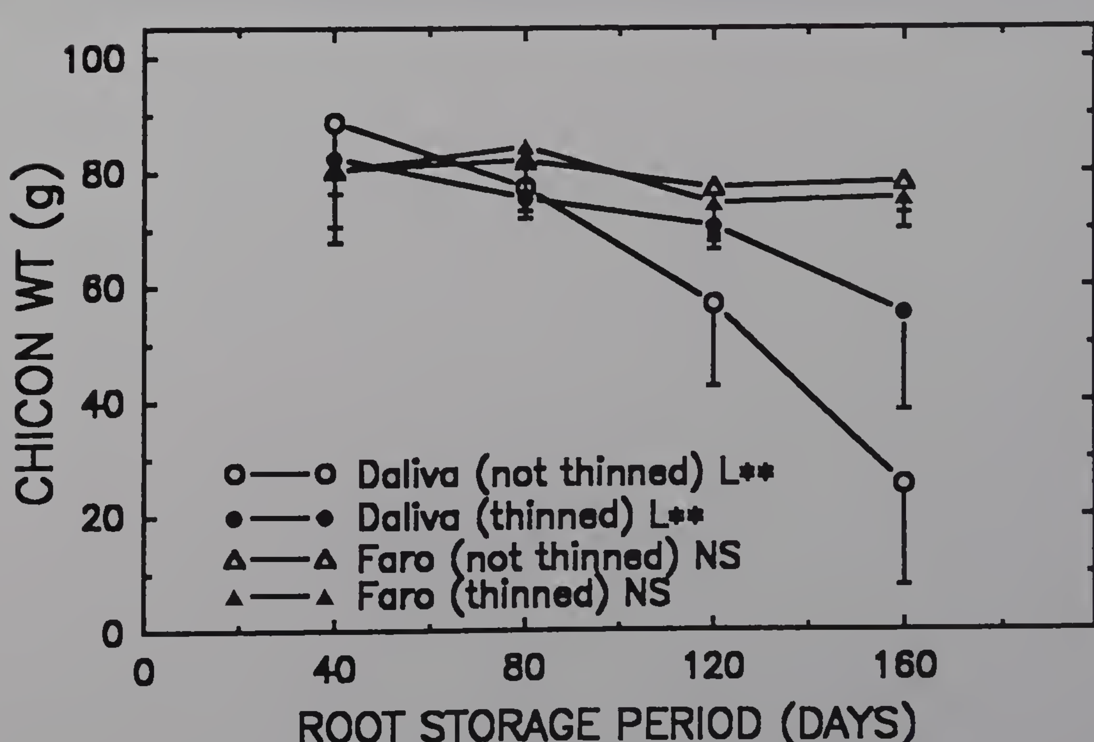
The marketable yield ratio of 'Daliva' decreased linearly over storage time for all three plant populations, meaning more weight was lost to trimming at the later forcings. While chicons produced from roots grown at the low population required more trimming, they still produced the largest and highest quality chicons. The marketable yield ratio of 'Faro' did not significantly

Figure 2.9 Effects of plant population and storage period on the average weight of marketable trimmed chicons produced from 'Daliva' and 'Faro' roots. Points represent means of 4 replications and vertical bars represent 1 SD. L** and NS denotes significant linear regression at the 1% level and no significant regression, respectively.

Figure 2.10 Effects of thinning and storage period on the average weight of marketable trimmed chicons produced from 'Daliva' and 'Faro' roots. Points represent means of 4 observations and vertical bars represent 1 SD. L** and NS denotes significant linear regression at the 1% level and no significant regression, respectively.



Daliva
● 22 plants m⁻² L**
▲ 29 plants m⁻² L**
■ 44 plants m⁻² L**
Faro
●—● 22 plants m⁻² NS
▲—▲ 29 plants m⁻² NS
■—■ 44 plants m⁻² NS
CHICON WT (g)
ROOT STORAGE PERIOD (DAYS)
0
20
40
60
80
100
120
160



o—o Daliva (not thinned) L**
●—● Daliva (thinned) L**
Δ—Δ Faro (not thinned) NS
▲—▲ Faro (thinned) NS
CHICON WT (g)
ROOT STORAGE PERIOD (DAYS)
0
20
40
60
80
100
120
160

differ among forcing times, averaging near 60% for all treatment combinations (Figure 2.11).

Marketable yield index (MYI) gives an indication of marketable product obtained from a given initial weight of roots at forcing, allowing for calculation of expected yields of chicons from yield of roots. The highest yield index for 'Daliva' occurred at the earliest forcing, and decreased linearly over time for all populations (Figure 2.12 A). Calculating yield of roots and subsequent yield of chicons for 'Daliva' at the three populations and averaged for the first three forcings shows that plant populations of 220,000 and 290,000 plants ha^{-1} yielded approximately 12 MT ha^{-1}, while the high population yielded 11.4 MT ha^{-1}. There was no significant effect of storage period on the marketable yield index (MYI) of 'Faro' (Figure 2.12 B). Calculating yield for 'Faro' at the low population for all forcings shows a yield of 8.9 MT ha^{-1}. These yields are lower than those produced in the maturity-population study, which is presented in chapter 3. The cultivar-population experiment was planted late in the season (July 14) which could have resulted in incomplete development and maturity of the roots.

Figure 2.11 Effect of plant population and storage period on the marketable yield ratio of chicons produced from 'Daliva' and 'Faro' roots. Points represent means of 4 replications and vertical bars represent 1 SD. L**, Q**, Q*, and NS denotes significant linear regression at the 1% level, significant quadratic regression at the 1% level, significant quadratic regression at the 5% level, and no significant regression, respectively.

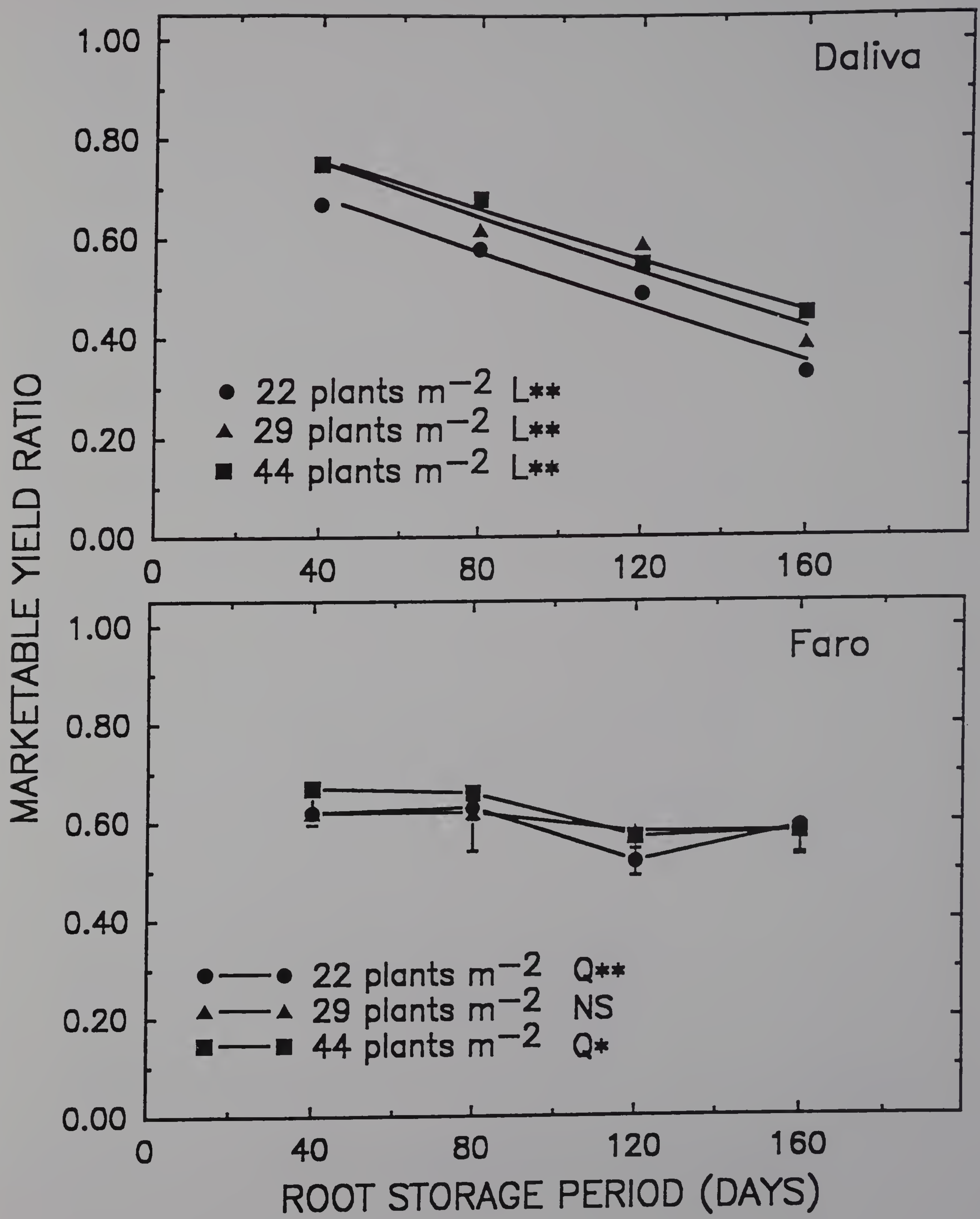
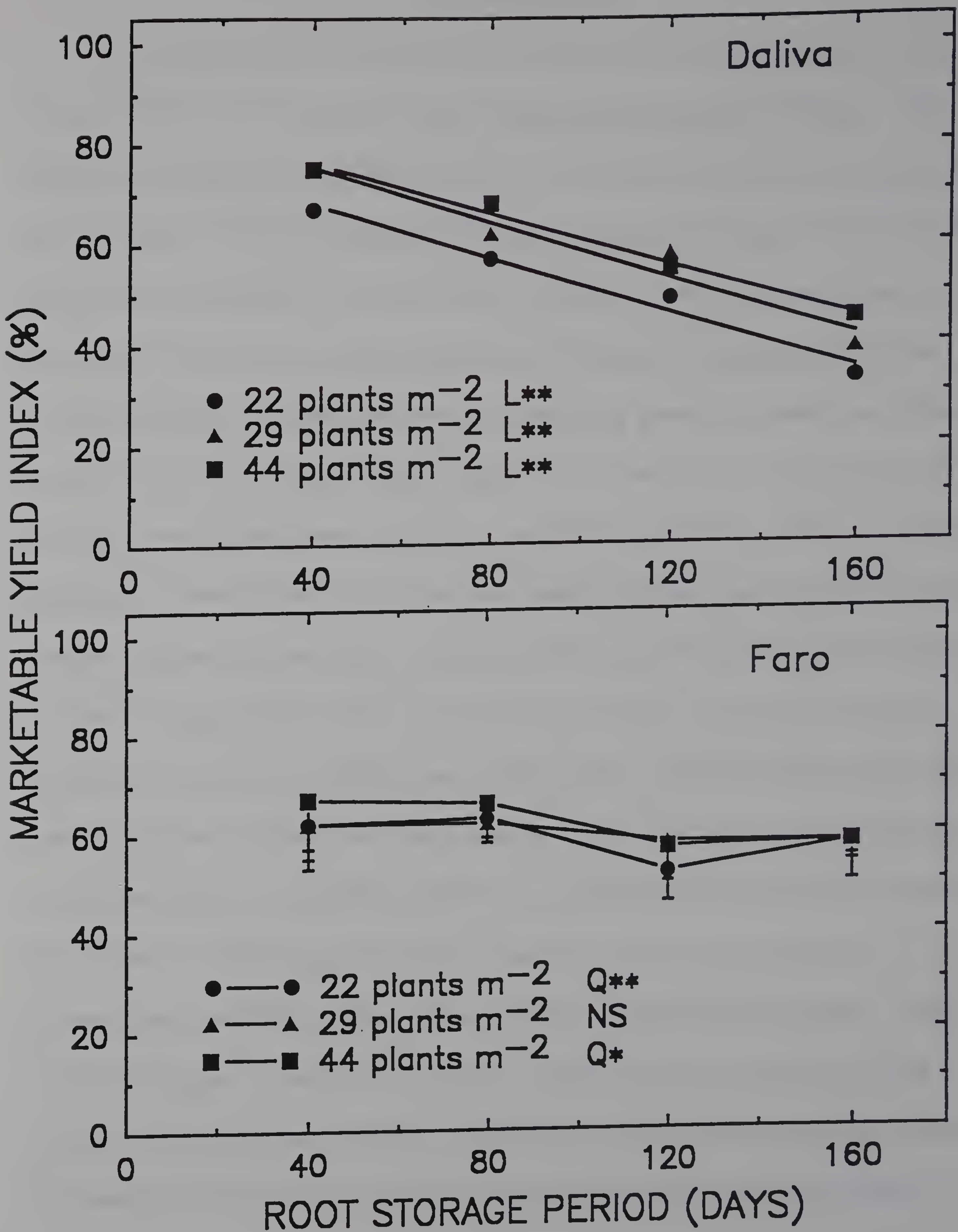

Daliva
● 22 plants m^{-2} L**
▲ 29 plants m^{-2} L**
■ 44 plants m^{-2} L**
Faro
●—● 22 plants m^{-2} Q**
▲—▲ 29 plants m^{-2} NS
■—■ 44 plants m^{-2} Q*
MARKETABLE YIELD RATIO
ROOT STORAGE PERIOD (DAYS)
0.00
0.20
0.40
0.60
0.80
1.00
0
40
80
120
160

Figure 2.12 Effect of plant population on the marketable yield index (MYI) produced from 'Daliva' and 'Faro' plants. Points represent means of 4 replications and vertical bars represent 1 SD. L**, Q**, Q*, and NS denotes significant linear regression at the 1% level, significant quadratic regression at the 1% level, significant quadratic regression at the 5% level, and no significant regression, respectively.


Daliva
● 22 plants m−2 L**
▲ 29 plants m−2 L**
■ 44 plants m−2 L**
Faro
●—● 22 plants m−2 Q**
▲—▲ 29 plants m−2 NS
■—■ 44 plants m−2 Q*
MARKETABLE YIELD INDEX (%)
ROOT STORAGE PERIOD (DAYS)
0
20
40
60
80
100
0
40
80
120
160

C. Conclusions

The study indicates that plant population in the field significantly affects size and yield of roots, and the yield of chicons for the cultivar 'Daliva'. The higher the population the higher the yield of forceable roots, but the average root size is smaller. Total carbohydrates per root is greater with larger roots, which produced larger chicons. Actual yield of chicons per hectare of cultivated land was slightly larger at the lower populations. The lower populations have the added advantages of using less seed and producing fewer unusable roots, which are potential cost savings. Witloof chicory can be successfully planted with a precision seeder and grown without the need for handthinning. There is an slight reduction in crown diameter of the roots without thinning, which results in slightly smaller chicons, but the ability to plant naked seed with no subsequent thinning represents a large labor savings. Improved uniformity in spacing of seeds is a potential with the use of pelleted seed. Responses to different plant populations between the two cultivars is unclear because of poor population establishment of 'Faro', but there is a significant difference in response to storage period between the cultivars. 'Daliva' appears to be a true early cultivar when grown in Massachusetts, with the highest chicon yields produced early in storage. 'Faro' produced adequate results late in storage, suggesting that it can be used for forcing after long storage periods. The varying results between cultivars indicates that several cultivars must be grown to successfully produce witloof chicory for extended periods.

It should be noted that the data has all been obtained from a single root maturity of 120 days. The population information gained gives guidelines, yet lacks possible information on interactions with different maturities. According to the literature, determining proper root maturity is the component of production that is most difficult to determine. The research presented in the following chapter examines population-maturity interactions with 'Daliva'.

CHAPTER 3

GROWTH AND MATURITY STUDY

A. Materials and Methods

1. Cultural Practices

Field plots were prepared and fertilized as discussed in chapter 2. The experiment was planted on July 1 with a four-row, tractor-mounted Stanhay precision planter (model S870). Each belt had 45 #8.5 holes. The A choke plate on the seeder units and the A pulley setting on the seeder drive shafts were used to obtain an adequate plant population for thinning. 'Daliva' was the cultivar planted. The seedbed was moistened immediately after planting with a fan sprinkler, and plots were irrigated as needed. Weed control consisted of hand cultivation. Desired populations (21,900 and 43,800 plants ha^{-1}) were obtained by hand thinning, two weeks after emergence. The number of plants needed in 2 m of row was calculated and plots were thinned accordingly.

2. Growth and Development

The experimental design for the growth and development study was a split-plot with randomized complete blocks (3 replications). Plant population (22 and 44 plants m^{-2}) was the whole plot factor with days from planting (60-140 days at 10 day intervals) the subplot factor. The field plots consisted of four, 6.1 m long rows spaced at 38 cm. Plots were spaced 1.8 m on center.

Sampling for growth and development measurements of both populations occurred at 10 day intervals beginning at 60 days from planting and proceeding until the final harvest of 140 days. Roots were dug from each plot with consideration for proper competition for each sample plant. Distance between the next in-row plant did not exceed 6 cm for the 44 plants m^{-2} population and 12 cm for the 22 plants m^{-2} population. Sample size for each treatment combination was 12 roots. Crown diameter, root and shoot fresh wt, root and shoot dry wt, and % dry matter were measured. The 12 plants in the sample were randomly divided into two groups of 6, with 6 roots being used for dry wt, and 6 roots used for analysis of total soluble sugars.

Analysis of total soluble sugars was conducted at each field sampling date as well as at 6 sample dates during storage. Roots in storage were sampled at 20, 40, 60, 80, 100, and 120 days after harvest. The extraction method used was based on the procedure of Johnson et al. (1964). The six roots were sliced in half longitudinally. One half was discarded and the remaining half was diced to provide cubes approximately 0.3 cm in diameter. Diced roots were placed in 95 ml of 95% ethanol and the contents blended with a Waring food blender (model RL-4) for 90 sec. The blending time was conducted in 15 sec. intervals with 10 sec rests to avoid overheating of the homogenate. The homogenate was filtered through Wattman #1 filter paper. The filtrate was refrigerated immediately.

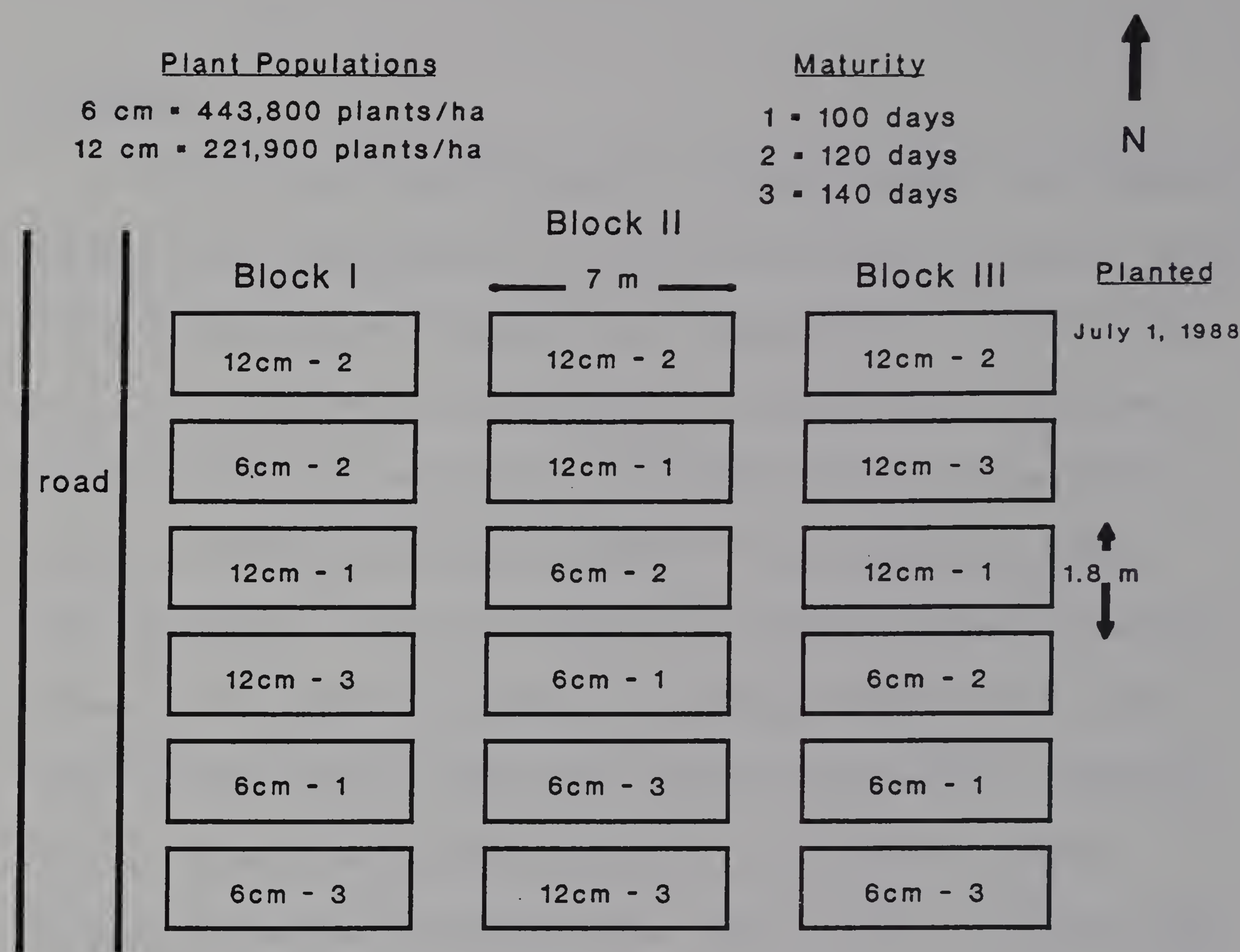
Total sugar content was measured colorimetrically. Due to interference, proteins were extracted from the sample prior to analysis. The extracts were brought to 100 ml. with 95 % ethanol. Two ml of extract was mixed with 1 ml of

1.6% $Ba(OH)_2$ and centrifuged for 10 min. at 3,000 r.p.m. One ml of 2.0% $ZnSO_4$ was added to the mixture and centrifuged for 10 min. at 3,000 r.p.m. Samples of the protein free extract were diluted 100x with distilled water and mixed thoroughly. The diluted sample (0.5 ml) was placed in a test tube and mixed with 5 ml of anthrone. The mixture was placed in a 33 C hot water bath for 15 min. The tubes were then transferred into cold running water for approximately 1 min. The absorbance of the mixture was read spectrophotometrically at 420 nm (Bausch and Lomb, model 442) and concentrations determined based on a series of fructose standards.

3. Field Stage

A split-plot design with randomized complete blocks (3 replications) was used for the root maturity/forcing study (Figure 3.1). The whole plot factors were harvest maturity (100, 120, and 140 days from planting) and plant population (as noted under growth and development). Storage period of roots prior to forcing (40, 80, and 120 days) was the subplot factor. Field plots used as for the study are described in the growth and development section. Roots were harvested as described in materials and methods section of chapter 2, at 100 (Oct. 8), 120 (Oct. 28), and 140 (Nov.17) days after planting. The harvest sample size was 6.1 m from two inside rows. Total number of roots harvested, total number of forceable roots (crown diameter $\geq$ 2.0 cm and minimal branching), total weight of forceable roots, and crown diameter (determined on a 12-root subsample) were measured. The forceable roots were placed into cold storage at 2^0 C $\pm$ 2^0

Figure 3.1 Experimental design and plot plan for maturity-population study. Diagram is not to scale.


Plant Populations
6 cm = 443,800 plants/ha
12 cm = 221,900 plants/ha
Maturity
1 = 100 days
2 = 120 days
3 = 140 days
N
Block II
Block I
7 m
Block III
Planted
July 1, 1988
road
12cm - 2
12cm - 2
12cm - 2
6cm - 2
12cm - 1
12cm - 3
12cm - 1
6cm - 2
12cm - 1
1.8 m
12cm - 3
6cm - 1
6cm - 2
6cm - 1
6cm - 3
6cm - 1
6cm - 3
12cm - 3
6cm - 3

and 95 % relative humidity. A harvest index was calculated by dividing the total weight of forceable roots by the total plant weight (roots and shoots). Sample size for determining the harvest index was 12 plants.

4. Forcing

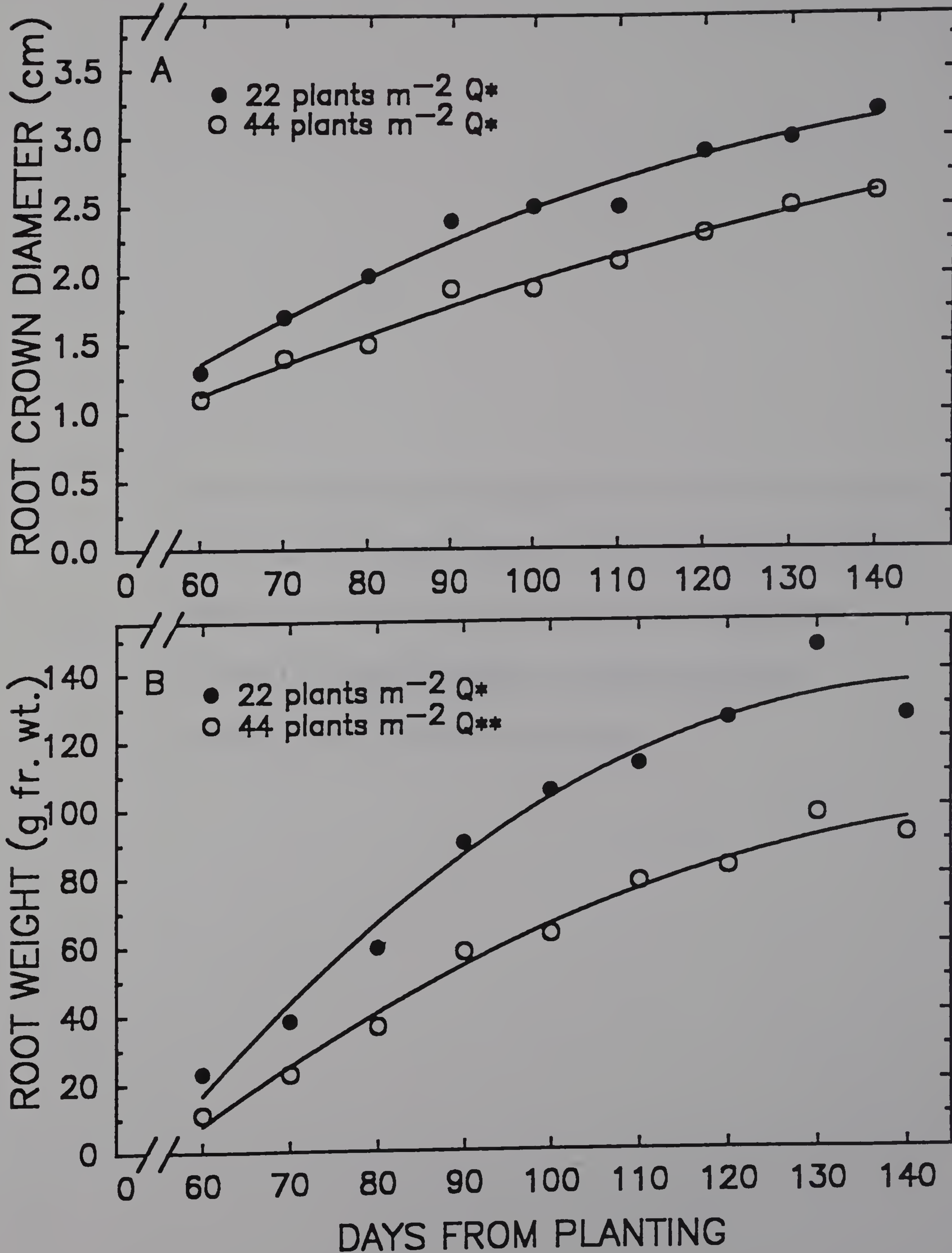
The roots were forced hydroponically, selected, prepared, and evaluated as described in the forcing section of the materials and methods of chapter 2. Roots from each field treatment were forced after storage periods of 40, 80, and 120 days. The 120 day forcing of each maturity was harvested after 31 days, due to the lower forcing temperature used. A marketable yield ratio and marketable yield index (MYI) was calculated as described in the materials and methods section of chapter 2. Correlation between crown diameter of roots and resulting trimmed chicon weight was calculated by measuring individual roots for crown diameter and the trimmed weight of the chicon the root produced. Analysis of variance, regression, and correlation procedures were conducted using the Statistical Analysis System (Sas Institute Inc., 1989). Analyses of variance of the dependent variables are presented in Appendix C (Tables A.9 - A.14). Levels of significance used were 5% for main effects and 10% for treatment interactions.

B. Results and Discussion

1. Growth and Development

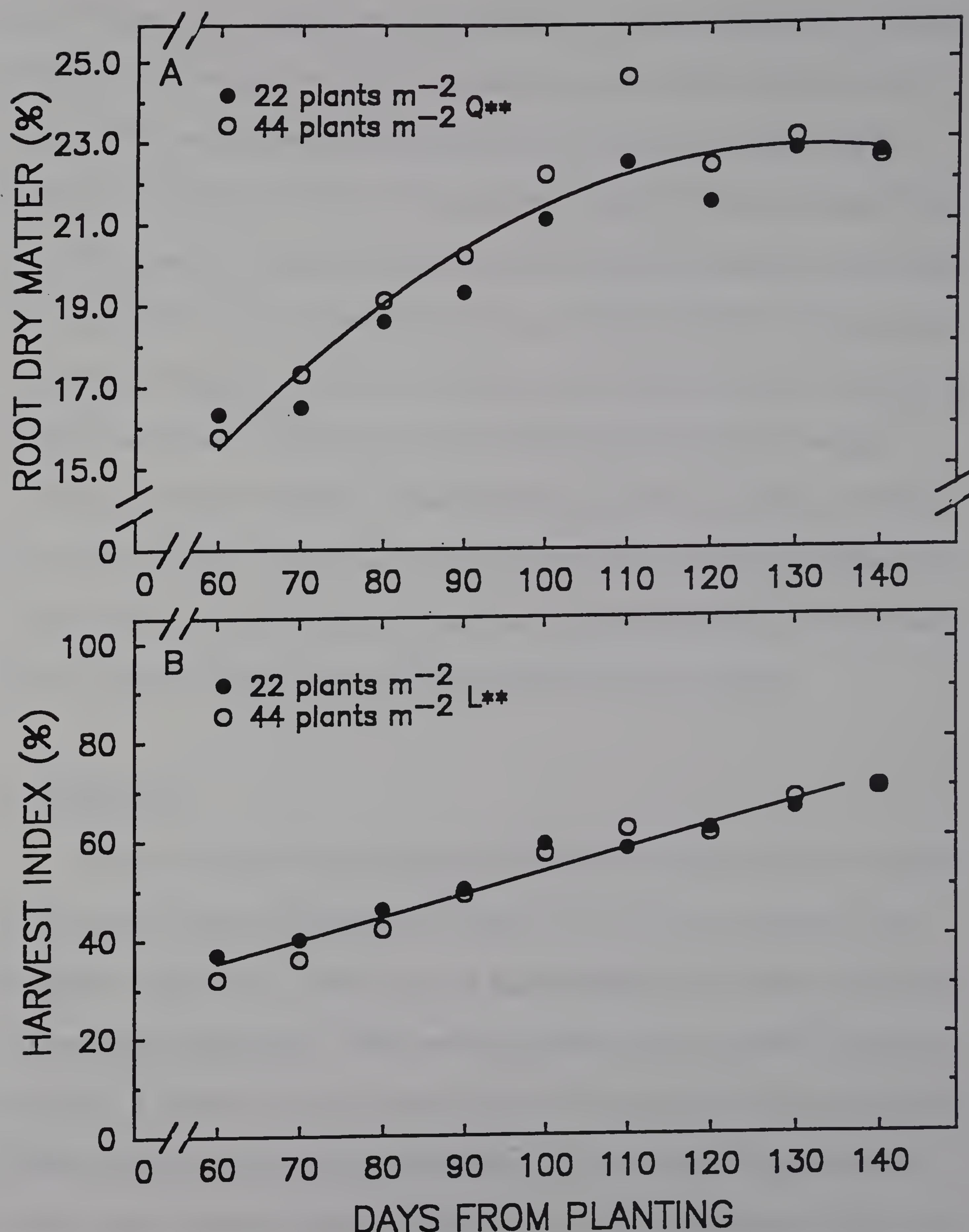
Crown diameter of roots increased at both plant populations reaching maxima of 3.2 cm and 2.6 cm for the low and high plant populations, respectively at the 140-day harvest date (Figure 3.2 A). Fresh weight of roots increased over time at both plant populations with maximum weights of 139 g and 99 g produced by the low and high densities, respectively at the last harvest date (Figure 3.2 B). Maximum % dry matter occurred at 110 days and remained constant for the following 30 days, with no significant difference between plant populations (Figure 3.3 A). Harvest index increased linearly to a level of 70% at 140 days, with no significant differences between plant populations (Figure 3.3 B). The lack of difference in the harvest index between the two population treatments shows that increased plant populations does not affect carbohydrate partitioning. However, total dry matter calculations revealed a significant difference between the two populations. Roots grown at 22 plants m^{-2} had total dry matter levels of 23, 28, and 29 g for maturities of 100, 120, and 140 days, respectively, while the high population had total dry matter values of 14, 19, and 21 g for the same maturities. Greater biomass accumulation of roots at lower populations resulted from increased growth, rather than increased percentage of stored carbohydrates. If total carbohydrate needs for forcing can be achieved at a high plant population, then suggested plant populations can be increased from the European recommendations of approximately 22 plants m^{-2}.

Figure 3.2 Effects of maturity and plant population on (A) crown diameter of roots and (B) fresh weight of roots of 'Daliva' plants. Points represent means of 3 replications. Q** and Q* denotes significant quadratic regression at the 1% and 5% level respectively.



A
● 22 plants m−2 Q*
○ 44 plants m−2 Q*
ROOT CROWN DIAMETER (cm)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
60
70
80
90
100
110
120
130
140
B
● 22 plants m−2 Q*
○ 44 plants m−2 Q**
ROOT WEIGHT (g fr. wt.)
0
20
40
60
80
100
120
140
DAYS FROM PLANTING

Figure 3.3 Effects of maturity and plant population on (A) % dry matter of roots and (B) harvest index (root d.w./total plant d.w.) of 'Daliva' plants. Points represent means of 3 replications. Q** and L** denotes significant quadratic and linear regression at the 1% level, respectively.


A
● 22 plants m^{-2}
○ 44 plants m^{-2}
Q**
ROOT DRY MATTER (%)
25.0
23.0
21.0
19.0
17.0
15.0
0
0
60
70
80
90
100
110
120
130
140
B
● 22 plants m^{-2}
○ 44 plants m^{-2}
L**
HARVEST INDEX (%)
100
80
60
40
20
0
0
60
70
80
90
100
110
120
130
140
DAYS FROM PLANTING

During growth, total sugars in roots approximately doubled between 100 and 140 days with no significant difference between plant populations. Following 20 days in cold storage, the level of sugars was nearly double that of roots at harvest. This was followed by a reduced rate of increase in soluble sugars, reaching a maximum of 110 to 120 mg/g fresh wt after 60 days of storage (Figure 3.4). The trend for changes in ethanol-soluble sugars during growth and storage are comparable to those measured by Fiala and Jolivet (1980) for Zoom, except that maximum sugars for Zoom was reached after 30 days storage. The amount of inulin converted to simpler sugars presumably decreased during storage, resulting in decreased levels of ethanol-soluble sugars late in storage. Cultivars are known to vary in the rate and timing of conversion of inulin to soluble sugars. 'Daliva' and 'Zoom' are considered early-to mid-season cultivars, with maximum levels of ethanol-soluble sugars reached relatively early in storage.

2. Field Stage

Yield of forceable roots averaged 32% more for plants grown at 44 plants m^{-2} than those grown at 22 plants m^{-2} (Figure 3.5 A), but were smaller at all maturities (Figure 3.2). Yield increased significantly between 100 and 120 days for both plant populations. There was no further increase in yield at the latest maturity. A minimal increase in size of the roots is gained with the late maturity, which could potentially improve chicon yield. While the high population had higher yields, there were more unusable roots at all three maturities (Figure 3.5 B), indicating wasted seed and increased field handling on the larger number of

Figure 3.4 Total soluble sugars in the roots of 'Daliva' plants during growth and storage. Storage data is from roots harvested after 140 days from planting. Points represent means of 3 replications. C** denotes significant cubic regression at the 1% level.

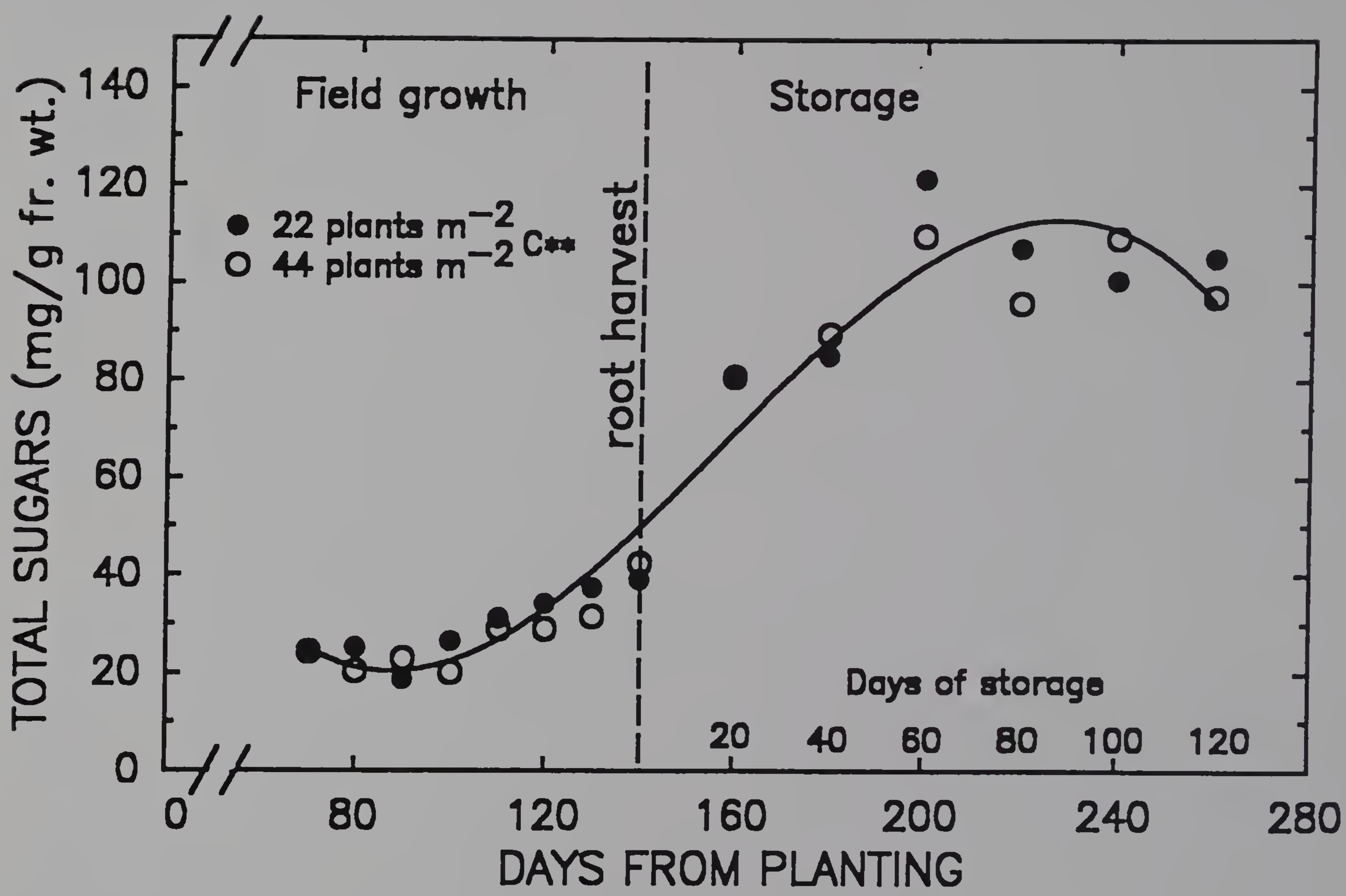
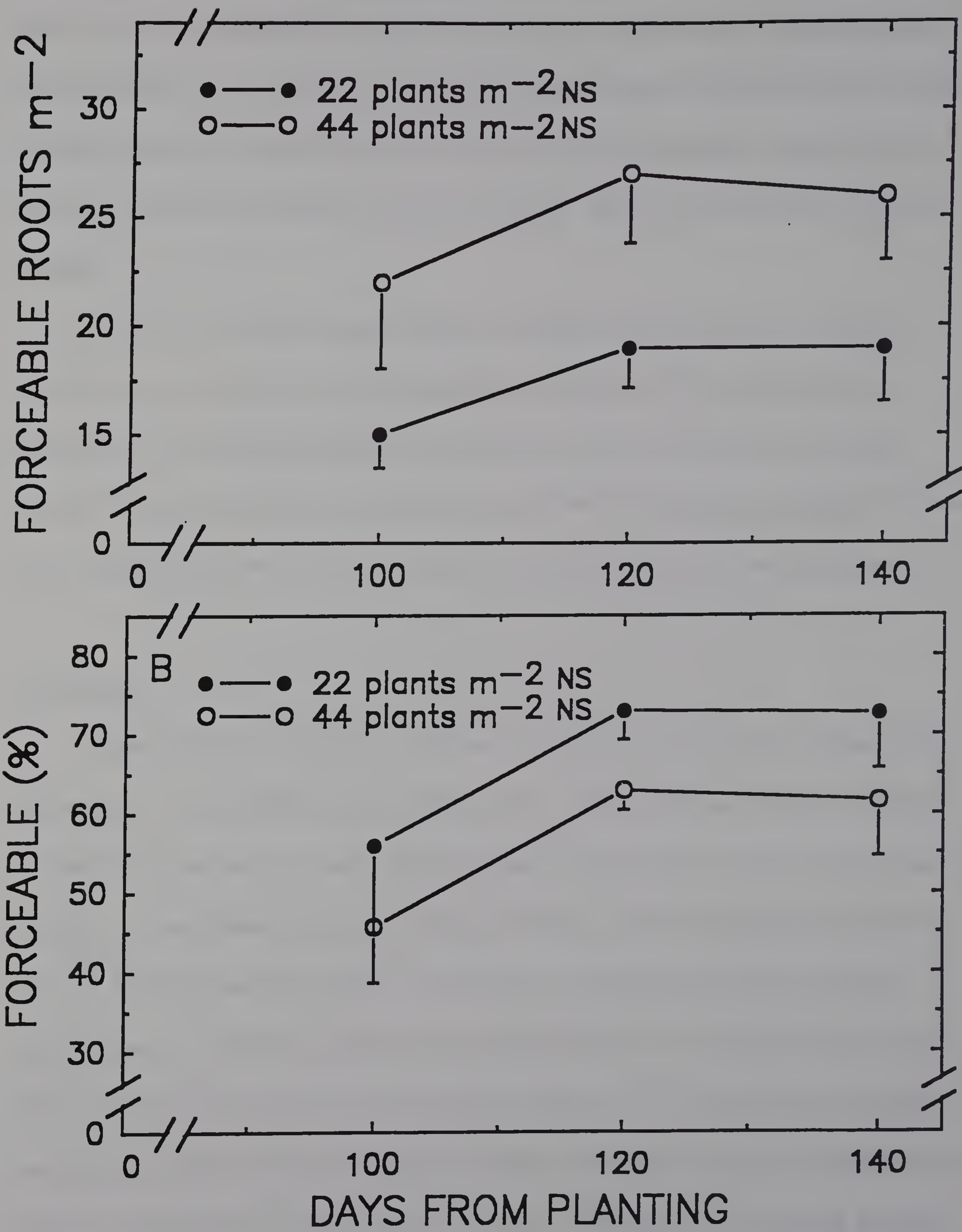

Field growth
Storage
root harvest
● 22 plants m−2
○ 44 plants m−2 C**
Days of storage
20 40 60 80 100 120
TOTAL SUGARS (mg/g fr. wt.)
0 20 40 60 80 100 120 140
0 80 120 160 200 240 280
DAYS FROM PLANTING

Figure 3.5 Effects of maturity and plant population on (A) yield of forceable roots, and (B) % roots forceable of 'Daliva' plants. Points represent means of 3 replications and vertical bars represent 1 SD. NS denotes no significant regression.


FORCEABLE ROOTS m−2
22 plants m−2 NS
44 plants m−2 NS
30
25
20
15
0
0
100
120
140
B
22 plants m−2 NS
44 plants m−2 NS
FORCEABLE (%)
80
70
60
50
40
30
0
0
100
120
140
DAYS FROM PLANTING

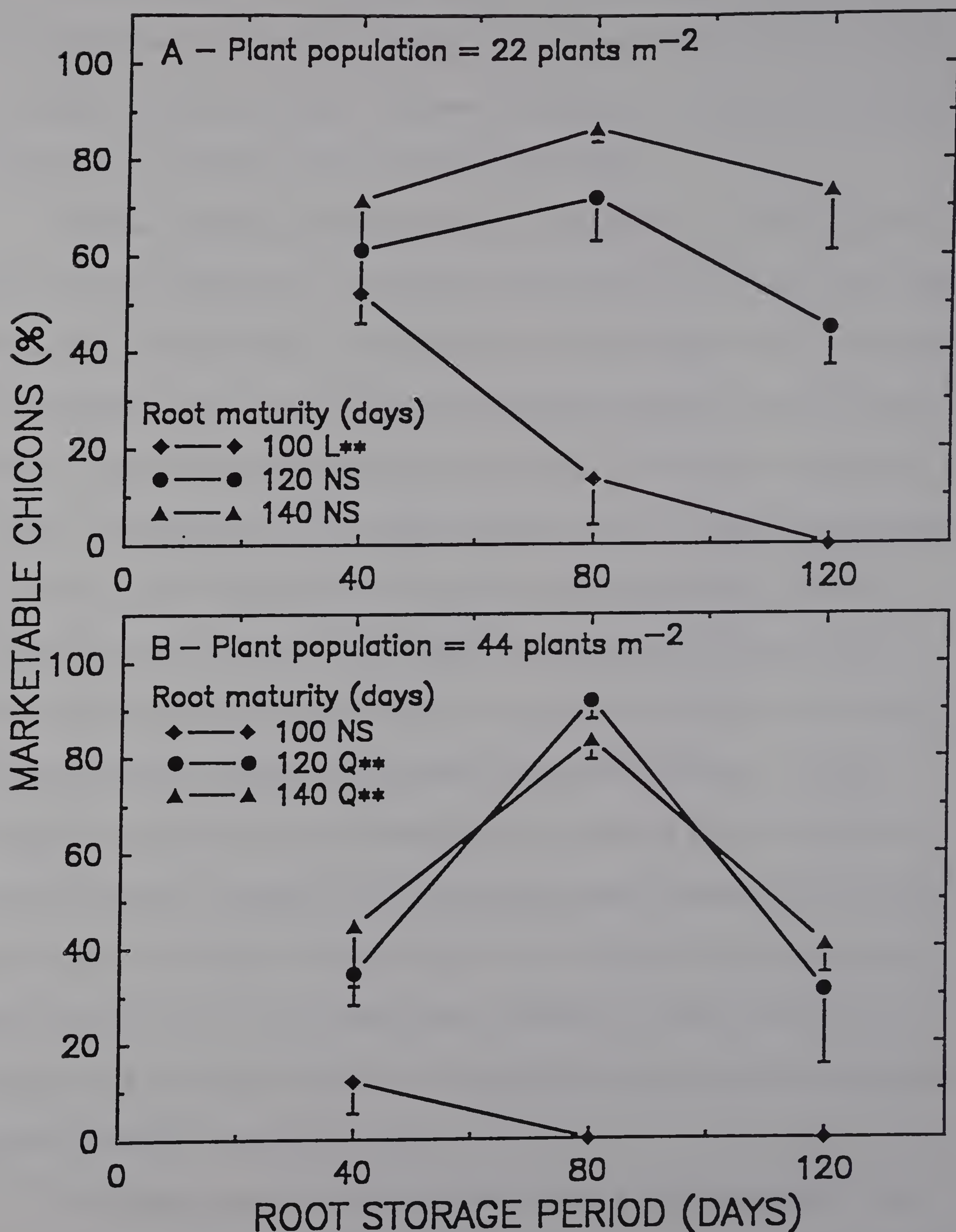
unusable roots. The increased cost of seed and grading of roots may be more than offset by the increased economic yield of forceable roots. Comparing the two populations at 140 days, the high population produced approximately 265,000 forceable roots ha^{-1} and 156,000 roots that had to be discarded, while the low population produced 190,000 forceable roots ha^{-1} and 66,700 roots that were not useable.

Results at the field stage suggest that high plant populations and later maturities are desirable for producing high root yields. The smaller roots produced at the high population are desirable because of increased packing density of roots in forcing trays (Corey et al., 1990), if yield and quality of chicons are not greatly reduced when compared to yields of chicons from larger roots.

3. Forcing

Roots that were grown for 120 and 140 days produced the highest yields and quality of marketable chicons (Figure 3.6). Roots harvested after 100 days resulted in either poor or zero yields of chicons except when roots were grown at 22 plants m^{-2} and forced early in storage (40 days). Poor forcing results from roots of 100 days maturity may be attributed to inadequate levels of stored carbohydrates. The % dry matter was similar to that of 120 and 140 day roots (Figure 3.3 A), but the roots were smaller (Figure 3.2 A and B) and therefore contained a smaller total carbohydrate reserve. Results imply that 'Daliva' roots should be grown for a minimum of 120 days. The similarity of forcing results from roots grown for 120 and 140 days indicates that there is a minimum maturity

Figure 3.6 Effects of root maturity, storage period and plant population on yield of marketable chicons produced from 'Daliva' roots. Points represent means of 3 replications and vertical bars represent 1 SD. L**, Q**, and NS denotes significant linear regression at the 1% level, significant quadratic regression at the 1% level, and no significant regression, respectively.

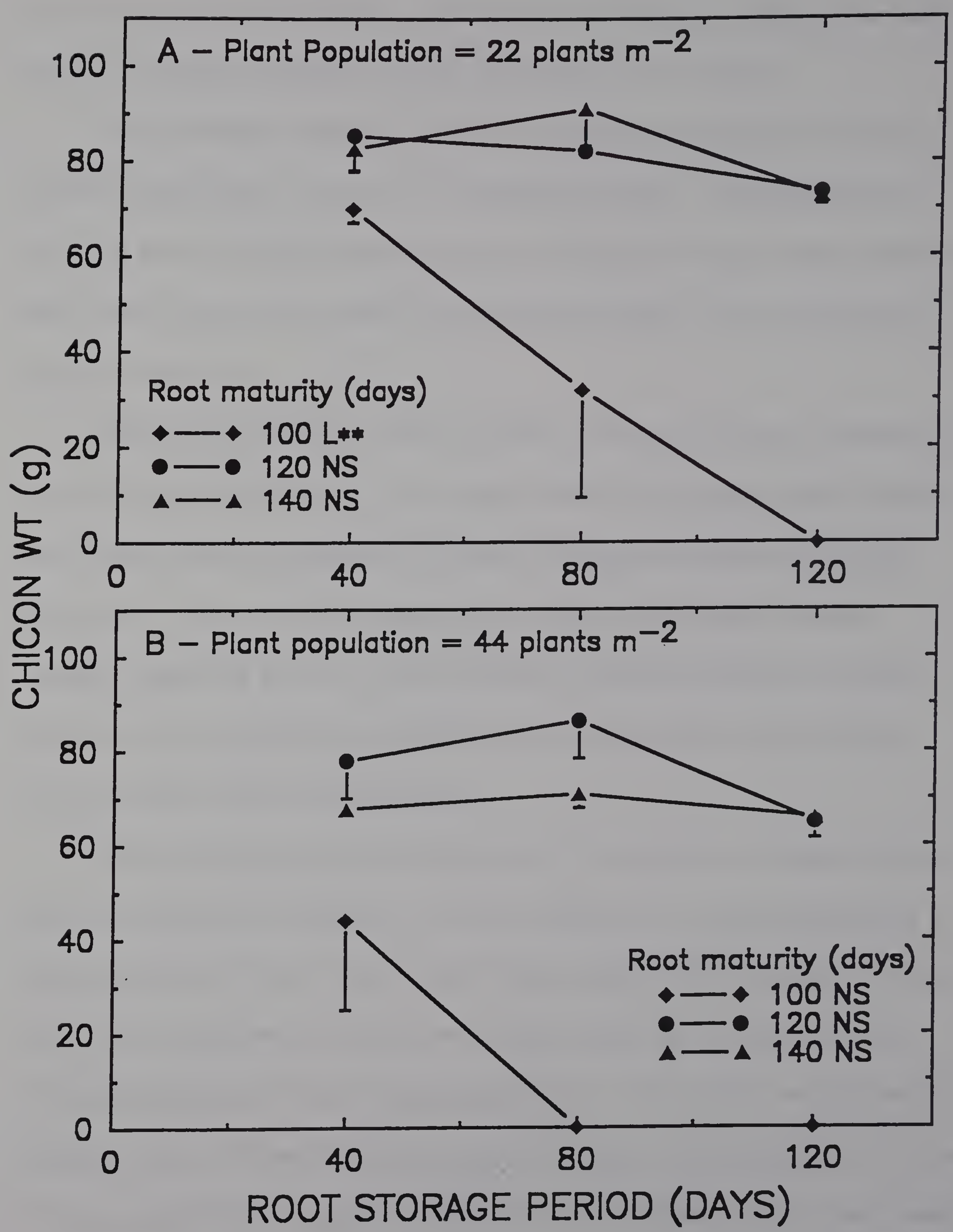

A – Plant population = 22 plants m−2
Root maturity (days)
100 L**
120 NS
140 NS
B – Plant population = 44 plants m−2
Root maturity (days)
100 NS
120 Q**
140 Q**
MARKETABLE CHICONS (%)
ROOT STORAGE PERIOD (DAYS)
0
20
40
60
80
100
120

that must be reached. After that minimum is achieved there is little gain from increased maturity, suggesting a threshold of total stored carbohydrates required to produce marketable chicons. Increases in carbohydrates beyond the threshold level do not necessarily result in increased chicon yield.

Optimum yields for either population treatment were produced after 80 days of storage (Figure 3.6). The 80 day storage period corresponds to the region of maximum ethanol-soluble carbohydrates in the roots (Figure 3.4). Poor yields of marketable chicons from roots grown at the high population and forced after 40 days suggests that population affects development of roots and readiness for forcing. Perhaps roots grown at higher densities require a longer growing period to reach a desired maturity than roots grown at lower populations. Percent marketable chicons declined sharply when roots grown at 44 plants m^{-2} were forced after 120 days of storage, while roots grown at 22 plants m^{-2} for 120 and 140 days produced consistently high yields of marketable chicons. Average weights of marketable chicons forced from roots grown at the low population produced chicons averaging 5 to 7 g heavier than those produced from the high plant population (Figure 3.7). The smaller roots from the high plant population may have led to lower total carbohydrates available for chicon growth. This suggests that successful forcing late in storage is dependent upon the maturity of roots and soluble carbohydrate levels.

Calculating root yield and subsequent chicon yield for maturities of 120 and 140 days and averaging results of the three storage periods shows that a plant population of 44 plants m^{-2} will result in a chicon yield of 19.1 MT ha^{-1}, assuming

Figure 3.7 Effects of root maturity, storage period, and plant population on marketable trimmed chicon weight produced from 'Daliva' roots. Points represent means of 3 observations and vertical bars represent 1 SD. L** and NS denotes significant linear regression at the 1% level and no significance, respectively.


A – Plant Population = 22 plants m−2
Root maturity (days)
100 L**
120 NS
140 NS
B – Plant population = 44 plants m−2
Root maturity (days)
100 NS
120 NS
140 NS
CHICON WT (g)
ROOT STORAGE PERIOD (DAYS)
0
20
40
60
80
100
0
40
80
120

adequate field and growing conditions. A plant population of 22 plants m^{-2} results in a chicon yield of 15.8 MT ha^{-1}. Overall yield of chicons is higher with roots grown at the high population, but average chicon size is smaller.

The marketable yield ratio, which is inversely proportional to trim loss, showed trends similar to those of % marketable chicons. The best ratio was produced from both plant populations after 80 days of storage, where marketable yield ratio averaged about 60% for roots harvested after 120 and 140 days of growth (Figure 3.8).

Marketable yield index (MYI) provides a means of relating economic yield to pre-forcing weight of roots. The highest yield of chicons per initial weight of roots results from roots grown for 120 and 140 days and stored for 80 days (Figure 3.9). These results correspond to results with the other response variables suggesting that the 120 and 140 day maturities and 80-day storage period treatment combinations maximized use of the stored carbohydrates, producing high yields of quality chicons.

The correlation of crown diameter of a root and the subsequent chicon yield was calculated to determine if crown diameter is a useful guideline for estimating the potential of roots to yield high quality chicons throughout storage. Root size is significantly correlated with chicon yield, but the nature of the correlation depends on the storage period of roots. Roots that were forced after storage periods of 40 and 80 days, required minimum crown diameters of 2.6 and 2.7 cm, respectively, to produce marketable chicons (Figure 3.10). Roots stored for 120 days required a crown diameter of 3.4 cm to yield marketable chicons.

Figure 3.8 Effects of root maturity, storage period, and plant population on marketable yield ratio of chicons produced from 'Daliva' roots. Points represent means of 3 replications and vertical bars represent 1 SD. L**, Q*, and NS denotes significant linear regression at the 1% level, significant quadratic regression at the 5% level, and no significant regression, respectively.

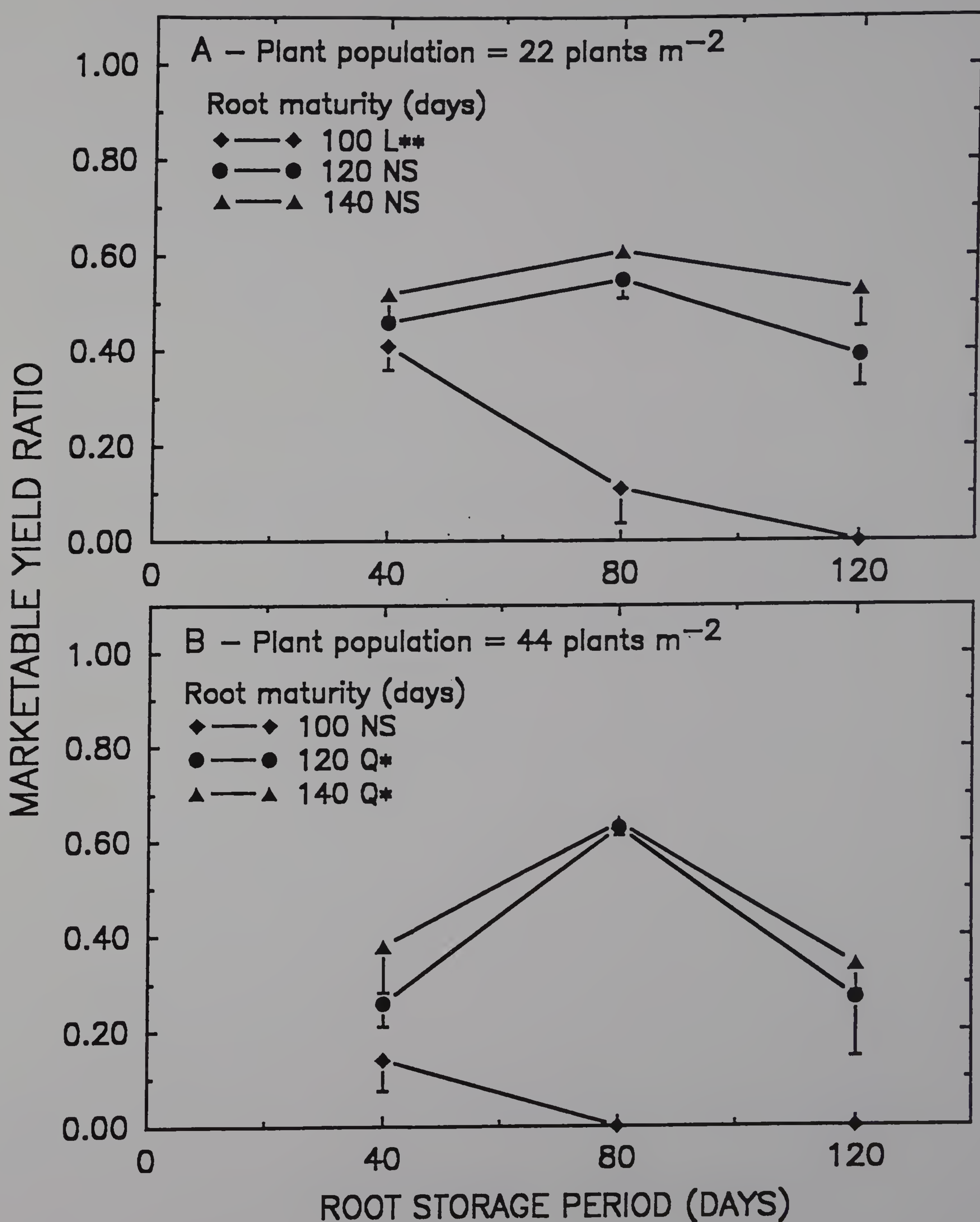
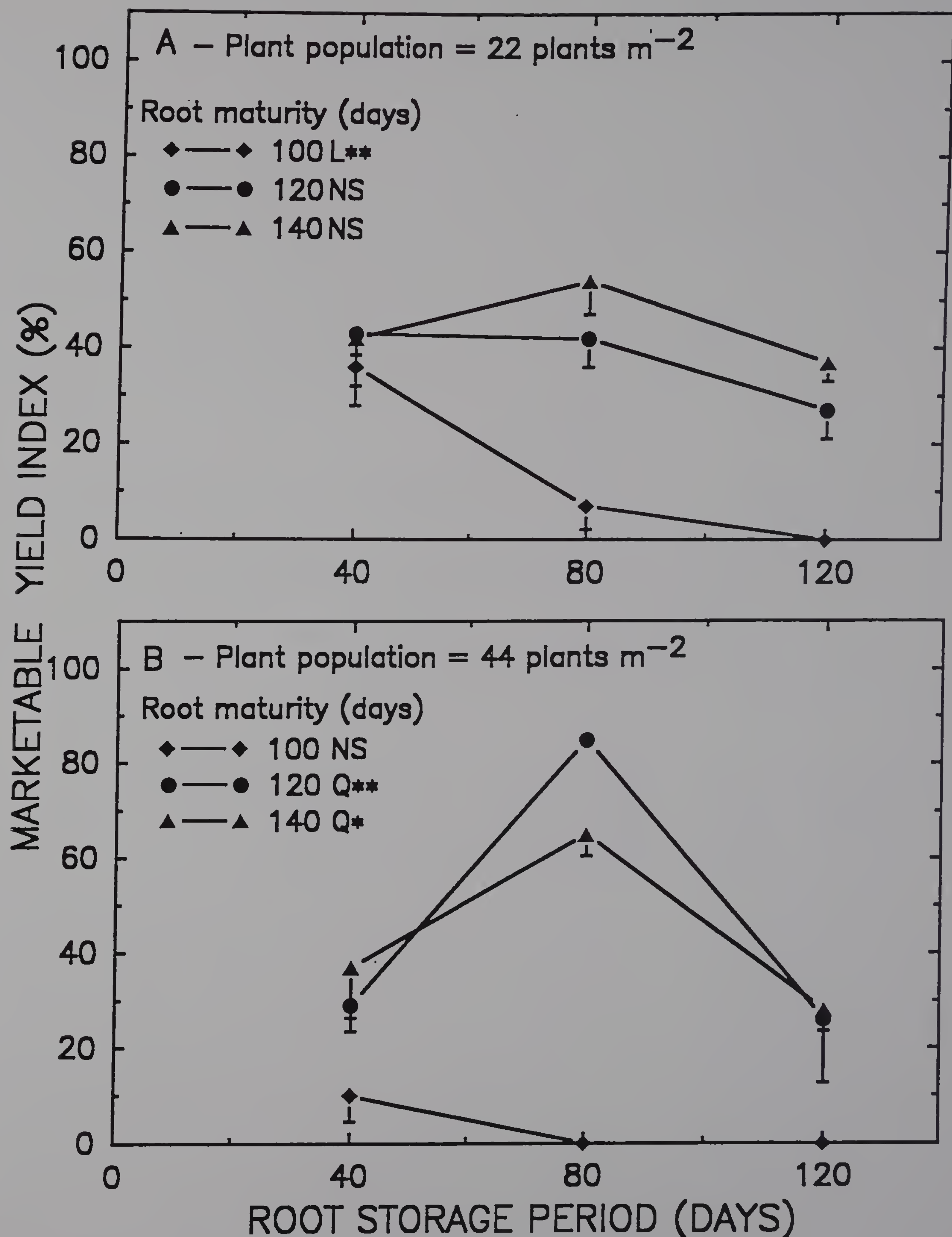
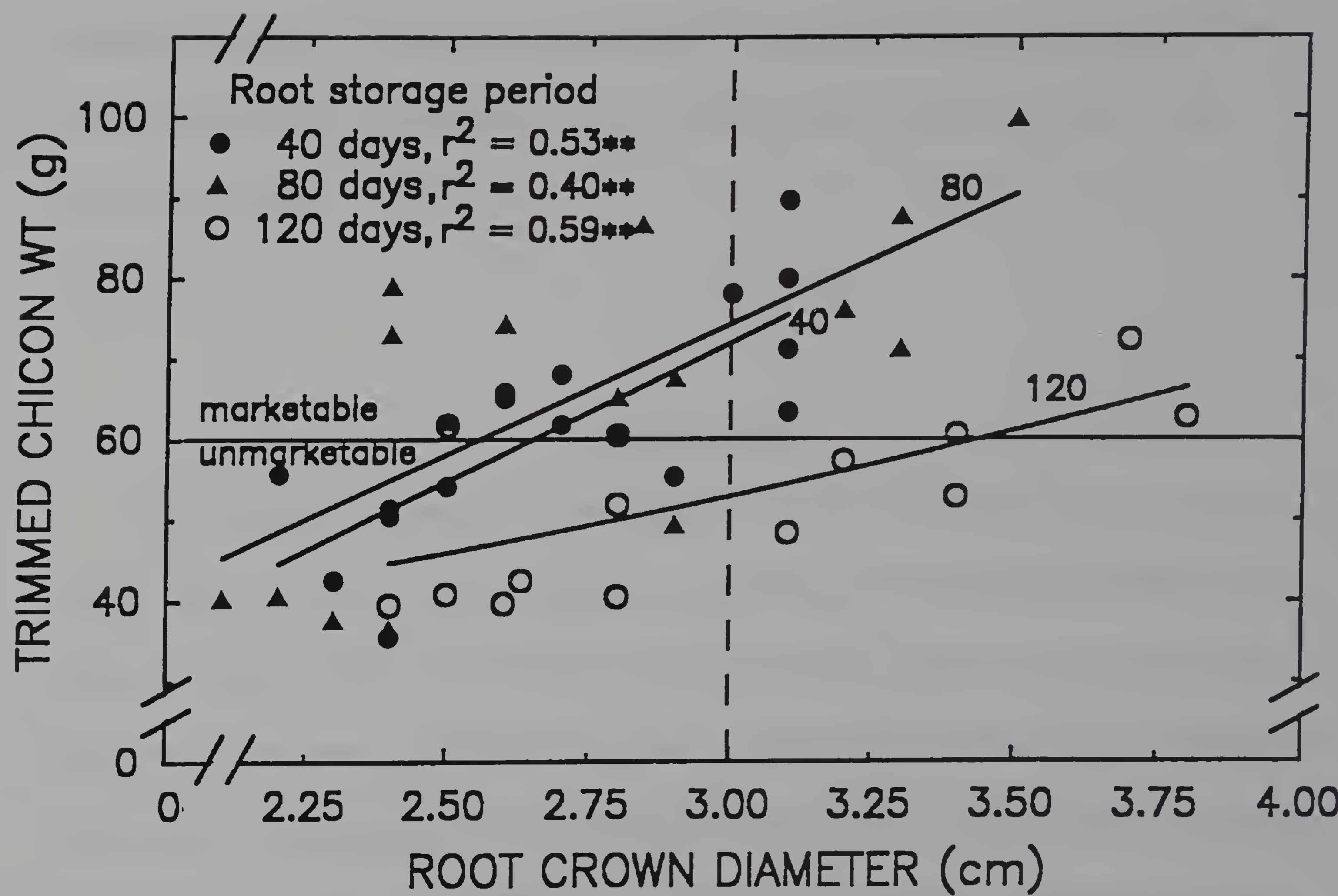

A – Plant population = 22 plants m−2
Root maturity (days)
100 L**
120 NS
140 NS
B – Plant population = 44 plants m−2
Root maturity (days)
100 NS
120 Q*
140 Q*
MARKETABLE YIELD RATIO
ROOT STORAGE PERIOD (DAYS)
1.00
0.80
0.60
0.40
0.20
0.00
0
40
80
120

Figure 3.9 Effects of root maturity, storage period, and plant population on marketable yield index (MYI) produced from 'Daliva' roots. Points represent means of 3 replications and vertical bars represent 1 SD. Q** and Q* denotes significant quadratic regression at the 1% and 5% levels, respectively. L** and NS denotes significant linear regression at the 1% level and no significant regression, respectively.



A – Plant population = 22 plants m^{-2}
Root maturity (days)
100 L**
120 NS
140 NS
B – Plant population = 44 plants m^{-2}
Root maturity (days)
100 NS
120 Q**
140 Q*
MARKETABLE YIELD INDEX (%)
ROOT STORAGE PERIOD (DAYS)

Figure 3.10 Relationships between crown diameter of roots and trimmed chicon weight for 3 storage periods. Points represent means of 3 replications. ** denotes significance at the 1% level.


Root storage period
40 days, r2 = 0.53**
80 days, r2 = 0.40**
120 days, r2 = 0.59**
80
40
120
marketable
unmarketable
TRIMMED CHICON WT (g)
100
80
60
40
0
0
2.25
2.50
2.75
3.00
3.25
3.50
3.75
4.00
ROOT CROWN DIAMETER (cm)

There is a substantial difference in the % of marketable chicons produced when the data is classified into two groups of different size roots; roots with crown diameters ≥ 3.0 cm and roots with crown diameters < 3.0 cm. The larger roots produced 80% marketable chicons, while the smaller roots produced 42% marketable chicons. Results suggest that total stored carbohydrate determines the ability of a root to produce chicons of high quality, especially after long periods of storage.

C. Conclusions

Determining appropriate combinations of plant population, root maturity, and storage period for specific cultivars is important for optimum production of witloof chicory. Climatic variability requires specific studies to understand the responses of cultivars to different regions. Results indicate that plant population and maturity directly affect carbohydrate content of roots, with threshold levels of root carbohydrates required for high yield of quality chicons. Storage period affects the availability of ethanol-soluble sugars for forcing, subsequently affecting yield and quality of chicons. Optimum field and forcing results occurred with 'Daliva' roots grown for a minimum of 120 days and forced after 80 days of storage. Larger roots produced consistently high yields, especially following long periods of storage. This is presumably attributed to larger carbohydrate reserves. High yields of roots and chicons can be obtained at 44 plants m^{-2}, a population considerably higher than those used in Europe. However, there are the added costs of extra seed and field handling of more unusable roots. Individual chicons from roots grown at the high plant population were smaller, which will be an important consideration in meeting specific market needs. Additional studies of different plant populations and planting configurations are needed to refine recommendations. Finally, this study has provided guidelines for selection of appropriate plant populations, harvest maturities, and storage periods for 'Daliva' grown in the Northeastern U.S., essential for maximizing chicon yield and quality throughout the forcing season.

APPENDIX A

ROW LOCATION

Roots harvested for yield data and forcing were obtained equally from one inside and one outside row from each four row plot. Roots grown in an outside row were included because in a four row planting system, half of the planting borders a tire path, which is approximately 18 cm wider than between row spacing. The wider spacing potentially leads to reduced between row competition.

A study was performed to determine if placement of row, inside or outside, had an effect on size, weight, and % dry matter of roots. Data from the study is presented in table A 1.

Table A 1. Effect of row location in relation to adjacent rows on size and weight of witloof chicory roots.

Row location	Crown diameter (cm)	Fresh wt (g)	Dry Matter (%)
Inside	2.8	85	23.4
Outside	3.1	106	23.7
Results of t-test	+	+	

+ denotes significance at the 10% level.

Location of row appears to affect the size and weight of roots, with larger roots produced in outside rows. The small increased size of roots, significance detected at the 10% level, produced from outside rows is likely attributable to increased space between adjoining rows. Plants in outside rows have more space for development of leaves and roots, which appears to result in larger overall plant growth. Accurate measure of yield requires the incorporation of outside rows. The number of rows per plot and width of tire tracks alters the percentage and the affect of variation in yield with row location.

APPENDIX B

STANHAY SEEDER EVALUATION

Evaluation of the Stanhay precision seeder (model 887), the most commonly used precision vegetable seeder in the northeast, was performed to determine if witloof chicory could be direct seeded and grown successfully without thinning. Thinning is a major labor expense that would limit viability of production of witloof chicory on a commercial scale. The ability of a seeder to singulate seeds (space individual seeds at a determined distance) determines the potential for direct seeding and growing chicory without thinning.

Field plots described in chapter two and three were used to evaluate the singulation percentage of the stands planted with the Stanhay seeder. All plots that were surveyed were planted with the belts described in the materials and methods section of chapter 2, using the "A" pulley setting in the maturity - population study and the "A", "B", and "C" pulley settings in the cultivar - population study. After the first true leaves were formed, the percentage of singulation of seeds was calculated. Plants that were separated by more than 1 cm were considered to be singles. Plants that were within 1 cm or less of another plant were considered multiples. Multiples were classified as doubles or more than two plants together.

The results indicate that witloof chicory can be successfully planted with adequate singulation with the use of the Stanhay precision seeder. The percent of singulation ranged from 72% in the maturity-population plots to 79% in the "doubles" as opposed to "multiples'" in both plots. Cultivar, pulley and cultivar-pulley interactions had no significant effect on the percentage of singulation. Any difference in size or shape of seeds between hybrid cultivars appears to be negligible. Planting at different populations with the appropriate belts, via changes in pulley settings, does not alter the precision of the Stanhay planter. The results indicate that the Stanhay seeder can successfully singulate naked witloof chicory seeds during planting.

Figure A. Singulation of naked hybrid witloof chicory seed by a Stanhay precision belt seeder (model S870).


100
80
60
40
20
0
%
SD±
7.0
8.1
5.2
singles
doubles
multiples
SD±
13.3
6.2
4.3
Treatments
Pulley NS
Cultivar NS
Maturity – Population
Cultivar – Population

C. Analysis of Variance Tables.

Table A. 2 Analysis of variance of fresh weight and crown diameter of roots. S. Deerfield, MA, 1988.

Source of Variation	Degrees of Freedom	Mean Square	
		Root Wt[a]	Crown Diameter
Blocks	3	849.3024	1.7962
Cultivar (C)	1	1295.3650+	24.3000*
Error A	3	204.4506	0.9351
Population (P)	2	1191.8705	6.5018
C x P	2	1113.1605	10.5852+
Error B	12	496.1888	2.8837
Treatment[b] (T)	1	640.1269	1.6333
C x T	1	164.5714	19.2000+
P x T	2	383.1582	0.2518
C x P x T	2	762.7427	1.8352
Error	15,16[c]	647.0500	4.8697
Total (corrected)	44,45[d]		

* and + denotes significance at the 5% and 10% levels, respectively.

aRoot Wt = Fresh weight of roots.
bTreatment = Thinning treatment of plants in the field.
c15,16 = Error for dependent variables root wt and crown diameter, respectively.
d44,45 = Total corrected error for dependent variables root wt and crown diameter, respectively.

APPENDIX C

ANALYSIS OF VARIANCE TABLES

Table A. 2 Analysis of variance of fresh weight and crown diameter of roots. S. Deerfield, MA, 1988.

Source of Variation	Degrees of Freedom	Mean Square	
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* and + denotes significance at the 5% and 10% levels, respectively.

aRoot Wt = Fresh weight of roots.
bTreatment = Thinning treatment of plants in the field.
c15,16 = Error for dependent variables root wt and crown diameter, respectively.
d44,45 = Total corrected error for dependent variables root wt and crown diameter, respectively.

Table A. 3 Analysis of variance of total yield of roots and yield of forceable roots. S. Deerfield, MA, 1988.

Source of Variation	Degrees of Freedom	Mean Square Total Roots[a]	Mean Square Forceable Roots[b]
Blocks	3	271.2129	655.7795**
Cultivar (C)	1	8400.1333**	1017.9187**
Error A	3	52.3240	16.9646
Population (P)	2	2034.6553**	382.9289**
C x P	2	1076.0643**	80.6789
Error B	12	142.7879	54.7363
Treatment[c] (T)	1	946.4083**	129.1687
C x T	1	715.4083*	41.4187
P x T	2	78.5643	11.9287
C x P x T	2	87.6098	39.7698
Error	16	109.8645	66.3046
Total (corrected)	45		

** and * denotes significance at the 1% and 5% levels, respectively.

aTotal Roots = Total yield of roots.
bForceable Roots = Yield of forceable roots.
cTreatment = Thinning treatment of plants in the field.

Table A. 4 Analysis of variance of percent dry matter of roots and percent of yield of roots that is forceable. S. Deerfield, MA, 1988.

Source of Variation	Degrees of Freedom	Mean Square % Dry Matter	% Forceable[a]
Blocks	3	52.8302	372.9091*
Cultivar (C)	1	1088.2308*	2389.6687**
Error A	3	73.8954	38.2146
Population (P)	2	17.0174	206.4744
C x P	2	219.5826+	183.0198
Error B	11,12[b]	57.8022	120.5483
Treatment[c] (T)	1	16.5312	129.1687
C x T	1	2.5312	169.2187
P x T	1,2	11.2812	0.6562
C x P x T	1,2	7.0312	62.2244
Error	12,16[d]	12.1770	71.1796
Total (corrected)	38,45[e]		

**, * and + denotes significance at the 1%, 5% and 10% levels, respectively.

a% Forcable = Percent of total yield of roots that is forceable.
b11,12 = Error B for dependant variables % dry matter and % forceable, respectively.
cTreatment = Thinning treatment of plants in the field.
d12,16 = Error for dependant variables % dry matter and % forceable, respectively.
e38,45 = Total corrected error for dependant variables % dry matter and % forceable, respectively.

Table A. 5 Analysis of variance of harvest index of plants.
S. Deerfield, MA, 1988.

Source of Variation	Degrees of Freedom	Mean Square
Blocks	2	0.0042287
Cultivar (C)	1	0.0040833
Error A	2	0.0005567
Population (P)	1	0.0017633
C x P	1	0.0067500
Error B	4	0.0022576
Treatment[a] (T)	1	0.0007500
C x T	1	0.0000833
P x T	1	0.0000300
C x P x T	1	0.0009633
Error	6	0.0020111
Total (corrected)	21	

aTreatment = Thinning treatment of plants in the field.

Table A. 6 Analysis of variance of percent of yield of chicons that is marketable and average fresh weight of chicons. Amherst, MA, 1988/89.

Source of Variation	Degrees of Freedom	Mean Square % Marketable[a]	Mean Square Chicon wt.[b]
Blocks	3	3867.5933	3666.4788
Cultivar (C)	1	2813.0951+	5523.2996*
Error A	3	1271.7072	1595.5483
Population (P)	2	698.8782	1064.4137
C x P	2	746.9770	609.0909
Error B	12	4562.5652	2887.7773
Treatment[c] (T)	1	365.3055	990.1423*
C x T	1	213.4004	1462.8947*
P x T	2	28.8674	290.6264
C x P x T	2	86.2215	374.1650
Error C	16	3767.2291	2983.1858
Storage[d] (S)	3	29790.4276**	20319.4972**
C x S	3	31499.8311**	13819.9270**
P x S	6	3468.4812*	1825.2596
T x S	3	1529.8486	1548.5756+
C x P x S	6	1672.2947	2883.7763+
C x T x S	3	884.6732	2607.9067*
P x T x S	6	1526.8687	1818.6446
C x P x T x S	6	2419.2822	1915.0788
Error	102	25661.5833	24310.6587
Total (corrected)	183		

**, * and + denotes significance at the 1%, 5% and 10% levels, respectively.

aMarketable = Percent of yield of chicons that are marketable.
bChicon wt. = Average fresh weight of chicons.
cTreatment = Thinning treatment of plants in the field.
dStorage = Period of storage of roots before forcing.

Table A. 7 Analysis of variance of marketable yield ratio of chicons. Amherst, MA 1988/89.

Source of Variation	Degrees of Freedom	Mean Square
Blocks	3	0.2492309
Cultivar (C)	1	0.1741970
Error A	3	0.1015372
Population (P)	2	0.0889406+
C x P	2	0.0604255
Error B	12	0.1650688
Treatment[a] (T)	1	0.0017913
C x T	1	0.0234657
P x T	2	0.0200487
C x P x T	2	0.0179774
Error C	16	0.3226641
Storage[b] (S)	3	0.6607651**
C x S	3	0.6088962**
P x S	6	0.0878085
T x S	3	0.0003614
C x P x S	6	0.0875694
C x T x S	3	0.0053016
P x T x S	6	0.0731267
C x P x T x S	6	0.0514859
Error	102	0.0173829
Total (corrected)	183	

** and + denotes significance at the 1% and 10% levels, respectively.

aTreatment = Thinning of plants in the field.
bStorage = Period of storage of roots before forcing.

Table A. 8 Analysis of variance of initial root weight and total chicon weight (untrimmed). S. Deerfield, MA, 1988/89.

Source of Variation	Degrees of Freedom	Mean Square Root Wt[a]	Mean Square Chicon Wt[b]
Blocks	3	19501.884	136912.800
Cultivar (C)	1	171.339	621795.385*
Error A	3	41601.443	31231.570
Population (P)	2	489640.781**	6811.725
C x P	2	474851.632**	23425.326
Error B	12	40804.947	45224.512
Treatment[c] (T)	1	58138.752	1189.767
C x T	1	26722.248	173241.236**
P x T	2	24312.558	12068.721
C x P x T	2	1570.491	12546.391
Error C	16	23262.035	19905.046
Storage (S)	3	74212.853**	693924.011**
C x S	3	70937.711*	674961.401**
P x S	6	92449.328**	80758.407*
T x S	3	38648.656	38216.245
C x P x S	6	47267.996*	52344.982
C x T x S	3	63208.763*	15010.291
P x T x S	6	42539.505*	22867.053
C x P x T x S	6	2682.835	19181.875
Error	102	18585.479	30024.216
Total (corrected)	183		

** and * denotes significance at the 1% and 5% levels respectively.

[a]Root Wt = Initial weight of roots before forcing.
[b]Chicon Wt = Total weight of chicons untrimmed.
[c]Treatment = Thinning treatment in the field.

Table A. 9 Analysis of variance of fresh weight and crown diameter of roots. S. Deerfield, MA, 1988.

Source of Variation	Degrees of Freedom	Mean Square Root Wt[a]	Mean Square Crown Diameter
Blocks	2	3483.3872	3.4905
Population (P)	1	13747.3066+	275.1779*
Error A	2	1052.8738	4.2557
Maturity (M)	8	8172.5816**	180.4937**
P x M	8	241.8250	2.7800*
Error	32	221.7009	1.2460
Total (corrected)	53		

**, * and + denotes significance at the 1%, 5% and 10% levels, respectively.
aRoot Wt = Fresh weight of roots.

Table A. 10 Analysis of variance of % dry matter of 'Daliva' roots and harvest index of plants. S. Deerfield, MA, 1988.

Source of Variation	Degrees of Freedom	Mean Square % Dry Matter	Mean Square Harvest Index
Blocks	2	4.349629	0.026201
Population (P)	1	2.666666+	0.001066
Error A	2	0.167222	0.003516
Maturity (M)	8	40.911018**	0.096103**
P x M	8	0.440833	0.001312
Error	32	0.405717	0.002021
Total (corrected)	53		

** and + denotes significance at the 1% and 10% levels, respectively.

Table A. 11 Analysis of variance for yield of forceable roots and percent of total yield of roots that are forceable. S. Deerfield, MA, 1988.

Source of Variation	Degrees of Freedom	Mean Square Forceable Yield[a]	Mean Square % Forceable[b]
Blocks	2	544.6666	672.0555
Population (P)	1	1073.3888	600.8888**
Maturity (M)	2	153.1666	456.0555**
P x M	2	5.7222	5.3888
Error	10	63.2000	55.8555
Total (corrected)	17		

** denotes significance at the 1% level.

aForceable Yield = Yield of forceable roots.
b% Forceable = Percent of total root yield that is forceable.

Table A. 12 Analysis of variance of total soluble sugars of roots. S. Deerfield, MA, 1988.

Source of Variation	Degrees of Freedom	Mean Square
Blocks	2	9.7665
Population (P)	1	224.5182
Error A	2	17.6190
Maturity (M)	13	8357.2712**
P x M	13	57.6240
Error	52	85.5460
Total (corrected)	83	

** denotes significance at the 1% level.

Table A.13 Analysis of variance of percent of yield of chicons that are marketable and average fresh weight of chicons. Amherst, MA, 1988/89.

Source of Variation	Degrees of Freedom	Mean Square	
		% Marketable[a]	Chicon Wt.[b]
Block	2	353.1914	207.1689
Population (P)	1	2849.0267**	2086.2465*
Maturity (M)	2	13606.2114**	15328.9904**
P x M	2	218.2114	175.7156
Error A	10	200.9878	332.7090
Storage (S)	2	2753.1339**	2871.9141**
P x S	2	1088.6498*	196.5141
M x S	4	1468.7148**	1462.5034**
P x M x S	4	303.6913	133.0978
Error	22	282.8573	171.5489
Total (corrected)	51		

** and * denotes significance at the 1% and 5% levels, respectively.

a% Marketable = Percent of yield of chicons that are marketable.
bChicon Wt. = Average fresh weight of chicons.

Table A.14 Analysis of variance of marketable weight ratio trimmed chicon weight/initial root weight ratio of chicons.
Amherst, MA, 1988/89.

Source of Variation	Degrees of Freedom	Mean Square Mkt. Wt. Ratio[a]	Mean Square Chicon/Root Wt[b]
Block	2	0.0254001	0.0204034
Population (P)	1	0.3745082**	0.0008148
Maturity (M)	2	1.5039577**	0.6473296**
P x M	2	0.0112153	0.0363212
Error A	10	0.0280313	0.0204243
Storage (S)	2	0.2440807**	0.2109671**
P x S	2	0.1000504*	0.0896549*
M x S	4	0.1765235**	0.0915209**
P x M x S	4	0.0404930	0.0262967
Error	22	0.0284071	0.0157301
Total (corrected)	51		

** and * denotes significance at the 1% and 5% levels, respectively.

aMkt. Wt. Ratio = Marketable chicon weight/total chicon weight ratio.
bChicon/Root Wt = Total chicon weight/ initial root weight ratio.

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