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Title: FACTORS AFFECTING SURVIVAL AND VIGOR OF COLD-STORED STRAWBERRY NURSERY STOCK

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Field survivals of strawberry (Fragaria x ananassa) runner plants dug from December to April in both 1979 and 1980 were above 90% when planted about May 1. When plants from the same digging dates were planted in early June, survival of March-dug 'Olympus' declined to 88% and survival of late-April-dug 'Totem' declined to 70% and 44% for 1979 and 1980 respectively.

Field vigor mostly parallelled survival in 'Totem'. 'Olympus' vigor was 25% greater for April- versus January-dug stock when planted May 1, 1979, and evaluated after fifteen weeks. 1980 fruit yield per plant was also 25% greater in April- versus January-dug 'Olympus' planted May 1, 1979. However, January-dug 'Totem' outyielded late-dug plants by up to 25% for both early and late planting dates.

Fungicide treatments, storage temperature, and nursery source did not significantly affect survival or vigor of March-dug 'Olympus' plants.

Greenhouse root growth of January-dug plants was up to ten times

greater than that of April-dug plants of both cultivars in 1979 and 1980. The incidence of apical damage, a possible result of cold-storage injury, increased from near zero for January- and February-dug plants to 50-90% for March- and April-dug plants. Storage temperatures of -3° to 0°C had little effect on plant quality, except for up to a three-fold increase in the incidence of apical rot for -3°C over 0°C storage.

Carbohydrate concentrations showed a declining trend with later digging dates in both cultivars. In 'Totem', free sugars in roots declined by 60% from January to April in both years. Starch levels in 'Olympus' declined about 65% from a January high to a March low in 1980. Changes in carbohydrate status were associated with greenhouse root growth as well as survival and vigor in both the field and greenhouse. Plant viability and carbohydrate levels seemed related to weather preceding each digging date and developmental stage.

FACTORS AFFECTING SURVIVAL AND VIGOR OF COLD-STORED STRAWBERRY NURSERY STOCK

by

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Typed by LaJuana Decker for Bruce Decker

This thesis is dedicated

to my wife, LaJuana,

who, through the love of Christ,

is beautiful

on the inside as well as the outside;

and whom I love dearly, as my own flesh.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Transplant Performance of Strawberry Nursery Stock Relative to Digging Date, Storage Treatment, and Planting Date

Root Growth and Viability of Strawberry Nursery Stock as Related to Digging Date and Carbohydrate Status

Note: This thesis is presented in the form of two papers to be submitted to the Journal of the American Society for Horticultural Science. The format of the papers corresponds to that required by these journals.

FACTORS AFFECTING SURVIVAL AND VIGOR OF COLD-STORED STRAWBERRY NURSERY STOCK

INTRODUCTION

Production of strawberry nursery stock is dependent on a relatively simple vegetative propagation system. Each "mother" plant produces many stolons, generating up to fifty or more young plantlets that root and can be dug for new plantings. Successful nursery propagation depends on the ability of these young plantlets to establish vigorous stands upon replanting.

Traditionally, plants were dug as early in spring as possible and transplanted immediately into nearby growers' fields. Since 1945, however, the production of strawberry nursery stock in the United States has shifted from small local, hand-dug operations to large volume, highly mechanized operations located in isolated, virus-free areas. In addition to marked cost reduction, this shift has resulted in the advancement of a specialized and sophisticated production system. Such centralization facilitates the introduction and proliferation of new cultivars, maintenance of quality certified stock, and stability within the marketplace. These advances have only been possible with technical innovations facilitating the harvesting, handling, storing, and shipping of plants with minimum subsequent field losses. This system, however, has not been without problems.

Central to the development of large scale nurseries has been the use of modern commercial cold storage. Worthington (54) states that success of strawberry plant cold storage is dependent upon "proper plant condition (dormancy, hardiness, and freedom from winter injury), use of film liners to prevent desiccation, and precise storage temperature".

The physiologic condition of the strawberry plant at a given time is directly related to its ontogenetic development. This course of development is primarily the consequence of environmental conditions. Digging date fixes the physiologic status of the plant somewhat by transferring it from a changing environment to a static one in cold storage. Thus, digging date becomes the chief factor controlling "proper plant condition".

In recent years Oregon strawberry growers have experienced substantial losses as a result of poor survival and vigor of spring-planted strawberry plants. Growers have sustained losses of up to 40% in some plantings, especially of the cv. 'Totem'. These studies were instituted in order to isolate the source of such losses and attempt to determine some physiologic bases for them. The physiology of strawberry runner plants is also examined with respect to determination of ideal digging date.

REVIEW OF THE LITERATURE

PHYSIOLOGIC CONDITION OF STRAWBERRY PLANTS FOR STORAGE

Genetic and environmental factors interact to affect the physiologic condition of the plants. Variation in the sensitivity of cultivars to different storage temperatures and digging dates has been shown. Worthington (54) showed that three of four cultivars dug in mid-November in Maryland could be stored at -1.1^{o}C for five months, but the cv. 'Albritton' dug on that date failed to grow satisfactorily after two months storage at any temperature tested (-4.4, -1.1, 2.2^{o}C). Haller (20) found that the cv. 'Dorsett' was particularly sensitive to digging in late October, whereas other varieties had a better field response to fall digging, though still much weaker than winter-dug plants. Angelo (5) showed large differences in the rate of acquisition of hardiness and capacity of different cultivars to withstand exposure to freezing at -10^{o}C. These genetic variations are generally due to adaptations of certain cultivars to regional climates, day length, and growing season. Although intensity and timing of physiologic responses may differ, the general pattern of dormancy and hardiness development is common to most cultivars.

Dormancy

Several workers have pointed out the necessity of storing only dormant plants (8, 10, 20, 54, 55). Dormancy in strawberries is not well characterized, but its onset can generally be identified by a decrease in growth rate, shorter petioles, smaller leaves, and a gradual senescence of older leaves. Darrow and Waldo (13), by adjusting day length, presented early evidence for photoperiodically induced rest. The critical short-day length was variable for cultivars adapted to different parts of the world. This is not a true rest since plants can be forced to grow, although in a much less vigorous manner, if exposed to warm temperatures and long photoperiods. Jahn and Dana (23) brought plants into the greenhouse at different dates in the fall and discovered that plants exposed to a longer "dormancy period" grew more rapidly and progressively approached the normal spring growth pattern.

In strawberry, as in many perennial plants, there is an accumulation of storage carbohydrates as the plants enter dormancy. Murneek (40) found that apple trees moved a large part of their reserve carbohydrates to the roots in winter. He also evidenced transport of carbohydrates from leaves into shoots prior to abscission in the fall (41). Long (32) showed a dramatic seasonal rise in storage carbohydrates, especially starch and hemicellulose, in the roots of strawberry plants as they entered dormancy in the fall. These levels declined through the dormant winter period and especially during the time of spring growth, anthesis, and fruit development. Gardner (15) showed that forcing strawberry plants into a carbohydrate deficient condition in the fall resulted in weak growth the following spring. Yerkes, et. al. (56) found that by evaluating starch content, maturity of rose rootstocks could be estimated. Immature plants rooted and grew slowly, and did not graft well, whereas mature plants were much more vigorous. Bringhurst, et al. (10) suggested the use of starch levels in strawberry roots as a possible index of maturity. Plants with starch levels below about 35% of the root cortex capacity were limited in their survival and vigor after short-term storage and failed to survive when planted out after eight months of cold storage. Plants dug later, with maximum starch reserves, survived well even after eight months storage. Similarly, Guttridge (17) reported that low carbohydrate reserves tend to restrict full expression of post-chilling vigor in strawberries. Freeman and Pepin (14) found a negative relationship between low starch in the roots (less than 30% of cortex filled) and vigorous growth only when the plants were set out under stress.

Chilling

Normally rest is broken by satisfaction of a chilling requirement (6, 13). Kronenberg and Wassenaar (24) showed clear varietal differences in the duration of dormancy and the amount of chilling necessary for the full expression of vegetative growth potential (7). This characteristic has been exploited horticulturally in specialized cultural systems in California (10, 50) and Florida (3, 4). In California, Voth and Bringhurst (49) found that vegetative and reproductive responses of plants varied with the nursery source and digging date for late fall and winter planted strawberries. Plants dug early in October or from nurseries at lower elevations showed a highly reproductive condition with poor vegetative vigor. Plants from higher elevations or dug in January, exhibited a vigorous vegetative condition with little fruiting. These effects were directly attributed to hours or chilling received by the respective plants. Albrechts and Howard (3) found that about fifteen days of chilling in cold storage produced the optimum balance of vegetative and reproductive growth of winter-planted strawberries in southern Florida, where the plants received little or no chilling in the field. In areas using the typical spring planting-matted row system, winter chilling in the field or in cold storage should be sufficient to provide maximum vegetative vigor (24). The chilling requirement of the common varieties (usually not exceeding eight weeks of field chilling or 800 hours below 7°C) would be met by the end of January in most temperate winter climates where large commercial nurseries are located, such as Maryland, Delaware, western Washington, and northern California (49).

Hardiness

Cold hardiness can be described as the degree to which a plant exhibits the ability to tolerate cold temperature without injury. Great variation exists in the capacity of different species to develop hardiness, with some tropical species being intolerant of even 5°C and other temperate species being able to withstand -196°C after proper hardening (51). The potential ability to harden is determined genetically and is integrally associated with the physiology and morphology of the plant.

Strawberry plants are among the least hardy of perennial fruit crops grown in temperate zones. However, their small size makes them easy to cover and mulch, allowing them to be grown in many northern locations, including Minnesota and Alaska (5, 12). Sometimes mulch is not applied at the proper time or winter conditions generally preclude its use, resulting in exposure of plants to damaging temperatures. In the Pacific Northwest, mulch is avoided because the cool moist winters are conducive to pathogen attack of mulched plants (14). During bouts of cold weather these plants can be particularly susceptible to damage since there is seldom winter snow protection.

The development of hardiness in strawberries has been studied by several workers (5, 9, 21, 37, 38, 48, 58). Angelo (5) found that different cultivars varied in the rate of acquisition of hardiness and the ultimate level achieved. Plants were also shown to harden and deharden quickly, with a twelve hour exposure to 0°C sufficient to cause considerable hardiness. Brierly and Landon (9) stated that the first frosty nights in the fall check all plant activity and effect the beginning of the development of hardiness. Hardiness is accumulated until a maximum is reached. The time of maximum hardiness varies with location, weather conditions, and cultivar. Harris (21) found that all cultivars studied increased in hardiness until March when kept frozen between -8° and -3°C. The minimum temperatures tolerated, -9° to -12°C, were used to measure hardiness.

Winter Injury

Damage following exposure to temperatures lower than plant minimum tolerance is termed "winter injury". This injury is characterized by an oxidative browning of the parenchyma tissue in the pith of the crown (37, 38). In severe cases, this damage occurs throughout the pith and into the vascular tissue and roots. Minor damage is reflected in slight browning of the lower part of the pith. In situations involving unhardened plants, or very severe freezing, the apex may also be damaged. This is characterized by a water-soaked condition and, in severe cases, by a blackening of bud leaves (54). Both the extent and intensity of browning are directly associated with the degree of cold stress (37, 38) and the resultant viability of the plants. Triphenyl tetrazolium chloride (TTC) dye reduction (37) and leachable electrolyte conductivity (21) have also been used to evaluate winter injury. In all cases, the minimum temperature tolerated by hardened plants without death was about -10^{o} to $-12^{o}C$.

Several other factors may influence the hardiness of strawberry plants. Steele et al. (48) showed that excessive soil moisture may result in greater winter injury to plants. They also showed that young terminal runners were more susceptible to injury than more mature runners. Zurawicz and Stushnoff (58) found that nutrient deficient plants were less hardy than plants with balanced N-P-K nutrition, both at the onset of acclimation and after hardening. Alternate freezing and thawing has also been shown to result in death to strawberry plants (35). Mader and Feldman (35) suggested carbohydrate exhaustion as the cause of this mortality. Brierley and Landon (9) showed that in spring, plants can reharden against light frosts during early stages of growth.

STRAWBERRY PLANT COLD STORAGE

Historically, strawberry plant nursery stock was grown by relatively small local nurseries. Plants were generally dug in the spring and shipped directly to growers at planting time. Because of problems with weak stands resulting from these late-dug plants (22), researchers began to investigate the possibility of digging plants while dormant, holding them in cold storage until planting time. This practice offered nursery growers other potential benefits including efficient labor management, escaping possible winter injury, and being less dependent on spring weather conditions for digging (1).

Digging Date and Storage Temperature

In Minnesota, Aamodt and Brierley (1) investigated the potential of fall digging. They were able to store plants dug as early as October 2 without the use of refrigerated storage in an unheated shed. Air temperatures as low as -10°C apparently caused no damage to the stored plants. Hoffman and Evans (22), in New York, obtained plants in March from Maryland and stored them at -0.5°C until normal planting dates in April and May. Stored plants gave results similar to freshly dug plants for early planting dates and superior results in later plantings. Haller (19) found that 'Howard 17' plants dug in late December in Maryland could be effectively stored at either 0° or 2.2°C resulting in stands far superior to freshly dug plants set out on the same date in late spring. Haller later (1939-1941) showed the viability of a wide range of cultivars in cold storage (20). He showed that plants dug after December 1 were consistently of high quality, whereas those dug earlier, especially in late October, were inferior. He also found that $0^{\circ}C$ was the most effective storage temperature since it was difficult to maintain adequately high humidity in the storage at below freezing temperatures.

Tests by Worthington (54) showed that a storage temperature of $-4.4^{\circ}C$ resulted in little adverse effect on subsequent field response of plants dug after December 1. 'Blakemore' plants dug in November did not respond well to -4.4° or $-2.2^{\circ}C$ but were satisfactory when stored at $-1.1^{\circ}C$. Worthington's data (54) makes it clear that $-2.2^{\circ}C$ is a satisfactory storage temperature for dormant plants and offers the distinct benefit of freezing the plants, reducing the water activity which generally inhibits fungal attacks. The use of freezing temperatures has become possible with the introduction of poly-film liners to prevent desiccation (53). Commercial nursery growers on the west coast have adopted the use of film liners and $-2.2^{\circ}C$ for storage of well-hardened and dormant stock (10).

Pathogens in Storage

Pathogen attack occasionally results in considerable losses of cold-stored strawberry runner plants. Usually, serious fungal growth in storage results from poor storage temperature control, inadequate circulation preventing temperature uniformity in the stacks of containers, or too slow a cooling rate. Storage temperatures should be at or below $-1.1^{\circ}C$ to prevent mold proliferation (28). Several workers suggest a maximum cooling time of fifteen days to reach -1.1°C (28, 29, 55). Worthington (55) also describes proper stacking arrangements to provide good air circulation within the cold storage unit. But if these optimum conditions are not met, pathogen attack may result (34).

Lockhart (27, 31) and Montgomerie (39) identified bacteria and fungi on stored plants, including: *Rhizopus spp.*, *Fusarium spp.*, *Rhizoctonia spp.*, *Cylindrocarpon spp.*, and *Botrytis cinerea*. The prevalence of *Rhizopus spp.* indicates a thermal history above 4°C since this is the lower temperature limit for growth of this organism. Later, Lockhart (28, 30) showed *Typhula spp.* to be the major pathogen in cold-stored strawberry plants in Nova Scotia. This mold growth was attributed primarily to poor air circulation resulting in inadequate cooling rates, such as 75 days to reach -1.1°C. A chloroneb dip at 18 g/l was effective in preventing *Typhula* growth at -1.1°C, whereas other fungicides tested were phytotoxic (29). Maas and Scott (33, 34), acknowledging the potential for poor temperature regulation, sought to use the systemic fungicide Benomyl as a pre-harvest field spray. Applications at 2.25 kg/ha 50% wettable powder effectively reduced the incidence of *Botrytis cinerea* on plants stored at +1° and +3°C. *Botrytis spp.*, however, have been shown to develop rapid resistance to such blanket applications, possibly making repeated treatments ineffectual. In New Brunswick, Graham, et al. (16) found a low temperature *Rhizoctonia* species which was able to grow in -2.2°C storage. Good control was obtained with the use of Thylate (7.4 g/l) as a pre-storage dip.

Cooling Rate

Lockhart (28) states that to avoid excessive development of mold in storage, plants should be cooled in storage to $-1.1^{\circ}C$ within fifteen days. Worthington and Vaught (55) examined several systems of packaging and stacking to maximize cooling rate and uniformity of temperature throughout the storage. Cooling was at equal rates using wooden or fiberboard cartons, although the temperature remained about $0.5^{\circ}C$ higher in the fiberboard boxes. Spaces between stacks and around the perimeter of the storage facilitated a more rapid cooling rate and allowed uniform temperatures throughout the plants.

Desiccation

As indicated earlier (page 3), Haller (20) found that below-freezing storage temperatures caused desiccation of strawberry plants which were not packed in film-lined containers, because of the difficulty of maintaining adequate humidity at these temperatures. Plants that were stored in bulk without trimming or packaging stored best at the freezing temperatures, apparently because the large mass of plants prevented excessive air exchange and moisture loss. When plants were packaged, damp sphagnum moss was added to provide moisture for the roots. Haller (20) studied the effects of supplementing moisture by wetting plants and moss during storage. He found an increase in growth with the various wetting treatments, although too much wetting resulted in mold growth at $2.2^{\circ}C$. Worthington and Scott (53)

Effectively solved desiccation problems by introducing the use of poly-lined crates for packaging and storage of plants. They also found sphagnum moss unnecessary in this system, resulting in a net savings in material costs and reduced shipping weight.

Defoliation

The standard practice of commercial nursery growers is to remove leaves by cutting the petioles just above the crown tissues prior to storage of runner plants. Haller (19,20) suggested this as a possible means of reducing desiccation in storage. Evaluation of his experiments showed no significant benefit to this practice. Puffer, et al. (44), in California, found that increased yield resulted when fall-planted stock was defoliated. But, in southern Florida, Albregts and Howard (2) found that when locally grown 'Tioga' and 'Sequoia' plants were defoliated prior to planting, reductions up to 30% in vigor and total yield resulted. When California-grown plants of the same varieties were planted in Florida, no detrimental effect was seen from defoliation. The authors attributed this to the difference in chilling history of the plants. Those grown in California had accumulated starch in the roots, characteristic of strawberries as they enter dormancy. Florida-grown plants had received no field chilling; consequently, no starch was detected in the roots, apparently resulting in weakened plants.

Respiration Rate

Respiration rate is an important consideration in the cold storage of plant materials. Respiration rate is a determinant in the storage life potential, response to temperature, and the required refrigeration capacity of the cold storage facility (32). Worthington (32) found average respiration rates of 6.5 and 11.9 mg CO_2/kg fresh weight/hr for dormant plants stored at -2.2^{o}and 0^{o}C respectively for six months. Brierley and Landon (9) showed that respiration rates of plants were depressed through the dormant season to a low of about 20 mg CO_2/kg fresh weight/hr in March for plants held in a cold frame at approximately 0^{o}C.

Respiration rates may be important in affecting the survival of plants through the winter. Long (32) showed that reserve carbohydrates decline from a maximum in December through the dormant period. Worthington (52) showed that total sugars declined in storage at both -2.2^{o} and 0^{o}C, but that the decrease was greater at the higher storage temperature. Mader and Feldman (35) showed that alternating temperatures between +3^{o} and -3^{o}C for 24 days resulted in a more rapid utilization of stored carbohydrate than when the plants were held at a constant 3^{o}C. They attributed this to higher respiration rates, and suggested that exhaustion of these carbohydrate reserves could be a factor in winter killing.

POST-STORAGE HANDLING AND GROWTH

Transportation

A potential problem encountered in transit is the rise of plant temperatures in unrefrigerated vans or rail cars. Worthington (55) found that plants shipped by rail had elevated to the 27°C ambient air temperature within the four days of shipment. This resulted in some root growth and undesirable top growth, which "would probably affect survival". He suggested that plants should be shipped immediately after removal from storage to take advantage of the existing low temperatures in the package, or be shipped in refrigerated cars.

Establishment

The establishment of uniform, vigorous stands of plants in the field is, of course, vital to successful strawberry production. Optimum establishment will result when stress and shock at planting time is minimized. High quality plant material and good production practices combined with favorable environmental conditions will most effectively accomplish this goal.

Rooting Physiologic Factors. One of the most important factors in the effective establishment and growth of propagated runner plants is regeneration and growth of roots. Rooting is a complex phenomenon which has been only partially elucidated. Several factors must be taken into account including the age, source, juvenility, nutritional status, physiologic condition, and hormonal balances of the plant material. Clearly, if the rooting capacity of a plant has been diminished, severe limitations are placed on its overall capacity to flourish.

Nutrition, especially as related to the nitrogen-carbohydrate balance, has been shown to be important in the rootability of plants. As early as 1923, Starring (46) showed that in tomato and _Tradescantia_ cuttings, low carbohydrates resulted in poor root initiation, whereas high carbohydrates resulted in very good root initiation and growth. He also found that nitrogen nutrition was not a major factor in root initiation and growth. Preston, et al. (43) found that the stage of maturity in azaleas interacted with nitrogen treatments. Succulent cuttings taken from low-nitrogen treated plants rooted better than cuttings from high-nitrogen treated plants. With mature cuttings, however, high-nitrogen treatments on the stock plant was more effective in augmenting rooting than low-nitrogen treatments.

Many biennial and perennial plants store carbohydrate in their roots in the fall to be used in the following spring for vegetative and reproductive growth (32, 40). Long (32) showed the seasonal pattern of carbohydrate fluctuations in the strawberry. Starch and hemicellulose reached a maximum about December 15, then declined throughout winter, then decreased more rapidly upon resumption of growth in spring. A particularly large carbohydrate demand apparently occurs at the time of flowering and fruiting.

More recently, Bringhurst, et al. (10) have shown that starch accumulation in roots can be correlated to the storability and the performance of strawberry plants. Presumably, carbohydrate reserves must be high enough to sustain the plants through storage and provide the initial cell building substrate for growth when set out in the field. Freeman and Pepin (14) found decreased vigor with plants low in carbohydrates but only when stress was placed upon the plants at planting time. Mann (37) described in detail the development of roots in strawberry. As dormancy is broken in the spring, one of the first changes that occurs is the conversion of starch in the parenchyma to usable forms. The development of lateral root initials soon proceeds with a prolific development of fine lateral roots, well furnished with root hairs. If carbohydrate reserves are low, one would expect this rooting phenomenon to be adversely affected.

Cultural Practices. As noted previously (pp. 2), the quality of runner plants received by growers is critical in plant establishment. Cultural practices also have an important impact on the establishment of uniform, vigorous, high-yielding stands in the field. Specific practices may vary in different regions, but a few general points will be emphasized here.

Planting date is critical to some of the specialized growing systems in California (10, 49, 50) and Florida (3, 4) in order to obtain the proper vegetative and reproductive balance to provide maximum early yields. Where plants are spring-planted, planting date is important only in facilitating establishment of adequate stands for maximum fruit production the subsequent year. Normally this is not a problem, as adequate numbers of runners are produced. In Scotland, Guttridge and Anderson (18) did not find that larger plants resulted in greater fruitfulness, although they were hesitant to generalize their conclusions about plant size to include other cultural systems. The effect of planting date on survival relates to two factors: the quality of the plants or their longevity in storage, and the weather conditions upon planting. Generally, weather through the planting season in Oregon becomes progressively hotter and drier from mid-April through June 1. This weather puts the plants under drought stress unless irrigation is supplied immediately after planting. Even if plants are well irrigated they may suffer drought stress at high temperatures, particularly if they are incapable of rapidly regenerating new root absorptive surfaces.

Plants are ideally positioned during planting with their roots fully covered by soil and the apex slightly above the soil surface. Plants set too deeply may smother and not grow, and plants set with exposed roots may wither and die.

The use of irrigation may be important in stand establishment if adequate soil moisture is not available (2). This could be especially important with late planting dates.

Certainly, good cultural practices must be maintained throughout the life of the planting if maximum vigor and yields are to be expected. Effective practices include: proper cultivar and site selection, weed and pest control, adequate fertilization and irrigation, and mulching when appropriate.

TRANSPLANT PERFORMANCE OF STRAWBERRY NURSERY STOCK RELATIVE TO DIGGING DATE, STORAGE TREATMENT, AND PLANTING DATE

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Abstract. Field survivals of strawberry (*Fragaria x ananassa*) cv. 'Totem' runner plants, dug in January, February, March, and April 1979, stored at -2°C, then planted May 1, 1979 were 98, 98, 94, and 97% respectively. 'Totem' plants dug on the same dates, stored at -2°C, but planted June 4, had field survivals of 98, 93, 80, and 70%. 'Olympus' plants dug on the same dates and planted in May and June had better than 96% survival except for March-dug and June-planted stock with 88% survival. The decline in field survival and vigor of 'Totem' nursery plants relative to digging date and later planting date was evidenced again in 1980 with April-dug and June-planted stock having only 44% field survival. 'Olympus' survival in 1980 was also similar to that of 1979, with survival above 88% for all treatments and lowest survival typically in March-dug plants.

Vigor indices mostly parallelled survival in 'Totem'. 'Olympus'

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vigor was 25% less for January-dug versus April-dug stock when planted May 1, 1979, and evaluated after fifteen weeks. Fruit yield per plant the following year was 25% higher for April-dug 'Olympus' than January-dug 'Olympus' planted on May 1, 1979. Conversely, January-dug 'Totem' yielded 25% more than March-dug 'Totem' when planted on the same date. June 4-planted 'Olympus' showed no differences in yield for the different digging dates. June-planted 'Totem' evidenced a similar response to digging date as on the May Planting date, with about a 25% reduction in yield on April versus January digging dates.

Pre-storage and pre-planting dips in a broad spectrum systemic or a Phycomycete-specific fungicide resulted in 85-93% survival for all treatments, including controls, suggesting that any anti-fungal action provided by these materials was without benefit under the conditions tested.

Storage temperatures of -3^{o}, -2^{o}, or $0^{o}C$, and nursery source did not significantly affect survival or vigor of March-dug 'Olympus' strawberry plants set out after two months storage, with survival remaining between 80 and 92%.

High volume production of strawberry nursery stock has become feasible only with innovations allowing large numbers of plants to be dug, handled, and shipped with minimum loss in subsequent field planting. Central to this development has been the use of improved commercial cold storage. Worthington (54) has stated that success of storage is dependent upon "proper plant condition (dormancy, hardiness, and freedom from winter injury), use of film liners to prevent desiccation, and precise storage temperature".

Genetic and environmental factors interact to affect the physiologic condition of the plants. Sensitivity of various cultivars to storage temperatures and digging dates has been shown (20, 54). Digging date is an essential consideration in effective cold storage, because it fixes the physiologic condition of the plants entering storage. Several workers have pointed out the necessity of storing only dormant plants (8, 10, 20, 54, 55). This dormant condition has been associated with an accumulation of carbohydrates required to prevent physiologic exhaustion in storage and to provide ample reserves for resumption of growth (10, 14).

Darrow and Waldo (13) presented early evidence for photoperiodically induced rest. This is not true rest because growth can be induced, although in a much less vigorous manner, with exposure to warm temperatures and long photoperiods (23). Normally, rest is broken by satisfaction of a chilling requirement (13, 23, 24). Cool temperatures are required for plants to reach a physiologic condition in which they are able to tolerate cold storage or overwintering. Thus, weather immediately preceding digging is of major consequence to the status of the plants. Bringhurst, et al. (10) showed that up to three weeks difference in developmental stage of strawberry could be expected from year to year and from lower to higher elevation under the same photoperiod, as shown by root starch levels and storability. The difference was associated with temperatures preceding harvest of the nursery plants. Under specialized cultural systems in California (10, 50) and Florida (3, 4), planting date has an important effect on the reproductive-vegetative balance of plants. Chilling history, whether in storage or in the field, has a direct impact on plant vigor and ultimately influences total yield. Later planting induces the plant to a more vegetative condition as a result of increased chilling in cold storage (49). In the Pacific Northwest, under spring-planted, matted-row conditions, planting date is presumably important only inasmuch as it relates to stand establishment, vigor, and subsequent yield effects the following year. Freeman and Pepin (14) suggest that poor vigor is not of major consequence under the matted row culture system since adequate runners are usually produced. They note, however, that under stress, less vigorous stands could result in reduced yield.

Storage conditions also have a direct effect on quality of nursery plants shipped to growers. Storage temperature is the most critical factor in storage, assuming the use of poly liners in fibreboard boxes, adequate air movement, and proper spacing of containers in storage (54). Early work by Aamodt and Brierley (1) showed good survival of dormant dug plants stored rough (unpackaged and ungraded) in a shed where the air temperature reached a low of -9^{o}C in mid-winter. Haller (19) found that -8^{o}C would kill 'Howard 17' plants, but -1.1^{o}, 0^{o}, or 2.2^{o}C storage of plants dug December 21 to March 21 was superior to spring-dug plants when planted from March 21 to June 21. Later

Haller (20) affirmed -1° to 0°C as the best storage temperature range since freezing presented problems of desiccation. However, Haller's studies were done without the use of poly film liners to prevent desiccation. Worthington (54) suggested that -1.1°C is the best storage temperature for plants dug in November in Maryland, which are more sensitive than fully dormant plants dug in mid-winter. Most commercial nursery growers on the west coast have adopted the use of -2.2°C for storage of dormant stock. Freezing is feasible with the use of poly liners to prevent desiccation and has the advantage of limiting pathogen problems. No apparent damage has resulted when dormant winter-dug stock is used (10, 54).

Pathogen problems in cold storage have been a major source of losses at times. Usually such problems arise as a result of poor storage temperature control, or inadequate circulation preventing maintenance of uniform low temperatures within the storage. But, Graham, et al. (16) reported the incidence of a *Rhizoctonia* species which caused considerable damage growing on plants held at -2.2°C. They were able to control the pathogen with the use of Thylate (7.4 g/l) in a pre-storage dip. Lockhart (27) identified bacteria and several fungi on cold-stored strawberry plants, including *Rhizopus spp.*, *Fusarium spp.*, and *Botrytis cinerea*. The presence of *Rhizopus*, however, indicates a thermal history above 4°C. Lockhart, in 1968 (28), showed *Typhula spp.* to be the major pathogen in cold-stored strawberry plants in Nova Scotia. This mold growth was mostly attributed to poor air circulation resulting in inadequate cooling rates--up to 75 days to reach -1.1°C. Maximum recommended cooling time is no more than fifteen to twenty days (28, 55). Lockhart (29) found that a chloroneb (Demosan) dip (18 g/l) was effective in preventing *Typhula spp*. growth at -1.1°C whereas other fungicides were either ineffective or phytotoxic. Maas and Scott (33, 34) reported that preharvest field applications of benomyl (2.25 kg/ha 50% wettable powder) could effectively reduce the incidence of *Botrytis cinerea* on plants stored at +1° and +3°C.

Strawberry growers in western Oregon have recently encountered severe problems with the survival and vigor of cold-stored strawberry nursery stock planted in spring. Failure of up to 40% with the cultivar 'Totem' have resulted in economic losses and inconvenience for both growers and nurserymen. Experiments were designed to isolate specific sources of loss under Oregon conditions.

MATERIALS AND METHODS

1979 Digging Date and Planting Date

Strawberry runner plants of the cultivars 'Totem' and 'Olympus' were obtained from a commercial nursery near Olympia, Washington. Eight hundred plants of each cultivar were hand dug from the same field on each date: January 20, February 22, March 20, and April 19. Leaves and stolons were removed, and the trimmed plants were sized and graded to commercial specifications (at least twelve roots over eight cm.), bundled in groups of 25 plants, and stored at -2.2°C in poly lined cardboard cartons until planting. Just prior to mechanical planting, plants were thoroughly thawed and roots trimmed to nine cm. Planting dates were May 1 and June 4. The field plot consisted of a modified split plot, with planting dates treated as main plots and all treatments randomized as sub-plots within main plots. Treatments consisted of four replications of 100 plants each.

Survival was evaluated three weeks after each planting date; and vigor was measured August 15, fifteen and ten weeks after the May and June planting dates respectively. Survival was determined by any sign of green growth. Leaves were counted and petiole length estimated on fourteen plants per replication. These values were multiplied together to provide a vigor index. Fruit yield after one year's growth was taken in 1980. Yield was taken from a ten-plant plot within each replication. Harvests were on three dates in June, 1980, and included rotten fruit. Average fruit size was obtained from a 25-fruit sample from each plot.

1980 Digging Date and Planting Date

'Totem' and 'Olympus' runner plants were obtained from the same nursery as in the 1979 study. Digging dates were December 12, 1979; January 16, February 14, March 11, April 3, and April 23, 1980. Nine hundred plants of each cultivar were handled as in the 1979 experiment. The field plots were modified to include six replications of fifty plants each. Three planting dates were April 25, May 15, and June 6, 1980.

Survival was evaluated three weeks after planting; vigor was measured six weeks after each planting. Runners were counted on October 1, 1980; 22, 18, and 15 weeks after the April, May, and June planting dates respectively. Survival was evaluated as in 1979, but vigor was evaluated for thirty plants per replication on a hedonic scale of 1 to 5 for each plant. Runners were summed for ten plants in each plot. Fruit yield data was not collected.

Fungicide Study

'Olympus' runner plants were obtained from the commercial nursery on March 15, 1979. Three hundred plants per treatment were treated by dipping roots of bundled plants in CGA 48988 (Ridomil) (37 mg AI/1), benomyl (Benlate) (1.2 g/1 WP), a Ridomil and Benlate mixture, and a water control, for twenty seconds at 10°C solution temperature. An untreated control group was also included. All plants were then stored at -2.2°C, as commercially recommended. A similar group of plants (without pre-storage treatment) was placed directly into -2.2°C storage. These plants were removed, thawed, and given the same fungicide treatments just prior to planting. Plants were set out on May 15, 1979, in a completely randomized design with three replications of 100 plants each. Survival and vigor were evaluated as in the 1979 digging date and planting date study.

Storage Temperature Effects

'Olympus' plants were obtained from a commercial nursery on March 15, 1979. Plants were placed in storage at -3.3°, -2.2°, and 0°C. Plants were set out on May 15, 1979, in a completely randomized design with four replications of 100 plants each. Survival and vigor were evaluated as in the 1979 digging date and planting date study.

Nursery Source

'Olympus' runner plants were obtained from two commercial nursery growers near Olympia, Washington, and from another grower near Burlington, Washington. Plants were stored at -2.2°C and planted on May 15, 1979. A completely randomized design included 100 plants in each of four replications. Survival and vigor were evaluated as in the 1979 digging date and planting date study.

RESULTS AND DISCUSSION

Digging Date - Planting Date Studies

'Olympus': Survival, Vigor, and Runner Production. The May 1, 1979, planting date resulted in excellent survival of 'Olympus' regardless of digging date (Table 1), with at least 96% survival in all cases. Survival of 'Olympus' was good on the early planting date in 1980 (Table 2). The somewhat greater losses in December- and January-dug plants could be attributed to some samples which were exposed to less than optimal 0^{o}C temperatures for up to three weeks prior to -2^{o}C storage. The June 4, 1979, planting date (Table 1) showed good survival for 'Olympus' except for a marked decline to 88% for the March-dug plants. The May 15 and June 6 planting dates in 1980 resulted in very good field survival of 'Olympus' dug in December, January, and February. Later-dug plants showed a declining survival rate with later planting. March-dug plants showed the lowest survival rate, although the loss was not serious, with survival remaining above 88%.

May, 1979 planted 'Olympus' showed somewhat increasing vigor with later digging dates (evaluated fifteen weeks after planting), although the differences were not statistically significant (Table 1). In 1980 (Table 2), no pattern in vigor expression was noted on the earliest planting date. 1980 vigor evaluations, however, were obtained only six weeks after planting, and were based on a more subjective evaluation than that taken in 1979.

The June, 1979 'Olympus' planting date showed the same increasing vigor with later digging dates as the May planting. Vigor of February-dug plants was almost 25% lower than vigor exhibited by April-dug plants. Conversely, in 1980, later digging dates resulted in less vigorous stands of plants than winter (December, January, and February)-dug plants. For both the May and June planting dates, vigor (measured at six weeks after planting) was significantly higher for winter-dug plants than those dug in March and April.

Differences in vigor of 'Olympus' compared across planting dates in 1979 were attributed essentially to the five weeks longer growth period for the May planting over the June planting. The ANOVA gave a significant F test for vigor differences among 1980 planting dates for 'Olympus' (Table 2). A notable increase in vigor occurs between the April and May planting dates. The June 1980 planting date showed a stabilizing of vigor, with values similar to May-planted stock.

An important aspect relative to strawberry plant vigor is runner production. In 1980, April-planted 'Olympus' produced maximum runners from December- and January-dug plants (Table 2). Minimum runner production was observed on March-dug plants. But, large plot-to-plot variation prevented mean separation despite a 70% decline in runner production of March-dug plants compared to December-dug plants. For the May planting date, 'Olympus' runner production was almost 150% higher from January-dug plants than from plants dug any other date, but the average remained low at about three runners per plant. Late planting had a nearly total inhibitory effect on runner production in 'Olympus', averaging less than one runner per plant for each digging date.

Survival data identified 'Olympus' as a sturdy cultivar; even in the worst instances, field losses did not exceed 12%. Best survival was typically found with winter-dug stock, as expected, since plants were most fully dormant then. Poorer survival of some winter-dug treatments in 1980 ('v' Table 2) could be attributable to the mishandling of plants noted previously (page 28). December- and January-dug plants remained unfrozen in $0^{o}C$ storage for two to three weeks, resulting in pathogen invasion of some bundles of 'Olympus' plants. Damage apparently carried into the field where certain replications showed fairly large losses, whereas other replications in the same treatment showed expected high survival rates of 96-99%.

March-dug plants consistently resulted in the poorest stands for both years. Weakness of the March-dug stock may be a consequence of the 'Olympus' spring growth habit. 'Olympus' is the first cultivar to begin active growth in the Pacific Northwest. In Washington, this may occur during the first warm spell in late February or early March. A surge of growth at that time could leave runner plants with a shortage of carbohydrate for root development, especially since new leaves are removed when plants are dug. Long (32) demonstrated the pattern of decreasing carbohydrate in strawberry plants as spring advances. Bringhurst, et al. (10) showed a strong relationship between starch levels in roots and storability of strawberry plants. The increased survival of April-dug over March-dug 'Olympus' may have resulted from a recovery of carbohydrate reserves as new leaf surface provided photosynthate. Association of poor survival with low carbohydrate reserves is supported by carbohydrate determinations reported elsewhere (see pages 58-60, this thesis).

Vigor and runner relationships were difficult to analyze because different evaluation procedures were employed in the two years of the study. The vigor index obtained in 1979 measured the vigor of mother plants only. Consequently, the impact of runnering on the 1979-planted stock is unknown. Vigor of 'Olympus' seemed to increase with later digging dates on both planting dates when evaluated fifteen and ten weeks after planting in 1979. In 1980, vigor at six weeks after planting decreased with later digging dates. An explanation may lie in the runnering habit of 'Olympus'. The greater tendency for early-dug 'Olympus' to produce stolons (Table 2) may have resulted in less vigorous mother crowns later in the season, similar to those evaluated in the 1979 study. In 1980, vigor measurements were made at six weeks after planting, before any runner production, and thus reflected total vigor at that time. The general increase in vigor from April to May planting in 1980 was attributed to moderating temperatures and increasing daylength as summer approached.

The nearly total inhibition of runner production in late-planted 'Olympus' suggests a change in hormonal balance, as the evidence does not indicate a simple time limitation for runner development. Greater stress placed on 'Olympus', as in late digging or late planting, seemed to reduce runnering. An explanation of the large plot-to-plot variation in 'Olympus' runnering may lie herein, since soil tilth, as well as irrigation distribution and weed competition, were somewhat varied throughout the field.

<u>'Totem': Survival, Vigor, and Runner Production</u>. 'Totem' exhibited a more dramatic pattern than 'Olympus' in its survival, vigor, and runner production (Table 2). The May 1979 planting date showed good survival for 'Totem' at all digging dates. In the June planting, however, declining survival with later digging date was evident, with 80% survival of March-dug plants and 70% survival of April-dug plants,

and 98% survival of January-dug plants. This pattern was repeated in 1980, although the early planting (April 25) did show greater losses (15%) of March-dug plants (Table 2). Survival of April-dug plants followed the 1979 pattern with a dramatic decline to only 44% survival for April 23-dug plants set out in June.

Vigor exhibited similar trends in 'Totem' for each planting date in 1979, with maximum vigor of January-dug plants, followed by a distinct decline in March- and April-dug plants. June planting resulted in a vigor index nearly 50% lower for April-dug plants than January-dug plants. Vigor results in 1980 were similar to 1979 for 'Totem', inasmuch as plants from winter digging dates showed highest vigor levels and later-dug plants were significantly less vigorous. On each planting date, April 23-dug plants exhibited the poorest vigor. April 23-dug plants set out in June were only about 50% as vigorous as December- or January-dug plants.

An examination of vigor across planting dates in 1980 revealed that, for winter digging dates, vigor at six weeks post-planting increased with successive planting dates (Table 1). For March 11 and April 3 digging dates, vigor tended to remain stable across planting dates. The April 23 digging date resulted in a decreasing vigor response as planting date progressed later into the spring.

Runner production in 'Totem' seemed related to vigor on each planting date in 1980 (Table 2). Runner counts were typically highest in January-dug plants and declined in March- and April-dug plants. Planting date obviously had a major impact on runner production in

'Totem', but the effect was attributed to the difference in growth period, six weeks shorter for the June than for the April planting. Many of the runners produced from the late planting were immature and not yet firmly rooted on the October 1 evaluation date.

Survival of 'Totem' in both 1979 and 1980 clearly indicated that the cultivar is sensitive to long-term storage at -2.2°C when dug in late April. 'Totem' runner plants became progressively less tolerant of storage when dug as dormancy ended and growth began. The length of time in storage for these weaker plants was also important. Late-dug 'Totem' responded quite well when planted immediately or shortly after digging; but, with six weeks of cold storage, viability declined markedly. Again, survival was apparently related to carbohydrate reserves at the time of digging (see pages 58-60, this thesis). 'Totem' seemed particularly susceptible to low-carbohydrate stress, certainly more so than 'Olympus'. Figures 4b and 6b (pp. 72, 76) show the dramatic decline in 'Totem' root free sugars as digging date progresses in both years. Figure 5b (p. 74) shows the declining starch reserves also associated with later digging in 1980. These data (Tables 1 and 2) reflect a similar field response to this carbohydrate-deficient condition as was found by Bringhurst, et al. (10) and Freeman and Pepin (14) in fall-dug strawberries. If plants were dug in a dormant, well-hardened condition, as in December, January, or February, excellent survival was maintained regardless of planting date.

Vigor ratings correspond well with survival indices in both years with 'Totem'. The interaction between digging date and planting date in 1980, where early-dug plants grew more rapidly than late-dug plants with late planting, showed the relative vigor of plants from each digging date. As the season advanced, and weather and daylength became more favorable for growth, early-dug plants responded with fuller expression of their growth potential. In contrast, late-dug plants experienced further weakening in storage and responded with weaker growth on being set out, despite more favorable weather.

Differences in runner production of 'Totem' among digging dates became more pronounced as planting date progressed later into the spring (Table 2). Thus, some recovery of late-dug plants did occur with earlier planting dates. The shorter recovery period and the significantly poorer condition of the late-dug plants would explain the decline of more than 50% in runner production of late April- versus December-dug plants for the june planting date. Differences in runner production among planting dates for 'Totem' were attributed to differences in growth period.

Fruit Yield. Fruit yield (Table 1) in 1980 from the 1979 spring plantings revealed some unexpected results. May-planted 'Olympus' had a significantly higher yield from April-dug plants than January-dug plants. Yields for the May planting correlated well (r=0.93) with the vigor index determined fifteen weeks after planting. No relationship existed between vigor and yield for 'Olympus' planted in June. No differences in total yield were found between planting dates for 'Olympus', but average fruit size was greater for the June planting date.

The lower fruit yields for winter-dug 'Olympus' planted in May may have been due to differences in runnering and vigor as previously explained (p.30-31). Lack of differences in yield among digging dates on the June planting date probably resulted from sparse runner production for all digging dates and, consequently, more uniform plant stands. Lack of differences in yield between planting dates may have resulted from the larger average fruit size of the second planting date compensating for fewer fruit. Smaller crowns may have initiated fewer flowers on late-planted plants, and vigorous growth the following spring facilitated greater filling of these fewer fruits.

May-planted 'Totem' showed a positive relationship (r=0.88) between vigor and fruit yield (Table 1), with highest yields from January- and February-dug plants and lowest yield from March-dug plants. June-planted 'Totem' showed no statistically significant differences in yield among digging dates, although the highest yield did result from January-dug plants and lowest yield, from April-dug plants. No significant planting date effect was found in the ANOVA for fruit yield, but the trend was toward reduced yields on the June planting date. 'Totem' fruit size showed no statistically significant differences relative to digging date or planting date, but for each digging date, fruit size was slightly larger on the June planting date than the May planting date.

Although isolation of differences in 'Totem' fruit yields is difficult due to considerable plot-to-plot variation, the best treatment for maximum yields is apparently early planting of winter-dug stock. January-dug stock planted in May yielded 50% more than April-dug, June-planted stock. These data do not tell the entire story, however; only live plants were included in yield measurements for each plot. With only 70% survival of late-dug, late-planted 'Totem' compared to 98% survival of early-dug, early-planted stock, late digging combined with late planting could result in yield reductions of up to 50% in the first fruiting year if there is no replanting.

Weed competition may have been an additional factor in fruit production for the June planting date. The ability of the strawberry plants to compete was impaired by poor vigor of the late-dug stock for this planting date.

Conclusions. Results of studies of 'Olympus' and 'Totem' strawberry plants show a markedly different growth response to digging date and planting date between cultivars. With 'Olympus', neither later digging nor late planting has a negative effect on fruit yield; and, in fact, late-dug plants may yield more fruit as a result of production of fewer stolons. But, any reduction in survival of 'Olympus', as observed in the March-dug, late planted treatment, may result in lower yield since runner production would probably not compensate for this mortality.

'Totem' is subject to severe losses when dug in late April and stored for over two weeks at -2^{o}C. A pattern of declining viability occurs as digging season and planting season advance. In contrast, growers can expect excellent results from winter-dug stock, especially when planted early in the season.

Fungicide Study

The only significant treatment effect noted in the fungicide trials was poorer survival resulting from pre-storage treatment of the combination of Ridomil and Benlate (Table 3). This negative effect may indicate an antagonistic interaction or slight phytotoxic effect of these chemicals. Water-dipped control plants did not show increased losses in storage, probably because in -2.2°C storage nearly all of the free water becomes ice. Survival rates of above 90% indicate that storage of wet plants may be safe if they are rapidly cooled to freezing and remain frozen. Although not significant, the pre-plant water dip may have slightly improved survival. This improvement suggests a possible way to replenish water lost during harvest, storage, and handling, giving plants a slight boost at planting.

No significant differences in vigor were established among the various treatments due to considerable plot-to-plot variation. But, the pre-storage combination treatment with Benlate and Ridomil resulted in the least vigorous plants, about 40% less than the controls or the Benlate-treated plants. All treatments involving Ridomil resulted in a vigor index less than those of the controls or Benlate treatments, indicating a possible phytotoxic effect of Ridomil at the concentration used.

The results of the fungicide trials showed no fungal invasion under the conditions tested. They also indicated no beneficial carry-over effect in the field. The -2°C storage temperature and the relatively short duration of storage (two months) was apparently sufficient to prevent any pathogen invasion in storage. This protective effect is consistent with work by Lockhart (28), which showed temperatures maintained at or below -1^{o}C aided in the prevention of mold growth. He was able to control Typhula spp. in -1^{o}C storage with a chloroneb fungicide dip (29). Data reported here suggest such fungicide treatments may be unnecessary if plants are frozen at -2^{o}C.

Storage Temperature Study

After two months in storage, no statistical differences were observed in the field survival or vigor of 'Olympus' runner plants stored at -3^{o}, -2^{o}, and 0^{o}C (Table 4). These data suggest -3^{o}C may be best, with 87% survival, but other data indicate 89% survival for a treatment identical to the -2^{o}C treatment (Table 3, untreated control). Also, storage at -3^{o}C could be more injurious to plants in a less hardy physiologic condition wuch as might occur with growth resumption of late-dug plants.

The apparently favorable 0^{o}C results may be somewhat misleading because some plants (approximately 5%) were culled prior to planting because of a mild growth of fungal mycelia (probably Botrytis spp.) over the surface of the roots. No mold was found on plants stored at -3^{o} or -2^{o}C.

The storage for two months at 0^{o} to 3^{o}C may have been too limited in range to have allowed statistical separation of storage temperature effects to which Worthington (54) has attached significance. His work suggests -1^{o}C as the optimum temperature for long-term storage of November-dug strawberry plants, which are not fully dormant and hardened. This temperature may be superior for such immature plants. But, the risk of pathogen invasion, as a consequence of storage temperature fluctuations, is greater when plants remain unfrozen, and must be considered in choosing storage temperature.

Nursery Source Study

There were no significant differences in survival and vigor of 'Olympus' strawberry runner plants obtained from three different nurseries in Washington. An approximately 3^{o}C lower mean temperature in March and a later growing season at the Burlington, Washington site had no significant effect on the quality of the 'Olympus' cultivar. Different handling practices and variations in method of shipping of the three nurseries also seemed insignificant relative to survival and vigor.

Table 1. Field survival and plant quality of 'Olympus' and 'Totem' strawberry nursery stock relative to digging and planting dates (1979).

Planting Date	Digging Date	% Survival Olympus	% Survival Totem	Vigor Index[y] Olympus	Vigor Index[y] Totem	1980 Total Fruit Yield (kg/10 plants) Olympus	1980 Total Fruit Yield (kg/10 plants) Totem	1980 Average Fruit Size (g) Olympus	1980 Average Fruit Size (g) Totem
May 1	Jan 20	96a[z]	98a	229a	165a	10.5b	7.4a	13.7a	15.6a
	Feb 22	98a	98a	226a	145ab	10.9ab	7.4a	13.0a	15.1a
	Mar 20	98a	94a	282a	114b	11.9ab	5.6b	14.0a	14.2a
	Apr 19	98a	97a	290a	140ab	13.0a	6.2ab	13.1a	14.9a
	E.M.S.	3.729	6.958	500.59	64.698	3.843	1.695	0.6404	1.135
June 4	Jan 20	98a	98a	114a	109a	11.1a	6.8a	13.7ab	15.7a
	Feb 22	100a	93a	94a	99a	10.9a	5.4a	14.3ab	15.6a
	Mar 20	88b	80b	107a	71a	12.0a	6.3a	15.0a	16.0a
	Apr 19	97a	70b	129a	56b	11.1a	5.0a	14.5a	15.0a
	E.M.S.	11.271	52.208	110.49	40.87	4.463	6.371	0.8505	1.1836

[y]Vigor index is the product of leaf number x average petiole length (cm).
[z]Means separated among digging dates within each planting date and cultivar. Means followed by the same letter are not different at the 0.05 level of significance using Duncan's Multiple Range Test.

Table 2. Field survival and plant quality of 'Olympus' and 'Totem' strawberry nursery stock relative to digging and planting dates (1980).

Planting Date	Digging Date		% Survival		Vigor Index[x]		No. Runners[y]	
			Olympus	Totem	Olympus	Totem	Olympus	Totem
Apr. 25	Dec. 12		[v]89b[z]	97a	2.8b	3.6a	55a	120ab
	Jan. 16		[v]91ab	96a	3.4a	3.2b	50a	126a
	Feb. 14		97a	92ab	2.8b	3.4ab	42ab	123ab
	Mar. 11		94ab	85b	2.5b	2.8c	18b	100ab
	Apr. 3		98a	89ab	2.8b	2.5c	37ab	86b
	Apr. 23		98a	89ab	2.7b	2.5c	36ab	108ab
		E.M.S.	7.578	18.700	0.121	0.076	421.839	913.483
May 15	Dec. 12		[w]97	97a	3.5b	3.9a	10b	85a
	Jan. 16		99a	99a	3.9a	3.9a	29a	78ab
	Feb. 14		96a	96ab	3.4b	3.3b	9b	76ab
	Mar. 11		92b	90ab	3.0c	2.9bc	12b	56b
	Apr. 3		94ab	87b	3.0c	2.8c	7b	66ab
	Apr. 23		95a	72c	2.8c	2.3d	8b	60ab
		E.M.S.	6.324	28.6222	0.070	0.149	96.161	447.539
June 6	Dec. 12		[v]91ab	95ab	3.5a	4.1a	2ab	49a
	Jan. 16		97a	99a	3.8a	4.1a	8a	42ab
	Feb. 14		99a	93ab	3.7a	4.0a	5ab	38abc
	Mar. 11		88b	90b	2.9b	2.9b	3ab	26bc
	Apr. 3		93ab	76c	2.8b	2.7b	3ab	24bc
	Apr. 23		90ab	44d	2.6b	2.2c	1b	22c
		E.M.S.	12.167	14.656	0.122	0.026	18.346	116.559

[v]Values include replications with low survival which may be attributable to pathogen invasion as noted in text.
[w]Value based on two replications.
[x]Vigor is based on a 1 to 5 visual ranking.
[y]Runners per ten plants.
[z]Means separated among digging dates within each planting date and cultivar. Means followed by the same letter are not different at the .05 level of significance using Duncan's Multiple Range Test.

Table 3. Pre-storage and pre-plant fungicide effects on 'Olympus' strawberry plant field survival and vigor.

Treatment Timing	Treatment	% Survival	Vigor Index[y]
None	Untreated	89.3ab[z]	223a
Pre-storage	Water dip	90.7ab	230a
Pre-plant	Water dip	93.7a	218a
Pre-storage	Benlate	93.3a	228a
Pre-plant	Benlate	92.2a	222a
Pre-storage	Ridomil	89.0ab	183a
Pre-plant	Ridomil	90.0ab	190a
Pre-storage	Ben + Rid	85.0b	133a
Pre-plant	Ben + Rid	92.7a	198a
		E.M.S. 13.533	E.M.S. 572.242

[y]Vigor indes is the product of leaf number x average petiole length (cm).
[z]Means followed by the same letter are not different at the .05 level of significance using Duncan's Multiple Range Test.

Table 4. Storage temperature effects on 'Olympus' strawberry plant field survival and vigor.

Storage Temperature	% Survival	Vigor Index[y]
-3°C	87a[z]	188a
-2°C	82a	218a
0°C	80a	203a

[y]Vigor index is the product of leaf number x average petiole length (cm).
[z]Means followed by the same letter are not different at the .05 level of significance using Duncan's Multiple Range Test.

Table 5. Nursery source effects on 'Olympus' strawberry plant field survival and vigor.

Nursery	% Survival	Vigor Index[y]
1	89a[z]	218a
2	92a	173a
3	92a	196a

[y]Vigor index is the product of leaf number x average petiole length (cm).
[z]Means followed by the same letter are not different at the .05 level of significance using Duncan's Multiple Range Test

ROOT GROWTH AND VIABILITY OF STRAWBERRY NURSERY STOCK AS RELATED TO DIGGING DATE AND CARBOHYDRATE STATUS

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Abstract. Root growth of February, March, and April 1979-dug strawberry plants (*Fragaria x ananassa*) cv. 'Olympus' was 66%, 20%, and 10% respectively of root growth of January-dug plants when evaluated after two weeks in the greenhouse. January-dug 'Totem' had 50% more vigorous root growth than 'Olympus', but April-dug 'Totem' showed almost no root growth after two weeks. Similar trends of root growth for both cultivars were seen in 1980 trials.

In both 1979 and 1980, the incidence of apical damage, a possible result of cold-storage injury, increased from near zero for January- and February-dug plants to 50-90% for March- and April-dug plants. At the same time, survival for January- and February-dug plants declined from 85-100% to as low as 54% for March-dug 'Olympus' and late April-dug 'Totem' in 1980. Greenhouse survival closely approximated field survival in 1979, but was up to 35% lower than field survival in 1980 trials.

Storage temperatures in the -3^{o} to 0^{o}C range showed no statistically significant effects on rooting, shoot growth, or survival. But

colder (-3°C) storage temperatures increased the incidence of apical damage in March- and late April-dug 'Totem' up to three times for -3°C compared to 0°C (March-dug; Table 4).

Carbohydrate concentrations showed a declining trend with later digging dates in both cultivars. In 'Totem', free sugars in roots declined by 60% from January to April in both years. Starch levels in 'Olympus' declined about 65% from a January high to a March low in 1980. Changes in carbohydrate status were associated with changes in root initiation, survival, and shoot vigor at the various digging dates. Plant viability and carbohydrate levels were related to weather preceding each digging date and consequent plant activity and developmental stage at that time.

Proliferation of strawberry plants is generally considered a simple vegetative propagation system. Each mother plant produces stolons which root up to fifty or more young plantlets that can be dug and used in new plantings. Nursery businesses depend on the ability of these young transplants to establish vigorous stands.

An important factor in effective establishment and growth of propagated runner plants is regeneration and growth of roots. Rooting is a complex phenomenon which has not been fully elucidated. Several factors must be taken into account, including the age of the parent material, its source, nutrition, physiologic status, and hormonal balances (25). If the rooting capacity of a plant is diminished, severe limitations are placed on its ability to flourish.

Nitrogen-carbohydrate nutrient balances have been shown to be important in the rootability of plants (45). Starring (46), as early as 1923, showed that in tomato and *Tradescantia* cuttings, low carbohydrate status resulted in poor root initiation, whereas high carbohydrate status promoted good root initiation and growth. He also found that nitrogen nutrition was not a major factor in root initiation and growth. Preston, et al. (43) found in azaleas that the stage of maturity interacted with nitrogen treatments. Succulent cuttings from low-nitrogen treated plants rooted better than such cuttings from high-nitrogen treated plants. With mature cuttings, however, high nitrogen in the parent material was more effective in promoting rooting.

Many biennial and perennial plants store carbohydrate in their roots in the fall for subsequent spring vegetative and reproductive growth (32, 40). Long (32) showed a seasonal pattern of carbohydrate fluctuation in strawberry. Starch and hemicellulose reached a peak in December, then declined through winter and especially upon the resumption of spring growth. A particularly large carbohydrate demand was evident at the time of flowering and fruiting.

More recently, Bringhurst, et al. (10) have shown starch accumulation in roots to be related to the storability and subsequent performance of strawberry plants. Presumably carbohydrate reserves must be sufficient to sustain plants through storage and provide substrate for renewed spring growth. Freeman and Pepin (14) found decreased vigor with plants low in carbohydrate only when some stress was placed upon the new plantings.

Several workers point out the importance of using only dormant plants for long-term storage (8, 10, 20, 54, 55). The onset of rest in strawberries can be identified by a decrease in growth rate, shorter petioles, smaller leaves, and a gradual senescence of older leaves. Rest is induced by a photoperiod-temperature interaction requiring short days and cool temperatures to harden and mature plants. A chilling requirement of approximately six to ten weeks of field chilling below 7°C must be satisfied before rest is broken and vegetative vigor can be expressed (24).

Plants dug in the fall, prior to hardening and dormancy will not store well (10, 55). Little work has been done, however, to study the effect of late spring digging with subsequent cold storage. Spring digging is a common commercial practice in the Pacific Northwest despite the physiologic similarity of such plants to early-dug plants in the fall, when growth is occurring and carbohydrate reserves may be low (32). Mann (36) found that as dormancy is broken in the spring, starch breakdown occurs in the root parenchyma of strawberry. Lateral root initials then give rise to a prolific development of fine roots. Low carbohydrate levels would probably adversely affect this rooting process.

Non-dormant plants may be injured when suddenly exposed to long periods of cold, such as cold storage (20). Bringhurst has indicated that plants dug in California in November are adequate for short term storage (10).

Knowledge of strawberry plant respiration rate is necessary to determine the storage life potential, plant temperature response, and the required cooling capacity of the storage unit. Worthington (52) found respiration rates of 6.5 and 11.9 mg CO_2/kg fresh weight/hr for dormant plants stored at -2.2° and 0°C respectively. These low rates suggest a long storage-life potential for strawberry plants.

MATERIALS AND METHODS

1979 Greenhouse Studies

Strawberry runner plants of the cultivars 'Olympus' and 'Totem' were dug from the same fields on four dates: January 20, February 22, March 20, and April 19, 1979. These plants were trimmed, graded to commercial standards (at least twelve roots 3" long) and banded in groups of 25. These were placed in poly-lined cartons and stored at -2.2°C Fifty crowns from each treatment were evaluated for winter crown damage upon removal from storage. On July 6, 1979, 25 plants of each of eight treatments were set out in soil-filled flats in the greenhouse. Root growth, leaf number, the incidence of apical rot, and survival were evaluated on ten crowns for each treatment two weeks after planting and again on ten more crowns at ten weeks after planting.

Root growth was evaluated by counting the number of new lateral roots initiated on five average-sized primary roots. Crown damage, or winter injury, is a browning of the pith parenchyma caused by freeze injury. Severity was evaluated on the following 1 to 5 scale:

1. creamy white; no damage.
2. minor browning in lower part of pith.
3. moderate browning over approximately 2/3 of pith area, but vascular tissue still white and healthy.

4. severe browning over most of pith.

5. totally brown or dead.

Leaf number included all fully expanded leaves. Apical rot (+ or -) was determined by any evidence of decay in the crown apex. Survival was determined by any sign of viable green tissue in the crown.

Weather data reported in Figures 1 and 2 were from the NOAA-National Weather Service recording site at Olympia, Washington, about 10 km from the nursery.

1980 Greenhouse Studies

Strawberry runner plants were gathered as in 1979, except 'Totem' and 'Olympus' were dug on January 16, February 14, March 11, April 3, and April 23, 1980. Plants from all of the above treatments were stored at -2.2°C. Other treatments involved storage of 'Totem' at -3° and 0°C. Plants in 1980 were grown in a soil-less culture in the greenhouse by rolling crowns in newspaper. Fifty of these paper-wrapped plants of each treatment were set in plastic pots to facilitate observation of root initiation and growth. Pots were watered daily for seven days, then placed under a mist bench with heavy misting for the remainder of the experiment. Plants were fertilized with 20-20-20 fertilizer in solution added each week. Individual plantlets were treated as replications in the analysis of variance.

Root growth was evaluated on all fifty plants after seven days by counting new roots on the crowns and estimating new root length. Roots were evaluated again after misting for ten days. Crown damage, leaf number, apical rot, and survival were evaluated as in 1979 on all fifty plants of each treatment.

Carbohydrate Determinations

Plants of the same origin as the rooting experiments were used to determine carbohydrate levels. In 1979, three replications of two average size (10-15 g) plants each were selected on May 15, and approximately 5 cm of roots just below the crown were obtained. The crown was trimmed of all roots and petiole bases and sliced. These tissues were dried in a tunnel drier at 60°C for 48 hours, ground to pass 40 mesh screen, and 100 mg were extracted for sugar and starch determinations. Each sample was rolled in a 9 cm Whatmann #1 filter paper envelope, placed in 20 ml of 80% ethanol and boiled for three hours to extract soluble sugars. Sugars were determined using anthrone reagent (57) as a colorimetric test with glucose as a standard. Starch was determined by treating the residue of the sugar extraction with amyloglucosidase for three hours in a 50°C water bath (42). Glucose-equivalents of starch levels were measure, again using the anthrone test.

In 1980, the same procedure was followed except that five plants were used in each of five replications. Samples were obtained and dried about two weeks after each digging date rather than after storage as in 1979.

Respiration Rates

Respiration rates of 'Totem' and "Olympus' runner plants were determined for each of the 1979 digging dates. Within two weeks of obtaining the plants, approximately 700 g of plants were placed in each of two one-gallon jars and placed in -2.2°C cold storage. Air flow rate was regulated at 50 ml/min in an apparatus similar to that of Claypool and Keefer (11), and CO_2 was measured using a Beckman Model 865 infra-red gas analyzer. Respiration rate was determined and corrected for background CO_2 and temperature.

RESULTS AND DISCUSSION

1979 Greenhouse Studies

'Olympus' runner plants dug after January 31, 1979 exhibited decreasing root production as the nursery harvest season progressed. Root growth of February-, March-, and April-dug plants was 66%, 20%, and 10% respectively of root growth of January-dug plants when evaluated two weeks after planting (July 20). Recovery of 'Olympus' did occur after ten weeks in the greenhouse, but later-dug plants were still weaker, with root growth of April-dug plants only about 30% that of January-dug plants. 'Totem' root production was also dramatically affected by digging date. While roots of January-dug 'Totem' were very vigorous (50% higher than January-dug 'Olympus'), March- and April-dug plants showed almost no root growth after two weeks in the greenhouse. Again, recovery of surviving 'Totem' was good, but root vigor of April-dug plants remained only about 50% that of January-dug plants.

The incidence of apical rot increased dramatically with later-dug plants of both cultivars (Table 1). January-dug plants were free of this problem while April-dug plants showed up to 83% infected. 1979 survival levels in the greenhouse (Table 3) closely paralleled survival rates for late-planted strawberries in field trials (r=0.97). This relationship could prove useful if growers or nurserymen would desire a quick and inexpensive greenhouse test of plant quality prior to large-scale field planting. Further testing may be necessary, however, since greenhouse survival in 1980 was less closely related to field survival (r=0.67), perhaps because 1980 greenhouse treatments used a soil-less cultural system (see p. 50) compared to the 1979 soil-potted method.

'Olympus' dug in 1979 showed excellent survival (>95%) for each digging date except March, which had 85% survival. 'Totem' showed good survival (96-97%) of January- and February-dug plants, but exhibited a steep decline in survival of March- (80%) and April- (59%) dug plants. The severity of winter injury as assessed by browning of crown tissues did not differ significantly among digging dates for either cultivar in 1979 (Table 1).

The numbers of new roots and leaves, incidence of apical rots, and percent survival all indicated a general weakening of both strawberry cultivars as they are dug later in the nursery harvesting season. Weakness was particularly apparent in April-dug 'Totem' with only 59% greenhouse survival and very poor initial root and shoot growth. However, good vegetative recovery of surviving plants did occur by the September 14 evaluation date. Eighty-five percent survival of March-dug 'Olympus' compared to at least 95% survival for other digging dates suggested that March-dug plants were weakest. The somewhat better vigor levels and recovery shown by March-dug plants compared to April-dug plants may reflect the elimination of weak March-dug plants which did not survive at all.

The transition between February- and March-dug plants reflects weather and consequent plant activity prior to each of these digging dates. Figure 1 shows temperatures near the nursery sites during the 1978-79 winter and spring. Prior to the February digging date, plant activity was low as daily high temperatures remained generally between 5° and 10°C. By the March digging date, however, several days in the 15° to 20°C range had caused rapid expansion of new leaves, especially in 'Olympus'. By the April digging date, several weeks of warm temperatures had occurred with continued growth resulting in the appearance of flower buds. These stages of growth and development seem related to carbohydrate levels as discussed on page and in Figures 3 - 6.

The incidence of apical rot may also be related to weather preceding harvest and to the developmental stage of the plants. Although this problem was not thoroughly analyzed, it seemed that decay resulted from a secondary invasion of injured tissue by saprophytic bacteria and fungi. Primary injury was apparently due to physiologic damage or freeze injury as the result of subjecting actively growing, de-hardened plants to cold-storage temperatures. The incidence and severity of decay became serious only as dormancy ended and active shoot growth began (Tables 1 and 2, Figures 1 and 2).

The failure to find differences in severity of winter injury was attributed to extreme cold (-22°C) in early January, 1979, prior to any digging date (Figure 1). This type of injury is apparently permanent. The influence of winter injury on these plants was not great, however, since January-dug plants showed consistently high survival and root initiation despite exposure to these temperatures.

<u>1980 Greenhouse Studies</u>

Results of 1980 greenhouse experiments (Table 2) showed patterns similar to those of 1979 for root and shoot growth, percent survival, and incidence of apical rots. The rooting index used in 1980 showed a marked difference between cultivars on early digging dates; 'Totem' was approximately two and one-half times more vigorous than 'Olympus', for January- and February-dug plants when evaluated June 7. This rooting difference between the cultivars declined somewhat, but was still almost twice as great for the January-dug 'Totem' as for 'Olympus' on the June 17 evaluation date. March- and April-dug plants of both cultivars showed the same marked decline in rooting ability as seen in 1979, with rooting remaining very poor on April 23-dug plants even after ten days of heavy misting (June 17 evaluation date). New leaf production parallelled the rooting pattern with almost 35% fewer leaves produced on later-dug plants of both cultivars.

Apical rot incidence was similar to 1979, with severe infection in late-April-dug plants (92%), but little incidence in January- and February-dug plants (2-20%).

Trends of greenhouse survival relative to digging date were also similar to 1979 results (Table 2), but actual levels were up to 35% lower in 1980 (March-dug 'Olympus'). Generally poorer greenhouse survival in 1980 may be partially attributable to the soil-less culture used, which possibly placed plants under greater stress in the greenhouse. Comparison with field trials (Table 3) further suggests this system may have created a higher stress environment since survival was up to 40% higher in the field. Nonetheless, lower survival of March-dug 'Olympus' and late-dug 'Totem' compared to other digging dates reflected the relative weakness of plants from these treatments.

Crown evaluations showed January 1980-dug plants to be virtually free of winter injury (Table 2). All plants dug after February 1 showed evidence of winter injury. Temperatures of -18°C on January 26 (Figure 2) occurred after the January digging date, but caused moderate injury to plants remaining in the field. This freeze injury may be partially responsible for lower rooting indices in plants dug after the freeze, such as February-dug 'Totem'. However, the winter injury effect was not supported by the February-dug 'Olympus' response which is not different from that of January-dug plants. 'Olympus' may have acclimated to tolerate -18°C better than 'Totem'. Freezing stress tests, had they been performed on these two cultivars at that time, might have provided some useful insights as to the causes of the different responses.

Storage temperatures ranging from 0° to -3°C did not have a significant effect on the subsequent quality of 'Totem' runner plants dug in March and April (Table 4). These data do suggest that -3°C storage is more severe than -2°C since most measures of plant response to -3°C storage are poorer than comparable measures for -2°C storage. The injury of -3°C -stored plants is particularly apparent when comparing percent survival and percent apical rot for the low temperatures. Despite the unfortunate loss of some data (values in parentheses are estimates), it was concluded that 0°C storage did not maintain plants in a significantly better condition than -2° or -3°C storage. Zero degree storage did result in a lower incidence of apical rot, but did not result in any other apparent benefit. The failure of 0°C to prevent storage losses of late-dug 'Totem' is particularly emphasized by the 48% survival for April 23-dug, 0°C-stored plants.

Carbohydrate Analysis

Carbohydrate levels of plants dug at various dates in 1979, then sampled after several months of storage, showed a trend which suggests a relationship between carbohydrate status and rootability of plants (Figures 3 and 4). In 'Totem', carbohydrate (free sugars and starch) concentration tended to be fairly stable across digging dates, except for a general decline in soluble sugars of roots (Figure 4b), which declined about 60% from January (275 mg/g) to April (115 mg/g). Carbohydrate concentration in 'Olympus' fluctuated more than in 'Totem', but according to these data, was at a minimum on the March digging date, followed by a recovery for both free sugars and starch on the April digging date (Figures 3a,b and 4a,b).

Results of 1980 experiments where samples were taken soon after digging, showed a pattern more distinct, but similar to 1979 data. 'Totem' again showed nearly 60% decline in free sugars of roots from January (360 mg/g) to late April (150 mg/g) (Figure 5). This decline was accompanied by trends toward minimum starch levels in roots and crowns in March and again on April 23 (Figures 4 and 5). Starch concentrations in 'Olympus' followed patterns similar to 1979, with minimum levels in March (38 mg/g, 65% lower than January) followed by an increase in early April, then another decline. Sugar levels rose unexpectedly in March in 'Olympus', then declined again.

Although these data may not be conclusive, it seems that carbohydrate levels, particularly free sugars in the roots, were related to the rootability and viability of strawberry plants in this study. Survival, vigor, and rootability of 'Totem' showed a definite decreasing pattern as digging date progressed in both years. This decline was generally parallel to a declining carbohydrate status in 'Totem', especially in root soluble sugars. The minimum carbohydrate levels seen in 'Olympus' in March parallelled poorer survival rates seen for that digging date in both years. In 1980, the rise in starch levels on April 3-dug 'Olympus' followed by the decline for April 23-dug plants was parallelled by field survival of 'Olympus' dug on those dates and planted in early June (Table 3).

The less pronounced trends of carbohydrate changes in 1979 compared to 1980 could reflect the time that sample preparation was performed each year. In 1979, all samples for carbohydrate analyses were obtained on May 15 following cold storage. In contrast, 1980 samples were taken within two weeks after each digging date. Carbohydrate compositional changes often occur in plant material stored near freezing temperatures. Such changes could have led to the 50% less starch observed in 1979 than in 1980. Sugars were only about 20 to 30% less in the 1979-dug plants when analyzed than sugars in the 1980-dug plants just after digging.

The pattern of decreasing carbohydrate as digging date progresses into the spring is consistent with trends shown by Long (32), where carbohydrate, especially starch and hemicellulose decreased as growth progressed in spring. Bringhurst, et al. (10) found that when less than 50% of the root cortex of strawberry plants was filled with starch, long-term storage (over one month) resulted in poor field survival and vigor. Visual evaluations of starch content were not made in the current study, but declining starch levels during the 1980 digging season (Figure 5b) suggest that late-dug plants may have been in a similar poor condition for storage. Poor rootability of late-dug plants is probably due to reduced amounts of carbohydrate. Schrader (45) and Starring (46) both suggested low carbohydrate reserves to be a major limiting factor in the rootability of cuttings. If strawberry plants are dug after new root and shoot growth has begun in the field, reserves are especially depleted when this new growth is removed in trimming and handling.

Respiration Rates

Figure 7 shows the results of a preliminary, unreplicated experiment which demonstrates the effect of storage temperature on respiration rate of March 1979-dug 'Olympus' plants. The higher respiration rate at -3°C than -2°C may be the result of increased stress at -3°C, since March-dug plants were growing when dug; or of incomplete acclimation of plants to the storage temperature when readings were obtained. A more carefully designed statistical test of respiration rate differences would be worth trying. The difference in respiration rates between -2° and 0°C storage gives a calculated Q_{10}

value of 3.2 for this temperature range. This increase in respiration with temperature may be direct or it may be attributed to plants being frozen at -2°C but unfrozen at 0°C.

Respiration rates tended to decrease over long-term storage at -2°C (Figure 8). Both 'Olympus' and 'Totem' acted similarly in response to digging date and storage duration. Plants respired at approximately 7-9 mg CO_2/kg fresh weight/hr during the initial weeks after each digging date. This rate declined and tended to stabilize at 4-5 mg CO_2/kg fresh weight/hr after a month or more of storage. Depression of respiration rates during storage might be attributable to decreased availability of compartmentalized free sugar substrates for metabolic activity.

The absence of differences between 'Olympus' and 'Totem' respiration rates rejects our earlier hypothesis that sensitivity of 'Totem' to storage was the result of a detrimentally high respiration rate in storage.

Table 1. Strawberry nursery plant viability and quality relative to digging date--1979 greenhouse trials.

Cultivar	Digging Date	New Roots[w] July 20	New Roots[w] Sept 14	New Leaves/Crown July 20	New Leaves/Crown Sept 14	Browning[v] Severity	% Survival	% Apical Rot
Olympus	Jan 20	21a[z]	34a	2.5a	7.1a	2.6a	100[y]	0**[x]
	Feb 22	14b	14b	2.5a	5.0ab	2.4a	97	11
	Mar 20	4c	19b	2.3a	6.3ab	2.4a	85	45***
	Apr 19	2c	12b	1.0b	4.2b	2.3a	95	65***
	E.M.S.	55.886	201.572	1.364	8.628	0.707		
Totem	Jan 20	34a	42a	1.2a	3.9a	2.1a	96	0**
	Feb 22	18b	30ab	1.6a	3.5a	2.0a	97	5
	Mar 20	1c	19b	0.8b	3.4a	2.5a	80*	65***
	Apr 19	1c	22b	0.6b	3.2a	2.4a	59***	83***
	E.M.S.	107.347	350.942	0.536	1.169	1.295		

[v]Browning severity is a 1 to 5 visual rating of winter injury of crowns.
[w]Number of new roots initiated on five average primary roots.
[x]Chi-square using 15% infected as the expected value; $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
[y]Chi-square using 90% survival as the expected value; $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.
[z]Means are compared among digging dates for each cultivar. Means followed by the same letter are not different at the 0.05 level of significance using Duncan's Multiple Range Test.

Table 2. Strawberry nursery plant viability and quality relative to digging date--1980 greenhouse trials.

Cultivar	Digging Date	Rooting Index[w] June 7	Rooting Index[w] June 17	Browning[v] Severity	New Leaves Per Crown	% Survival	% Apical Rot
Olympus	Jan 16	94a[z]	395a	1.2c	2.9a	92[y]	6[x]
	Feb 14	68a	369a	2.6b	2.6a	84	20
	Mar 11	7b	120b	3.2a	1.9b	54***	50***
	Apr 3	12b	139b	2.4b	2.0b	76**	70***
	Apr 23	2b	86b	2.3b	2.0b	84	82***
	E.M.S.	3978	47,856	0.7050	1.319		
Totem	Jan 16	245a	743a	1.2c	2.1ab	86	10
	Feb 14	187b	546b	2.2b	2.3a	100*	2*
	Mar 11	44c	233c	2.9a	1.9bc	78**	18
	Apr 3	9c	184c	2.7ab	1.7c	76**	42***
	Apr 23	2c	69d	2.9a	1.8c	54***	92***
	E.M.S.	13,634	73,671	0.8638	0.7931		

[v]Browning severity is a 1 to 5 visual rating of winter injury of crowns.
[w]Rooting index is the product of the number of new roots x approximate average length (cm).
[x]Chi-square using 15% infected as the expected value; $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.
[y]Chi-square using 90% survival as the expected value; $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$.
[z]Means are compared among digging dates for each cultivar. Means followed by the same letter are not different at the 0.05 level of significance using Duncan's Multiple Range Test.

Table 3. Field and greenhouse survival of strawberry nursery stock relative to digging date.

Year	Cultivar	Digging Date	% Survival Greenhouse	% Survival Field
1979	Olympus	Jan 20	100[y]	98a[z]
		Feb 22	97	100a
		Mar 20	85	88b
		Apr 19	95	97a
			E.M.S.	11.271
1980	Olympus	Dec 12	--	91ab
		Jan 16	92	97a
		Feb 14	84	99a
		Mar 11	54***	88b
		Apr 3	76**	93ab
		Apr 23	84	90ab
			E.M.S.	12.167
1979	Totem	Jan 20	96	98a
		Feb 22	97	93a
		Mar 20	80	80b
		Apr 19	59***	70b
			E.M.S.	52.208
1980	Totem	Dec 12	--	95ab
		Jan 16	86	99a
		Feb 14	100*	93ab
		Mar 11	78**	90b
		Apr 3	76**	76c
		Apr 23	54***	44d
			E.M.S.	14.656

[y]Chi-square using 90% survival as the expected value; *$p < 0.05$, **$p < 0.01$, ***p 0.001.

[z]Means are compared among digging dates for each variety and year. Means followed by the same letter are not different at the 0.05 level of significance using Duncan's Multiple Range Test.

Table 4. Strawberry (cv. 'Totem') nursery plant viability and quality relative to digging date and storage temperature--1980 greenhouse trials.

Digging Date	Storage Temperature	Rooting Index[x] June 7	Rooting Index[x] June 17	New Leaves Per Plant	Browning[y] Severity	% Survival	% Apical Rot
Mar 11	-3°	39a[z]	149ab	2.1a	2.9a	72[w]	42**[w]
	-2°	45a	233a	1.9a	2.9a	84	18
	0°	49a	220a	2.1a	2.7a	82	14*
Apr 23	-3°	3b	33c	1.1b	2.6a	34	96
	-2°	2b	69bc	1.8a	2.9a	54	92
	0°	(3)b[v]	(95)bc	(1.9)a	2.5a	48	78*
	E.M.S.	1022	30,786	0.999	0.952		

[v]Values in parentheses are estimates. Letters were assigned to these values using a variance approximately the same as that for other treatments in this study.

[w]The mean for the three storage temperatures for each digging date was used as the expected value in the Chi-square analysis; $^{*}p<0.05$, $^{**}p<0.01$.

[x]Rooting index is the product of the number of new roots x average length (cm).

[y]Browning severity is a 1 to 5 visual rating of winter injury of crowns.

[z]Means are separated within columns. Means followed by the same letter are not different at the 0.05 level of significance using Duncan's Multiple Range Test.

Figure 1. Maximum and minimum recorded temperatures during 1979 strawberry nursery stock digging and planting season. (Source: National Oceanic and Atmospheric Administration, National Weather Service, Recording Station; Olympia, Washington.)

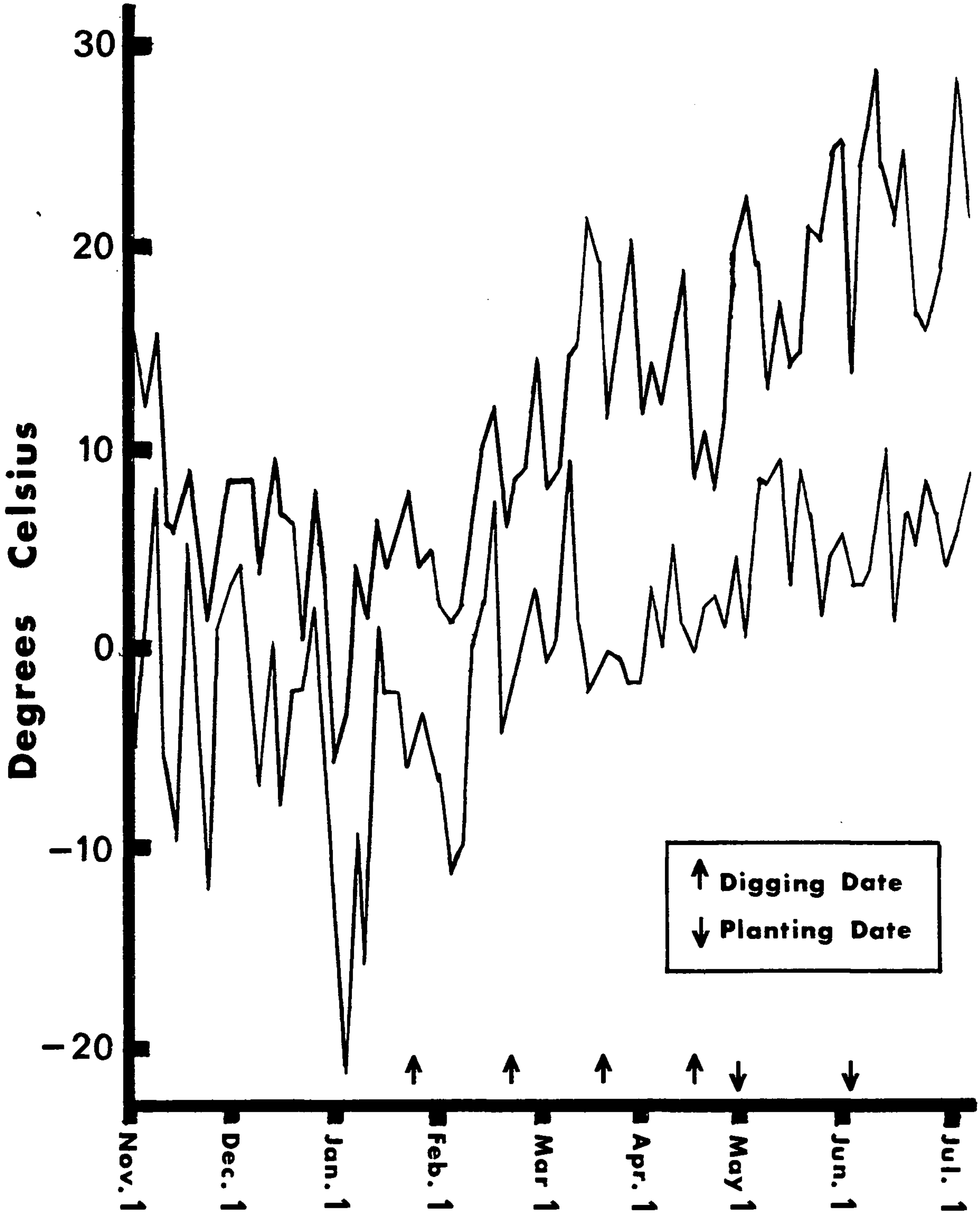

30
20
10
0
−10
−20
Degrees Celsius
Digging Date
Planting Date
Nov. 1
Dec. 1
Jan. 1
Feb. 1
Mar 1
Apr. 1
May 1
Jun. 1
Jul. 1

Fig. 1

Figure 2. Maximum and minimum recorded temperatures during 1980 strawberry nursery stock digging and planting season. (Source: National Oceanic and Atmospheric Administration, National Weather Service, Recording Station; Olympia, Washington.)

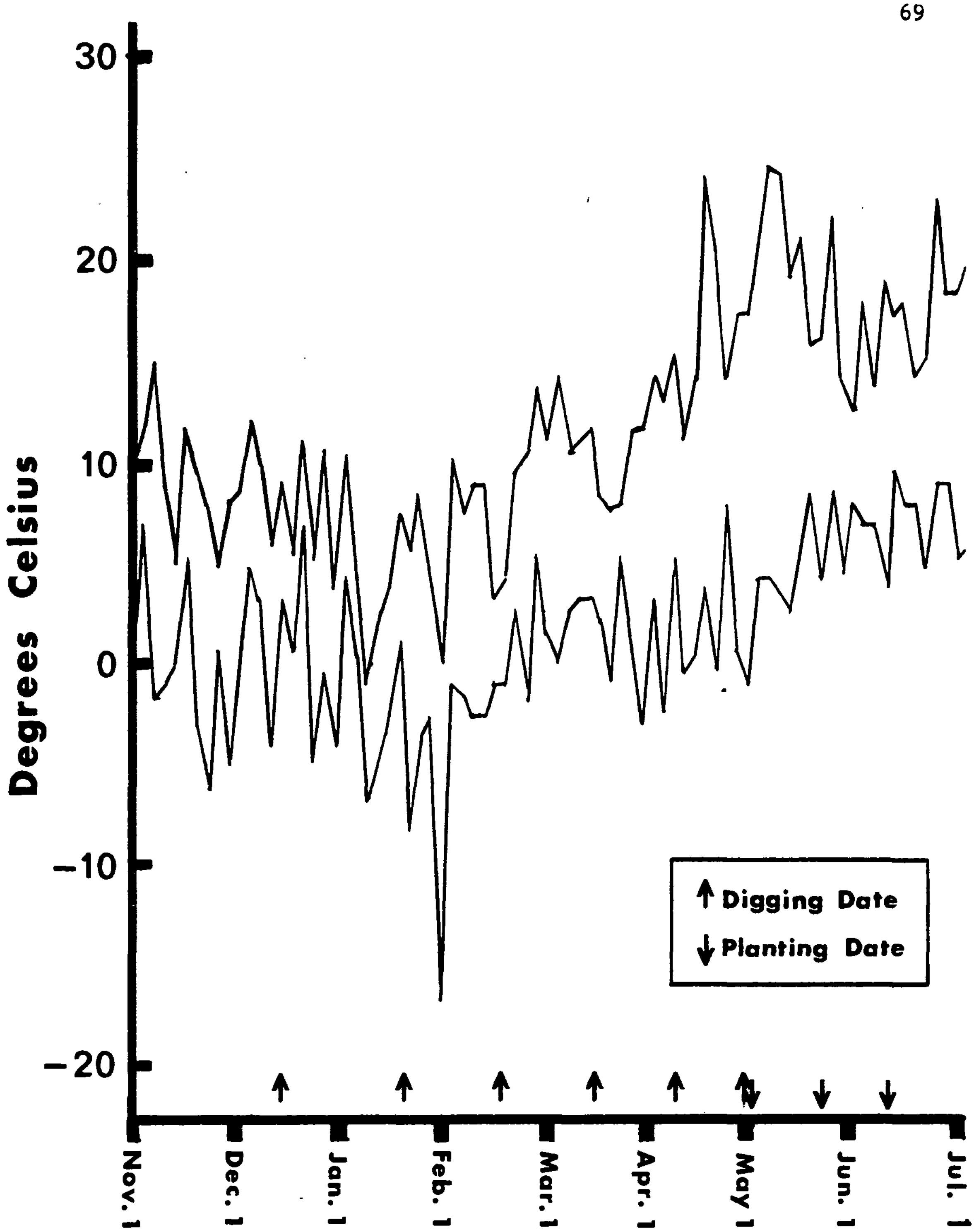

30
20
10
0
−10
−20
Degrees Celsius
Digging Date
Planting Date
Nov. 1
Dec. 1
Jan. 1
Feb. 1
Mar. 1
Apr. 1
May 1
Jun. 1
Jul. 1

Fig. 2

Figure 3a. Starch concentration (mg/g dry weight) of strawberry crowns relative to digging date (1979 study).

Figure 3b. Starch concentration (mg/g dry weight) of strawberry roots relative to digging date (1979 study).

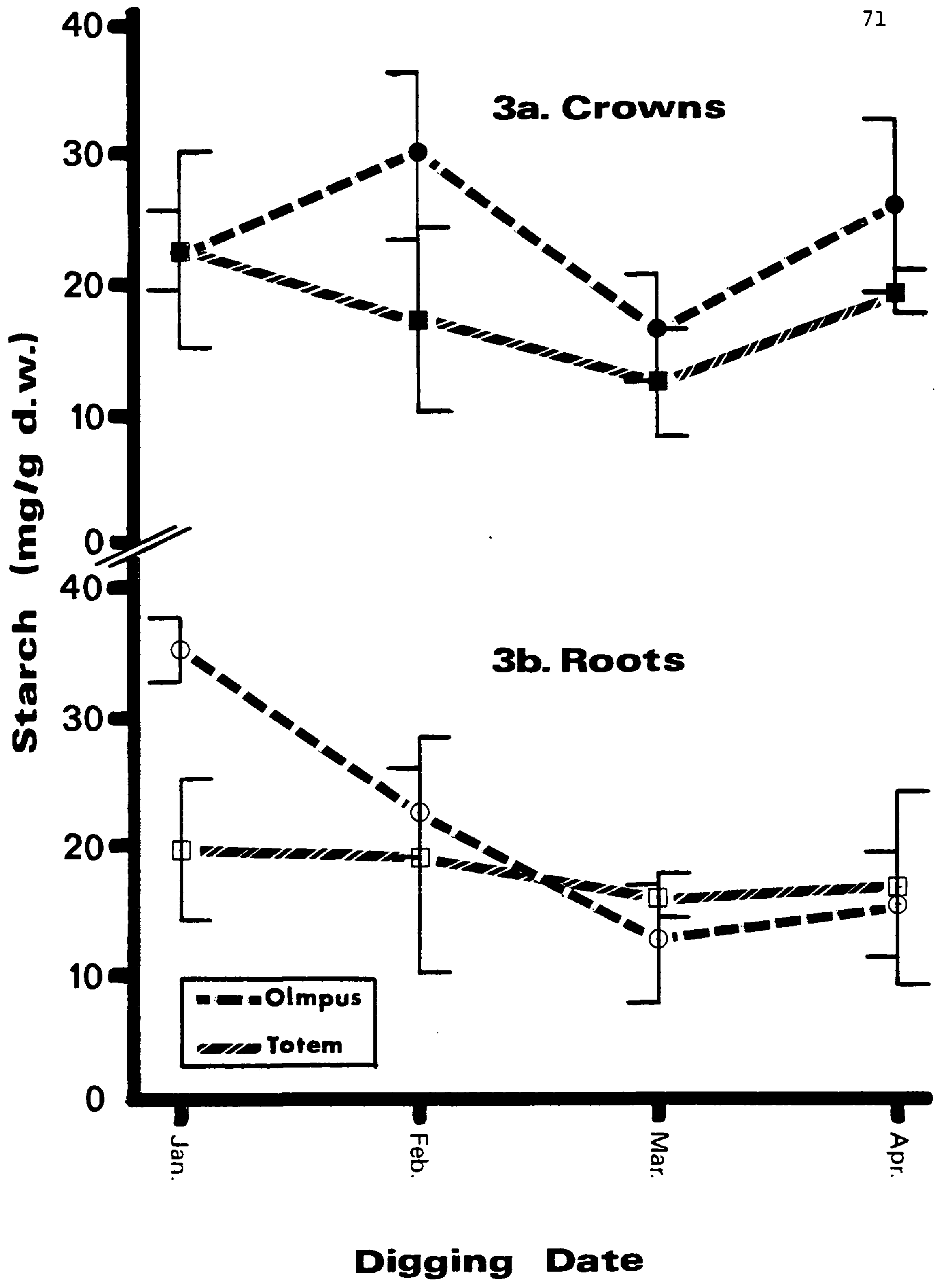

40
30
20
10
0
40
30
20
10
0
3a. Crowns
3b. Roots
Starch (mg/g d.w.)
Olmpus
Totem
Jan.
Feb.
Mar.
Apr.
Digging Date

Fig. 3

Figure 4a. Free sugar concentration (mg/g dry weight) of strawberry crowns relative to digging date (1979 study).

Figure 4b. Free sugar concentration (mg/g dry weight) of strawberry roots relative to digging date (1979 study).

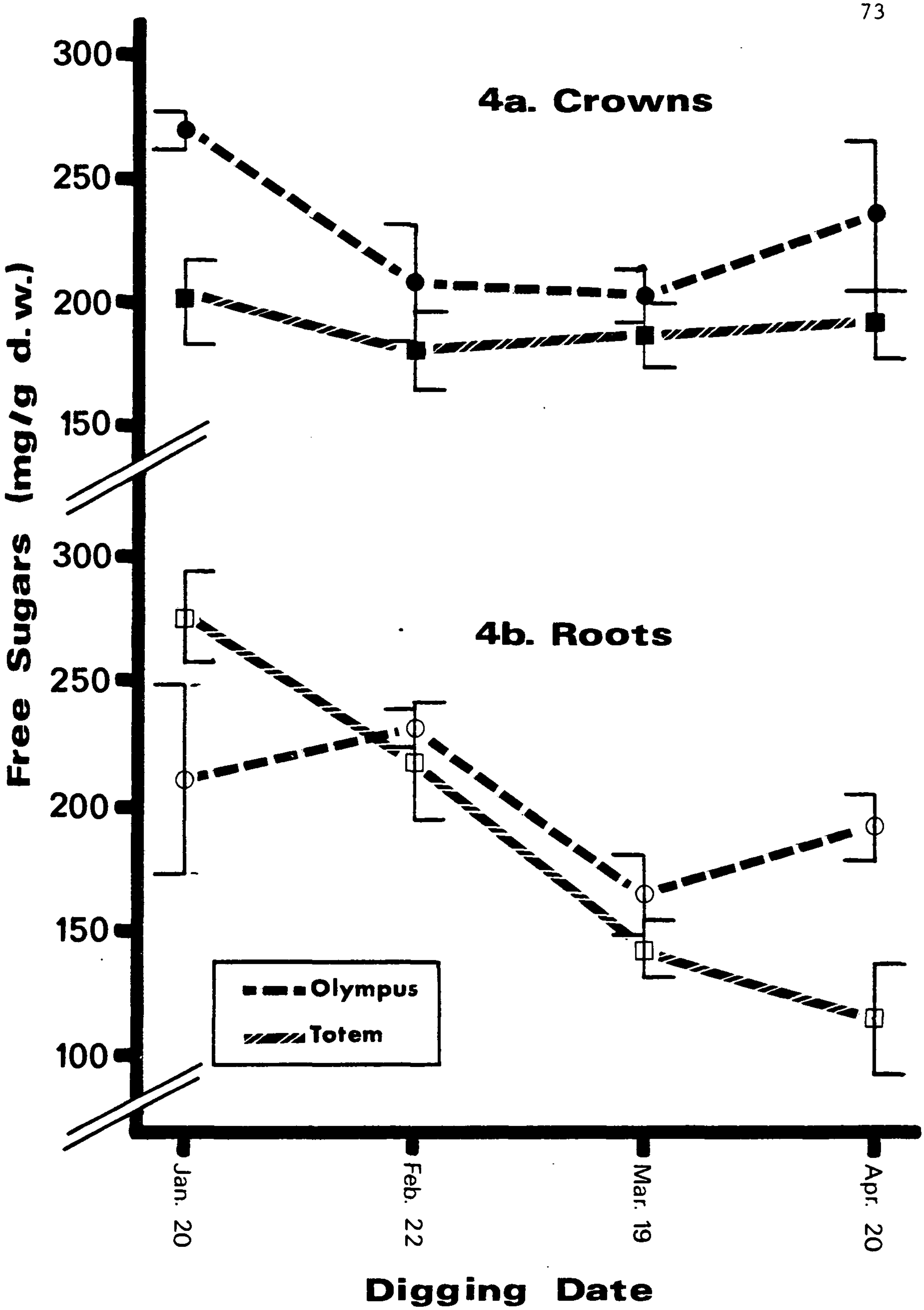

4a. Crowns
4b. Roots
Free Sugars (mg/g d.w.)
300
250
200
150
300
250
200
150
100
Olympus
Totem
Jan. 20
Feb. 22
Mar. 19
Apr. 20
Digging Date

Fig. 4

Figure 5a. Starch concentration (mg/g dry weight) of strawberry crowns relative to digging date (1980 study).

Figure 5b. Starch concentration (mg/g dry weight) of strawberry roots relative to digging date (1980 study).

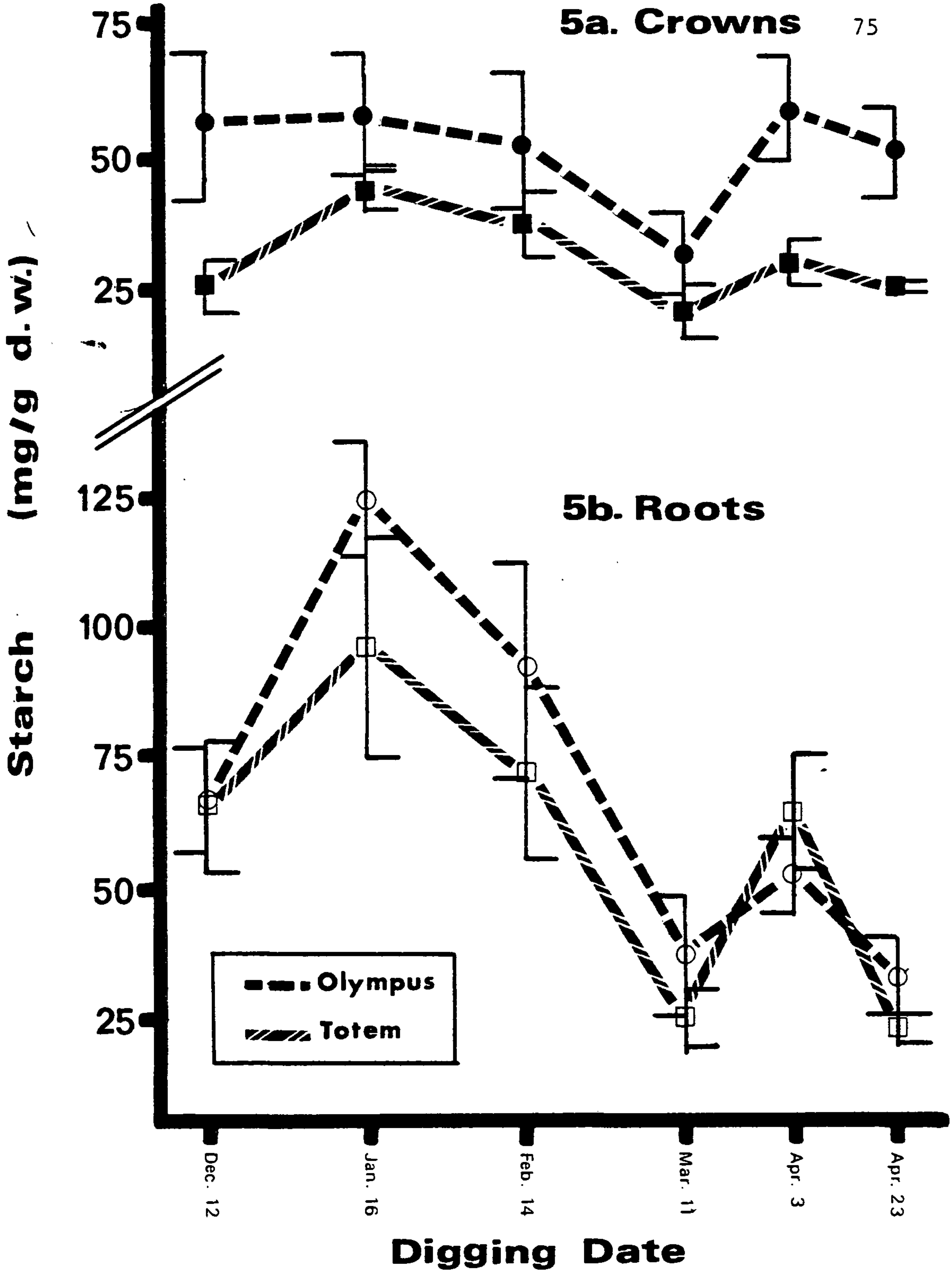
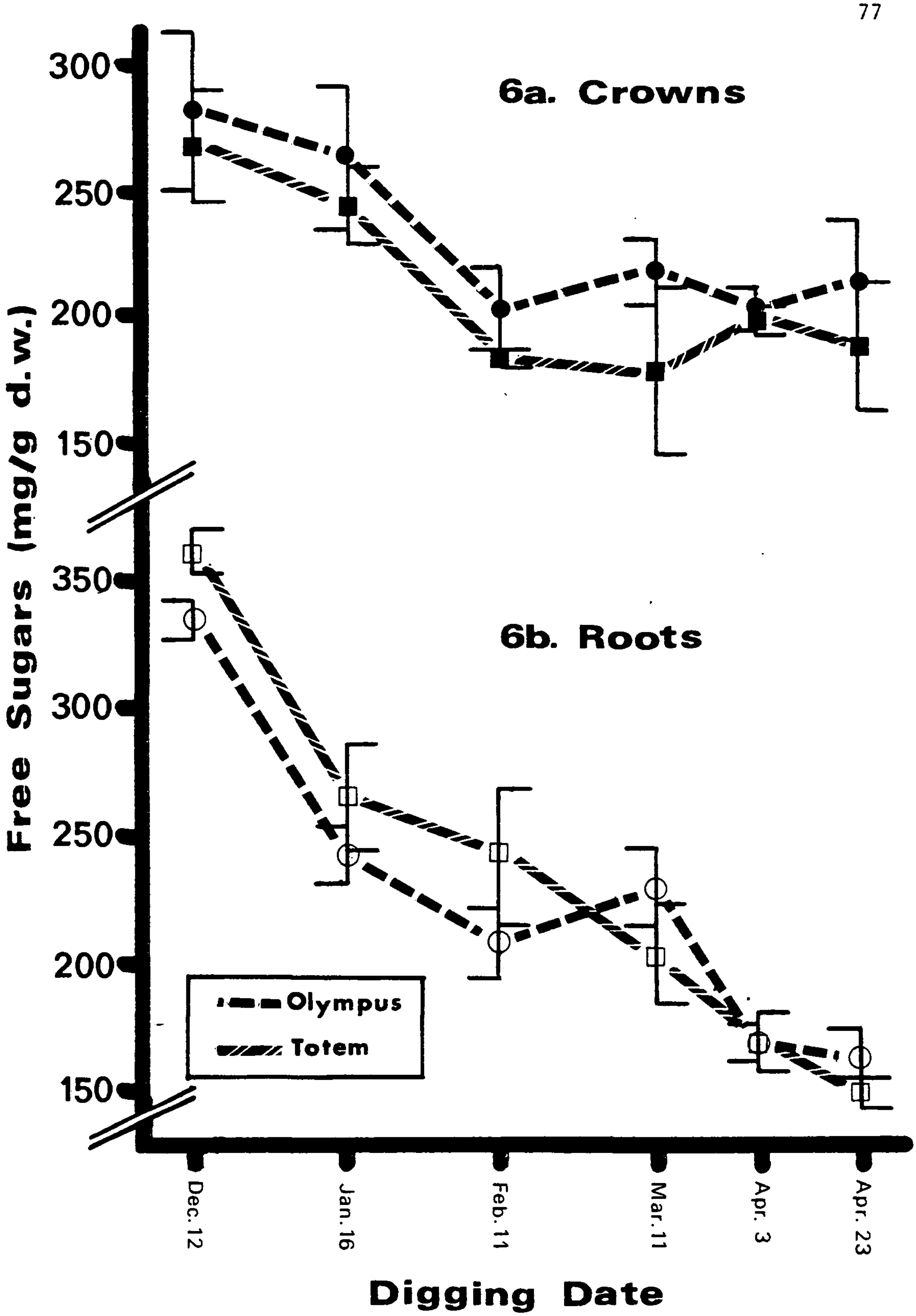

5a. Crowns
5b. Roots
Starch (mg/g d.w.)
75
50
25
125
100
75
50
25
Olympus
Totem
Dec. 12
Jan. 16
Feb. 14
Mar. 11
Apr. 3
Apr. 23
Digging Date

Fig. 5

Figure 6a. Free sugar concentration (mg/g dry weight) of strawberry crowns relative to digging date (1980 study).

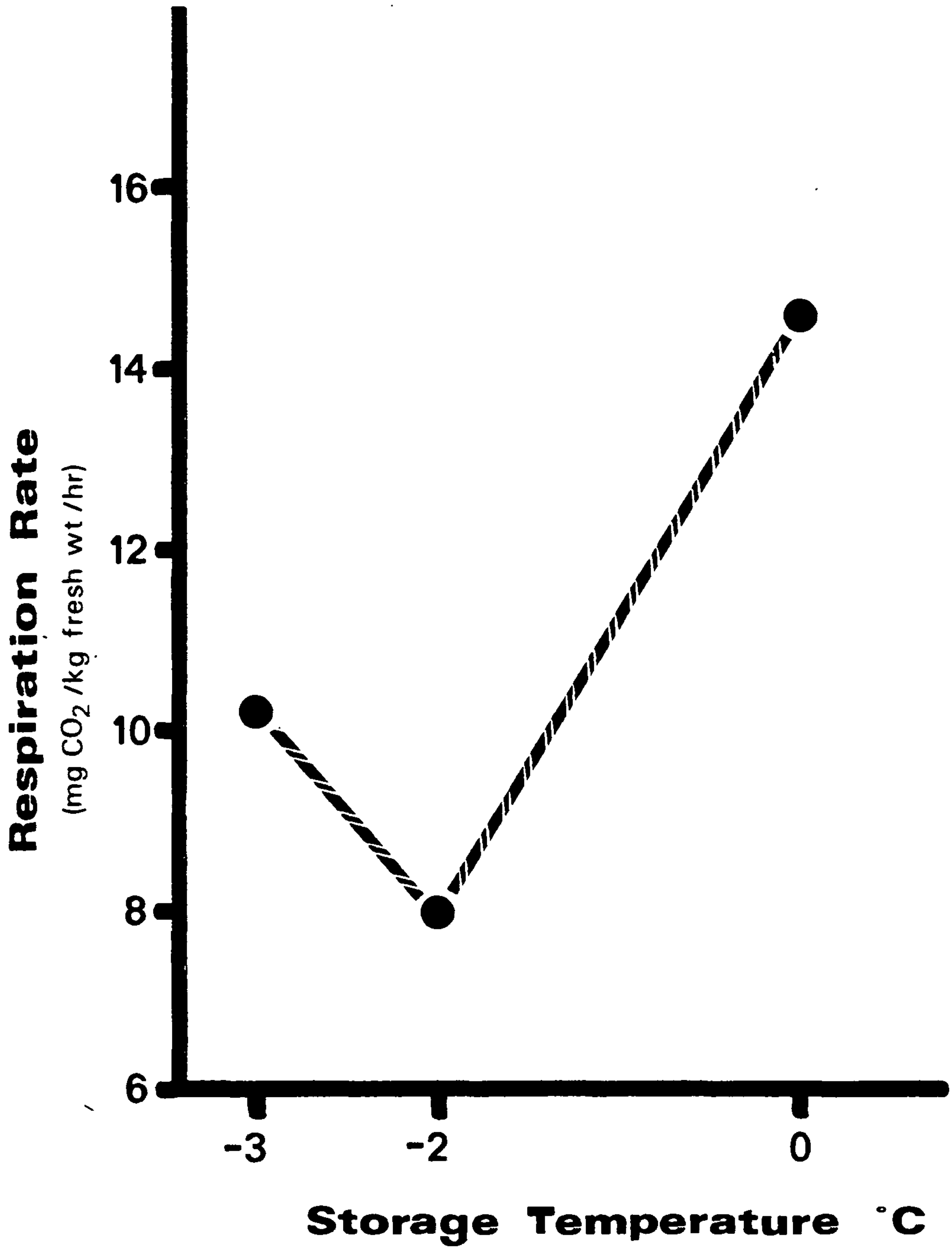
Figure 6b. Free sugar concentration (mg/g dry weight) of strawberry roots relative to digging date (1980 study).



6a. Crowns
6b. Roots
Free Sugars (mg/g d.w.)
300
250
200
150
350
300
250
200
150
Olympus
Totem
Dec. 12
Jan. 16
Feb. 11
Mar. 11
Apr. 3
Apr. 23
Digging Date

Fig. 6

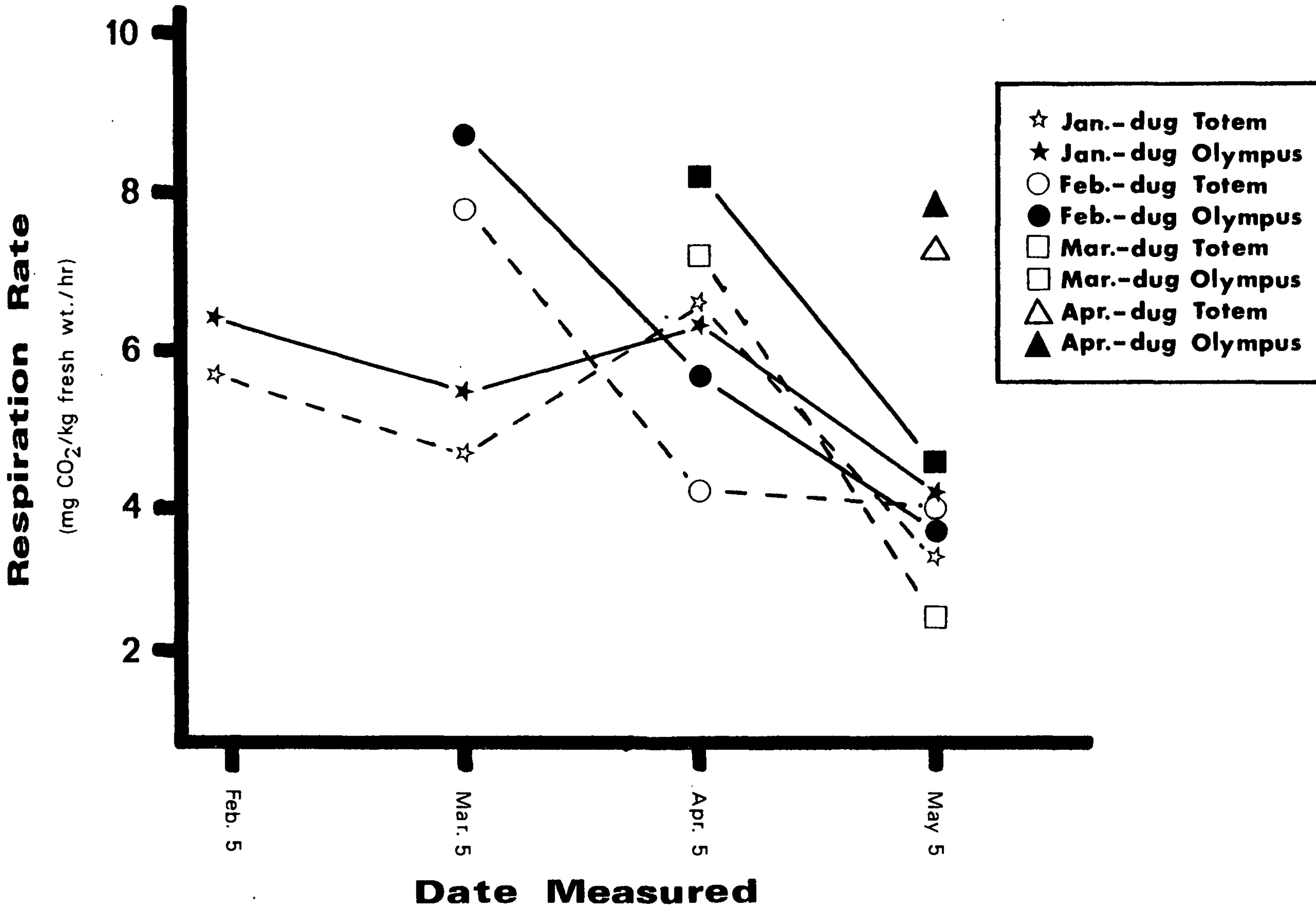
Figure 7. Respiration rate of 'Olympus' strawberry runner plants relative to storage temperature.



16
14
12
10
8
6
Respiration Rate
(mg CO_2 /kg fresh wt /hr)
-3
-2
0
Storage Temperature °C

Fig. 7

Figure 8. Respiration rate of strawberry nursery stock relative to digging date and storage duration.



Respiration Rate
(mg CO_2/kg fresh wt./hr)
10
8
6
4
2
Feb. 5
Mar. 5
Apr. 5
May 5
Date Measured
Jan.-dug Totem
Jan.-dug Olympus
Feb.-dug Totem
Feb.-dug Olympus
Mar.-dug Totem
Mar.-dug Olympus
Apr.-dug Totem
Apr.-dug Olympus

Fig. 8

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