EVALUATION OF PREPLANT STORAGE TREATMENTS AND SUBSEQUENT GROWTH RESPONSES OF STRAWBERRY PLANTS AFTER TRANSPLANTING

by

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DEDICATION

To the memory of
my dearly beloved brother

IBISO HENRY HIGGWE

23 January, 1962 to 8 April, 1984

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INTRODUCTION

When dormant strawberry plants are received from nurseries, weather conditions may not permit immediate planting. Under these circumstances, plants must be subjected to favorable conditions to retain their viability. This may be achieved by heeling-in, but keeping plants in cold storage is more likely to keep them dormant. Cold storage of planting stock may be readily available for larger operations but not for growers holding plants for a few acres or a limited area.

It is therefore important to hold plants at an appropriate storage temperature, for the length of the required holding period. It has been recommended to keep plants at 4.4° to 5.5° C for a few days or at 0° to 2.2° C for a longer period after they arrive if not fully dormant. But to remain fully dormant they must be stored at -1.1° to 0° C (13). Under improper storage conditions of plants grey mold, Botrytis cineria, Persex Fr., is capable of infecting and killing strawberry buds (14, 20, 30, 32, 33, 34, 35, 37, 48, 49). Also, the fungus Rhizoctonia solani can infect planting stock, particularly when present in an old petiole base or in the soil, and cause crown and petiole infection or root rot (14, 20, 29, 30, 32, 35, 48, 49).

In view of the problems that occur in storage, the present study was conducted to determine the most appropriate storage and handling conditions prior to transplanting for subsequent plant survival and vigor in the field. The objectives were to compare each of three storage temperatures (1.2°, 7.2° and 12.7° C) for three different time regimes (8, 15 and 21 days) for Spring 1983; and to compare two storage temperatures (1.2° and 10° C) for 10 days for Spring 1985 experiments. Also, the

effectiveness of preplant fungicide dips, benomyl alone for 1983 and benomyl versus fosetyl-Al for 1985 experiments were evaluated.

Considerable work has been accomplished by other researchers to determine the proper conditions for plant storage, however environmental conditions and cultivars show variable results.

LITERATURE REVIEW

The strawberry of commerce, Fragaria x ananassa Duchesne is an herbaceous, perennial of the Rosaceae family (12, 15, 32). In its present cultivated form, the garden strawberry never existed as a wild plant (12). Its progenitor was the "pineapple" or "ananas" ("pine" for short), which originated around 1750 most likely in Holland (15). It is a hybrid seedling of Fragaria chiloensis which had been transported from Chile to Europe in 1714, and the pollen parent was F. virginiana Duch. from North America (12, 15).

Strawberries are propagated commercially by runners (11, 32). Plants raised from seeds are undesirable because strawberry seedlings are too variable. For this reason, old strawberry beds may have many untrue-to-name seedlings undesirable for propagation (11). A recent major advancement in propagation of strawberries is the Meristem Propagation (tissue culture) technique (9, 11). Under favorable conditions one strawberry meristem can be multiplied to yield more than ten million plants in a 12-month period (11).

Nursery Stock Handling

Proper handling of strawberry plants prior to planting and during the planting operation is essential for satisfactory plant growth and a high percent of plant survival (46). Dormant plants are generally considered most suitable for spring planting (24, 46) especially if transplanting is delayed. Survival and vigorous growth of plants depend upon proper plant condition (dormancy, hardiness, freedom from winter

injury), use of film liners to prevent desication and precise storage (50).

Plants for planting in Kansas and similar latitudes should be obtained in late winter for spring planting. At this stage they are dormant and will not be planted until environmental conditions are favorable, therefore storage must be provided (46). In more northern latitudes plants are usually dug during late winter and early spring (29, 39). Plants dug in early winter and held in storage, if properly stored, are as good as freshly dug plants (24) as sometimes used in Florida and California. In some cases, stored plants are superior to freshly dug plants (19, 24, 47). However, if runner plants could be dug in late fall and stored, winter injury would be avoided (19). Unpredictable weather conditions during a digging season and differences in weather among years prevent setting specific digging dates. This uncertainty can cause nurserymen labor-management problems, increase the possibility of winter injury, and affect the volume of plants put into storage (50).

Plant Maturity Considerations

When early-harvested, immature plants are used for planting, stands are often spotty and even high survival plantings lack starting vigor, which usually result in low production throughout the life of the planting (6). Mature nursery plants might be described as those which will give uniform stands and satisfactory field performance when transplanted immediately after digging or after a period of storage (6). Bringhurst, et. al. (6), have reported using a starch test to determine strawberry plant maturity, but indicated that the method had not been standardized for practical use. Furthermore, even if a simple method

could determine when plants first become dormant in the field, there might not be sufficient time to dig a large volume of nursery plants before fields are frozen, snow covered, or too wet for digging. Plants so left in the field, particularly if unmulched, are subject to winter injury from low temperatures and alternating freezing and thawing (50). Mader and Feldman (31), suggested that strawberry plants subjected to such alternating freezing and thawing, undergo physiological weakening leading to ultimate death. Hence, fall digging and cold storage of strawberry plants with precise temperature controls have been suggested to avoid these problems and maintained plant quality (50).

Cold Storage Temperatures and Periods

In establishing a new field, the value of early planting of strawberry runner plants to gain a heavy first-year crop has long been known (47). But the advantage that can be taken of this is restricted by the limited availability of plants early in the season. However, by cold storage the dormancy of lifted strawberry runner plants can be prolonged for at least 10 months and stored plants have been used in the United States for out-of-season plantings (47). Furthermore, the possibilities of hardening plants by storage temperatures have been reported. Angelo et. al. (5), reported that five days at 0° C hardened actively growing runner plants so that they withstood -10° to -5° C.

Cold storage of strawberry runner plants was developed in the United States of America, to overcome planting difficulties associated with severe winter temperatures (26). Considerable work has been accomplished to determine the proper conditions for plant storage but some of these are highly variable. This is because climate and weather

conditions differ among locations, hence each area has to adopt plant holding conditions best suited for that area.

There has been variation in results regarding the proper storage temperature by various researchers. Guttridge et. al. (22), reported that plants stored at -2.2, -1.1, 0° C all survived but after storage, the best growth was obtained from plants stored at -1.1° C. Hoffman (25), satisfactorily stored runners at -0.6° C for six weeks. Voth (44), reported that runner plants could be stored for six months at -2.2° to -1.1° but at temperatures above 0° C molds developed. Also, Bryant, Caretens and Crandall (7), found that a temperature of -1.1° to 0° C was satisfactory, but eight weeks storage at 0.6° to 1.7° C led to deterioration. Nelson and Hunter (38), suggested that temperatures between -1.1° to 0° C should be used saying that there seemed to be cold injury accompanied by decreased survival at -2.2° C and that growth will commence above 0° C. According to another report the freezing point of crowns may vary somewhat with cultivars, but averages about -1.4° C and that of roots -1.8° C (41).

Investigations on the use of polyethylene liners or bags have indicated that plants placed in storage in polyethylene are quickly cooled to about -0.6° to 1.1° C, and that this temperature is maintained in storage (41). In addition, it also prevents dehydration of plants in storage (41, 52). Work done on runner plants of Redgauntlet and Cambridge Favorite strawberry cultivars, showed that stored plants at -1.1° C runnered freely in the year of planting and grew with an erect habit in contrast to freshly lifted plants (47). In this report, it was also concluded that stored runners may satisfactorily be used as substitutes

for fresh ones to obtain the recognized advantages of early plantings (47).

Worthington and Scott (51), cited that June-set cold stored plants yielded as well as May- or April-set, emphasizing the value of dormant cold-stored plants for establishment of planting. Under summer conditions the establishment of dormant runner plants held at -1.1° C has been rapid, and even when post-planting conditions have been adverse, establishment and subsequent performance has been satisfactory (47). Stored runner plants are dormant when planted, therefore, they have low initial rates of transpiration and for this reason are probably better adapted to planting under potentially warm conditions than are freshly dug ones. Since fresh runner plants are in active growth when dug, they received a shock when transplanted and may wilt unless conditions are favorable (47).

It is noteworthy that these conditions are for various geographic areas and not generalized.

Standardization of Nursery Plants

The source of planting stock is important. It is best to obtain registered plants, that is, plants that have been grown under state supervision and the word registered on the bundle label, indicating that they are substantially virus-free (24, 39). Another class of plants called certified (18, 24, 45) indicate that they are also grown under state supervision and free of most diseases and insects (18, 24). Furthermore, it is important to obtain only plants produced during the preceding summer and fall (41, 45, 46). Older mother plants usually make poor growth and are often infested with the larvae of the crown borer

which may become a serious problem (10, 46).

There are a number of other factors involved such as variation among plant producers as to the type of plants put on the market (8). This variation may be in uniformity of size, trimming, and packing, resulting in lack of uniformity in planting and in plant survival. It has been reported that 8 to 10 percent of the total number of plants in 1,000 plant crates weighed between 2 to 4 grams (8, 27). Plants in this weight group are less mature in tissue development and theoretically have less food reserve than more mature plants (8). Such plants are less likely to survive long storage or in the field (8, 27). Plants that weigh between 4 to 12 grams each are reported to be more mature and have better survival rates (27). Freeman and Pepin (19), found that small runner plants (up to 5 grams fresh weight) dug at various times from mid-October through planting time resulted in unsatisfactory stand following cold storage. They also found that there were no significant differences in field survival, whether medium (5 to 10 grams) or large (10 grams and over) runner plants were used, but the large plants tended to produce a more vigorous stand (19).

Storage Diseases

Most nursery plants are cold-stored, then spring-set, or summer-set (California). They should be purchased from nurserymen who sell certified virus-nematode-free stock (11). It is important to obtain plants free from injurious diseases and nematodes because if either is introduced, the result is almost certain to be a short-lived planting with low yields of poor quality fruits (46). Control measures may be taken but these increase production costs and may not be entirely effective (46).

Strawberry roots and crowns are attacked by several fungi (32). In the absence of root-infecting fungal pathogens, the plants grow well in many different types of soil provided fertility is relatively high. In deeply tilled humus soil, healthy plants produce extensive fibrous root systems (32). The perennial structural roots originate from the crown (15, 32) and may penetrate as deeply as 2.5 meters into the soil (32). These roots support fascicles of transient, multibranched feeder rootlets (15, 32).

The structural roots and their major branches form an extensive central xylem and a phloem from the vascular cambium (32) and a thick bark-like tissue, polyderm, from the cork cambium (15, 32). In addition to conducting water and nutrients and providing protection, these tissues also store food reserves (15, 32). In contrast, the feeder rootlets which are white at first and then turn yellowish to light brown, deteriorate and die naturally within about two weeks and are soon replaced, often at the same sites by newly formed rootlets (32). Although the feeder rootlets are short-lived (32, 49), the health and productivity of the strawberry plant depends largely on the smooth course of this cycle of rootlet initiation, death, and replacement and the factor determining it (15, 32, 49).

Root growth is influenced by the amount of food reserve stored by the plant (32). Root growth occurs primarily during the period of vegetative and reproductive inactivity which is in the fall, winter and spring (15, 32, 49). Everbearing or day-neutral plants that bear heavy crops may enter the dormant period without enough food reserves to support vigorous root growth and rootlet replacement (32). Thus, they

tend to grow poorly the next year and their weakened root systems will therefore be susceptible to pathogenic fungi (32).

Strawberry roots, perhaps more than roots of other plants, provide tenancy in the rhizosphere for numerous species of fungi and bacteria, some of which may be pathogenic under certain conditions (32). Some of these colonize only senescent roots or injured root tissues previously attacked by a primary fungal parasites or by nematodes (32). In addition, the feeder rootlets that die naturally may provide an entrance for saprophytic soil fungi, actinomycetes, and bacteria into the heartwood of older structural roots (32).

The roots and crowns of dormant runner plants for transplanting may be free of all pathogenic organisms when obtained, but conditions in cold storage must be satisfactory or plants deteriorate resulting in loss after planting (46). Reports have shown that planting stock stored at improper storage temperatures have developed molds and consequently cause losses (17, 22, 29, 30, 32, 39). Thus there is evidence that storage conditions strongly influence plant quality (8).

Storage temperatures and period vary considerably from -0.6° C for six weeks (25) up to -2.2° C to -1.1° C for six or eight months (32, 44). Storage is often in polyethylene lined containers (32, 41, 52) or other containers designed to minimize dehydration (32). Occasionally however, optimal conditions for long-term cold storage do not prevail and plants begin to deteriorate. Also, plants put into storage before they reach full dormancy or stored at temperatures fluctuating above 0° C are subject to pathological deterioration (32). Long storage at temperatures of 0° C or above may allow development of mold organisms, resulting in

breakdown and decay (29, 41). According to a survey of cold storage units, three months after plants were in storage, mold occured at plant temperature of -0.8° C but were highest at 0.6° C and none was observed at -1.1° C (29).

Various organisms are associated with damage to or destruction of plants in cold storage. These include species of Botrytis, Rhizoctonia, Gnomonia, Cylindrocarpon, Fusarium, Gloeosporium, Mortierella, Typhula, Sporotrichum, and Chaetomium (32). The organisms most commonly found growing over the surface of roots or associated with cortical root rots of stored plants were Fusarium spp., Cylindrocarpon sp., Rhizoctonia sp., and bacteria (29, 30). Lockhart (30), however, found that isolations from cortical root rot lesions yielded the following in descending order of prevalence: bacteria, Rhizopus sp., Fusarium spp., Penicillium sp., Actinomucor sp., Gliocladium sp., Trichoderma sp., Harknesia sp., Alternaria sp., Botrytis cineria, and Gloeosporium sp. Montgomerie (37) reported, in descending order of frequency, the fungi isolated from runner plants stored at -1.1° C and 0° to 1.6° C and sampled at intervals over a ten-month period were a sterile fungus 'a', Cylindrocarpon radicola, Mortierella sp., Fusarium sp., Gnomonia fructicola, Rhizoctonia solani, Gloeosporium sp., Botrytis cineria, a sterile fungus 'b', Fusarium avenaceum, Penicillium sp., and a sterile fungus 'C'. However, of the more prevalent fungi, only C. radicola and Mortierella sp. were isolated more often from plants stored at the highest temperature. Longer storage time did not result in increased frequencies of isolation (37).

The most common and most destructive species are B. cineria (gray

mold), Gnomonia comari (stem end rot), and Typhula sp. (snow mold) (32). In a study it was found that about 90 percent of the fungi identified on plants after storage was B. cineria Pers. ex. Fr. (17). B. cineria also causes a bud rot of cold-stored plants that are kept for extended periods of time or at temperatures above the optimum for storage. Under these conditions flower and leaf buds are severely weakened or killed (32).

Control of Storage Disease

It has been ascertained that the more dormant the plants are, the less likely they are to heat up in transit and the better they keep in preplant storage (39). When growers receive plants from the nursery, it is essential to check the bundles and if necessary moisten the roots (24, 39). It is suggested that transplants may be held at 0° to 0.6° C for extended periods but temperatures may be allowed to rise to 1.7° to 4.4° C for seven to ten days before planting, or even 10° to 15.6° C for shorter periods, to break dormancy and and encourage rapid growth at the time of planting (14). On the contrary, experience in California suggested that allowing the temperature to rise in storage before planting may somewhat reduce runnering (14). Nevertheless, if the plants cannot be set immediately, it is important to put them into cold storage for as long as several weeks or until planting conditions are satisfactory (18, 24, 39). Plants should be stored in plastic bags to prevent drying and allow adequate moisture barrier and permit adequate gas exchange in cold storage (13, 24, 41, 52).

Control measures have included fungicide treatments (14, 21, 32, 33, 34, 35). Dipping or dusting plants with a protective fungicide before storage often improves plant survival during cold storage (32). Spraying

plants with benomyl (17, 32, 33, 34, 35) or thiophanate-methyl (topsin-m) (32) in the field before lifting or digging them also improves cold storage survival and the vigor of the plants when planted in new fields (32). Most of the work done has been on predigging treatments with benomyl (17, 33, 34, 35). Also, treatments after digging, just prior to cold storage have been conducted (21). Daubeny et. al. (17), reported that plants treated with benomyl before storage (predigging) resulted in significantly fewer plants with fungi than those not treated. However, Mass (33), found that with benomyl sprayed plants, four out of 19 cultivars showed no advantage over non-sprayed plants. This suggests that plant responses to benomyl treatment may be cultivar dependent. In some other studies, treatments with benomyl (predigging) resulted in up to 85 percent (35) control of plant decay after seven months storage at 0° C (34, 35). It is suggested that time of application made no significant difference in the condition of the plants during storage. However, fruit yield data of some cultivars indicated that late treatment (November 17) was more beneficial than early treatment (October) for maintaining overall plant quality (34).

Guttridge and Montgomerie (21) reported that dipping 'Cambridge Favorite' (a cultivar with poor survival after cold storage) plants in fungicides, particularly in thiram, before storage, improved their survival after cold storage. Furthermore, it was also observed that dipping in thiram after storage decreased the subsequent death-rate. On the west coast, success with preplant dip of transplants in benomyl has been achieved (14). Crowe (14), cited that preliminary tests in Kansas strongly suggested increased vigor and rapid early growth for benomyl-

-dipped plants.

It has been shown that although several cultivars responded to prestorage fungicide treatment, the most effective treatments varied with the geographical location of experimental plots. This illustrates that both environmental and genetic interactions play important roles in disease development and control (33).

Fungicides Used

A. Benomyl (Benlate)

This is commonly called Benomyl (Dupont) with the chemical name Methyl-1-(butylcarbamoyl)-2-benzimidazole-carbamate. It is a systemic and broad spectrum fungicide belonging to the chemical class Benzimidazole. It is formulated as a wettable powder containing 50 percent active ingredient.

Benomyl acts as both a contact and systemic fungicide. Deposits on a host plant may act as a contact fungicide to protect the host from fungal pathogens. The surface deposit has good residual qualities and a major portion remains intact as benomyl for several weeks. For systemic and curative action, a portion of the benomyl may penetrate the cuticle or move into an infection site and stop the infection process (that is a curative effect). In a more general systemic action, the fungicide moves from point of penetration in the water transport system (apoplast) to the areas of greatest transpiration. The acropetal movement may concentrate the fungicide at leaf margins or tips but does not move it out of leaf into untreated portions of a plant.

Mode of Action

Benomyl enters the fungus in minute quantities and appears to

inactivate the functions of microtubules. This is indirect evidence that binds to a protein subunit of microtubulin in sensitive fungi and this results in a distortion of mycelial growth and a cessation of cell division at the metaphase. Microtubules play a vital role in the spindle apparatus which faciliatates cell division.

It has been cited that benomyl used as a preplant dip of transplants can serve two purposes (14) as follows:

1. If storage and/or shipping conditions reduced vigor and favored storage diseases, then benomyl will reduce this effect somewhat.
2. Benomyl dip prevents early activity of the foliage diseases such as "Strawberry Leaf Spot" (also known as "Mycosphaerella Leaf spot" or "Ramularia Leaf Spot) and "Strawberry Leaf Scorch" (caused by the fungus Diplocarpon earlina) which are known to affect the vigor of transplant establishment. It is recommended to use one-half pound product per 100 gallons (i.e. 227 grams per 380 liters) of water for strawberry transplants. Plants should be immersed to give thorough wetting, then removed and allowed to drain before planting.

B. Fosetyl-Al (Aliette)

Fosetyl-Al is a fungicide belonging to a new family of compounds, phosphonates (Rhone-Poulenc Inc.). This group of compounds exhibit both upward and downward systemic activity and is primarily effective against phycomycete fungi. Its common name is fosetyl-Al with the chemical name, Aluminium trios-o-ethyl phosphonate.

It is a systemic fungicide in wettable powder formulation that contains 80 percent fosetyl aluminium. It is the first systemic fungicide to give effective control of strawberry red core disease caused by the fungus Phytophthora fragariae. It has both protective and curative properties. It is important to note that this compound is active only when the pathogen is present, and not preventive in action.

Mode of Action

Unlike most other fungicides, whether they are systemic or not, fosetyl-Al is characterized by its low direct activity on fungi. Fosetyl-Al acts through the intermediary of the plant which means it may need the plant to be active and stimulates the defense reaction of the plant. A plant infected by a fungus tries to defend itself by synthesizing compounds which are toxic to the fungus.

Fosetyl-Al is suggested for both stored or freshly dug strawberry runners. It is recommended to use 2000-3000 ppm solution of Aliette as a preplant dip, or two pounds active ingredient per 100 gallons (i.e. 908 grams per 380 liters) per acre as a preplant dip.

At this point, it is important to note that the value of cold-stored plants varies with conditions that prevail in an area (41). As previously mentioned, time of digging, storage conditions, and planting time differ between areas. In Kansas, plants may be received in mid march, however weather conditions may require storage of plants from a few days to several weeks. Hence proper handling and storage is essential to maintain plant quality.

MATERIALS AND METHODS

Experiments were conducted in two growing seasons, 1983 and 1985. Dormant strawberry plants were obtained from Ahren's Nursery in late March. Plants were received in bundles of 25 plants and 40 such bundles in a crate or box lined with polyethylene bag. In the 1983 experiment, 36 bundles of Redchief cultivar were used. This experiment involved holding plants in cold storage at three temperature regimes (1.7°, 7.2°, and 12.7° C) for three holding periods each for greenhouse tests (3, 8, and 15 days) and for field tests (8, 15, and 21 days). The plants were placed in 1.5 mil polyethylene bags (33, 34, 35, 50, 51) and put in the different cold storage units or chambers at intervals according to the required holding period. The polyethylene bags were folded loosely over the tops to allow for air circulation. Also, in the 1985 experiment, plants were obtained from the same source (Ahren's Nursery), but the cultivar Honeoye was used. In this experiment 20 bundles of plants were used. Plants were held at two temperature regimes of 10° C and 1.7° C for 10 days.

Culture Tests

These tests were conducted to detect if any pathogens were present before and after cold storage. For the 1983 test, a bundle of 25 plants was removed from the lot received before subjected to cold storage, and tested for fungal pathogens, especially gray mold (Botrytis cineria) which is a common disease of strawberry plants in cold storage.

The plants were washed thoroughly under running tap water for 5

minutes to eliminate loose soil particles and other contaminants on the crowns and roots. From each plant the crown, and 2 roots were randomly selected for use. The roots were removed at the crown junction, then all leaves, petioles, and other roots were separated from crowns and discarded. Roots used for isolations were surface sterilized for one minute, and crowns were sterilized for 5 minutes. The solution used for surface sterilization was freshly prepared 10 percent strength household bleach (0.05 percent NaOCl).

Two media used were acidified potato dextrose agar (APDA) and one quarter-strength potato dextrose agar (PDA/4). Culture plates were 100 x 15 mm sterile plastic petri dishes filled with 25 ml of agar medium. Root segments of 1 mm were taken from the point of the crown junction, approximately 0.5 cm for the upper root segment and 3 cm from the crown junction for the lower root segment. These were transferred aseptically onto the sterile culture media. Small aseptically removed crown tissues taken from the upper and lower central crown areas were similarly placed on culture media. Segments from half of the roots were placed on APDA and the other half were on PDA/4. Crown segments from each plant were placed on both media. Agar plates containing tissue specimens (isolates) were stored at 24° C with 8-hour-per-day room lighting. Fungal and bacterial growth were rated daily in case the micro-organisms overgrew each other.

In the 1985 tests, culture tests were conducted two weeks after cold storage at 1.7° and 10° C. From each of the storage chambers a bundle of 25 plants was taken and 10 plants randomly selected from each bundle. Procedures for isolations were the same as mentioned earlier. However,

samples in this test were taken from the lower crown and root tissues. From each plant, 3 root samples were randomly removed and from these, 3 tissue specimens taken from each root sample (totalling 9 specimens). Also, from each crown 9 specimens were taken from all sides of the lower crown. Also, 3 media were used namely, APDA, PDA/4 (same as for 1983) and VVS-PBNC which contains Pentachloro-nitrobenzene, Benomyl, Neomycin sulphate and, Chloramphenicol, V-8 juice, yeast extract and 3, Sucrose.

APDA is a medium commonly used for the isolation of fungi. It is acidified to prevent bacterial growth. PDA/4 allows bacterial cultures to grow, but the 1/4-strength tends to reduce or slow down fungal growth. VVS-PBNC is a selective medium for Phytophthora and Pythium.

Greenhouse Tests

At the end of the holding period in early spring 1983, plants from the three temperature regimes (1.7°, 7.2°, and 12.7° C) for three periods of time (3, 8, and 15 days) were removed from the cold storage chambers and taken to the greenhouse. Roots of plants were trimmed to 3/4 their original length. Half of the plants from each holding condition were dipped in a fungicide solution (benomyl) and the other half untreated, dipped in water (to ensure equal wetting of plants). Benomyl was applied at a rate of 2.27 grams per 3.8 liters of water (1.14 grams a.i.). A total of 270 plants were potted in 10 cm pots in a mixture of equal amounts of perlite, peat moss, and soil. There were 10 plants per treatment (holding condition) and 5 plants per subtreatment (fungicide). Treatments were replicated 3 times in a completely randomized design (CRD). Plants were watered as needed.

Blossoms were picked off regularly and plants were grown for 10

weeks. At the end of this period, plants were removed from pots and the roots washed thoroughly to eliminate media. Plants were grouped according to treatments and fresh weights taken after allowing water to dry off. The treatment groups were put in brown paper bags perforated to allow air circulation around plants, tops of the bags folded over, and then placed in an oven at 50° C for 48 hours after which dry weights were recorded.

In the 1985 greenhouse tests, a total of 150 plants were potted after 10 days of cold storage at 1.7° and 10° C. Three preplant fungicide dips were used as follows; benomyl at 2.27 grams per 3.8 liters (1.14 grams a.i.), fosetyl-Al at 9.8 grams per 3.8 liters (7.84 grams a.i.), and water. There were 5 plants per treatment and the treatment combinations consisted of two cold storage temperatures and three fungicide dips. Treatments were replicated 5 times in a CRD. Generally, procedures were the same as for the 1983 tests.

Two weeks after transplanting, blossom counts were made according to treatments for a period of 2 weeks. Plants were allowed to go to fruiting and fruit weights taken as a representative of yield data per treatment. At the end of 10 weeks plants were removed from pots, drying procedures as used for the 1983 test were followed, and dry weights taken.

Field Tests

Tests were conducted at the Ashland Horticultural Research Farm. Soil samples from the site were taken and tested for pH, N, and K before planting. The fertilizer 18-46-0 was applied at the rate of 90.8 kilogram per hectare. In the 1983 field tests, Redchief runner plants from the

different holding conditions (three temperature regimes 1.7°, 7.2°, 12.7° C; for three periods of time 8, 15, and 21 days) were subjected to two preplant fungicide dips (benomyl versus water). The roots were trimmed to 3/4 of their original lengths. Plants were then grouped according to treatments and some dipped in a benomyl solution of 2.27 grams per 3.8 liters of water (1.14 grams a.i.), and the control plants in water to ensure equal wetting for both group of treatments. There were a total of 540 plants, 18 treatment combinations and 10 plants per treatment combination. Treatments were replicated 3 times in randomized complete block design (RCBD). The plot size was 18.9 m x 18 m with plant spacings of 60 cm apart and row spacings of 105 cm. The plot was irrigated immediately after planting and as required thereafter.

Blossoms were picked off the first season and only runner counts were taken that season at three different times in June, July and August. Yield data was collected in the fruiting season the next year.

Honeoye runner plants from the two cold storage chambers (1.7° and 10° C) were subjected to three preplant fungicide dip treatments in the 1985 field tests. Two fungicides, fosetyl-Al and benomyl, and a control treatment of water dip were used. Plants were grouped according to the treatments required and dipped accordingly into benomyl solution at the same rate of 2.27 grams per 3.8 liters (1.14 grams a.i.); fosetyl-Al at 9.8 grams per 3.8 liters (7.84 grams a.i.); and a 3.8 liters of water. There were a total of 300 plants, 6 treatment combinations and 10 plants per treatment combination. Treatments were replicated 5 times in an RCB design. The plot size was 12.6 m x 18 m with same plant and row spacings as mentioned earlier.

Blossoms were not removed for the purpose of treatment evaluation. Berries were picked twice in the season and weights recorded (i.e. in June). In mid-July runner counts were also taken.

RESULTS

Isolations

In 1983, prestorage isolations (on APDA and quarter-strength PDA) were made from the crowns and roots of randomly sampled plants. The microorganisms isolated were grouped into five general categories: 1) whitish bacterial colonies (all colonies consistent in appearance); 2) yellowish bacterial colonies (also consistent); 3) apparent mixtures of these i.e., the whitish and yellowish bacteria; 4) occasional fungal colonies of Alternaria, Penicillium, Fusarium spp. and other undetermined fungi which were sometimes mixed with bacteria; and 5) no growth of bacteria or fungi. The root isolations yielded many diverse fungi and bacteria. No root sgements were free of microbial growth and many segments yielded several different types. No consistency was seen but Alternaria, Rhizoctonia, Penicillium, Fusarium, and five distinct but unidentified fungi were common.

Following storage treatments plant roots were visually rated to evaluate root health but no symptoms of discoloration or decay were observed.

In 1985 all strawberry plants used were in excellent condition before storage at 1.7° or 10° C; there were no apparent injuries or discoloration to crowns or roots. Visual rating of plants after 14 days in storage at both temperatures again indicated little discoloration of the root system or fungal growth on the surface of the plants.

Several genera of fungi were isolated from the roots and crowns of strawberry plants after 14 days in storage (Table 1). Aternaria sp. was

the most frequently isolated fungus from root and crown tissues at both storage temperatures, although the percentage of those samples containing Alternaria sp. was higher from plants stored at 10° C (49 and 31 percent of root and crown tissues respectively). Fusarium spp. were recovered from 16 and 20 percent of the crown tissues at storage temperatures of 1.7° and 10° C respectively. Potentially pathogenic fungi, (29, 30, 32) such as Pythium and Rhizoctonia spp., were recovered infrequently from roots and crowns. Other fungi isolated in order of frequency included Trichoderma, Penicillum, and Aspergillus spp. Bacteria were also frequently recovered from root and crown tissues; however, the frequency of these isolations and the genera involved were not determined.

Isolations of potentially pathogenic genera of fungi such as Rhizoctonia and Pythium were low. Nevertheless, a significant number of crown tissues were colonized by Fusarium spp. at both storage temperatures. Fusarium spp. have been associated with root and crown deterioration of strawberry plants in storage (29, 30, 32, 37), and these may affect the survival or vigor of plants after planting.

Greenhouse Tests--1983 and 1985

The analysis of variance structure, (Table 2) shows treatment effects and interactions on dry weight of strawberry plants grown in the greenhouse in 1983. Three-way treatment interactions of cold storage temperatures x storage periods x preplant fungicide dips indicated no significant interaction effects on dry weights of plants grown in the greenhouse (Table 3). There were no significant treatment interaction effects between the cold storage temperatures and the preplant fungicide dips on plant dry weights (Table 4). There were significant treatment

interaction effects between cold storage temperatures and storage periods on dry weight of plants (Table 5). The lower temperature (1.7° C) and longer storage period (15 days) interaction increased plant dry weight, while dry weight decreased with the higher temperature (12.7° C) and shorter storage period (8 days). No significant interaction effects were observed between cold storage period and preplant fungicide dips on dry weight of plants as indicated in Table 6. The analysis of variance structure for treatment effects and interactions on number of blossoms, fruit yield and dry weights of plants grown in the greenhouse in 1985 is shown in Table 7. There were no treatment interaction effects on the parameters measured (Table 8). However, all preplant fungicide treatments at 10° C significantly increased initial blossom development (seven days count) compared to those treated with fungicide at 1.7° C.

The 1983 tests indicated that cold storage temperatures did not influence plant growth as evaluated by dry weight of plants (Table 9). In contrast, the 1985 tests indicated a significant ($p = 0.05$) increase in dry weights of those plants stored at 1.7° C compared to those stored at 10° C (Table 10). Even though plants stored at 10° C had a significantly ($p = .05$) higher blossom production than those plants stored at 1.7° C, the final yield of the two storage temperatures were similar (58.3 and 53.5 grams respectively).

The length of time that plants were held in cold storage did not have a significant effect on plant growth as evaluated by plants dry weights in the 1983 test (Table 11).

A preplant fungicide treatment of benomyl in 1983 significantly increased plant dry weight when compared to the control plants (water

treated) (Table 12). In 1985, preplant fungicide treatments of benomyl or fosetyl-Al did not significantly increase the number of blossoms, fruit yield or dry weight of plants when compared to the control plants (Table 13).

Field Tests--1983 and 1985

The analysis of variance structure (Table 14) shows treatment interaction effects on fruit yield and runner development for 1983 field tests. Three-way treatment interaction effects between cold storage temperatures, storage periods and preplant fungicide dips is shown in Table 15. There were significant ($p = 0.05$) interaction effects on runner development but not on fruit yield. Cold storage at 1.7° C for 8 days and water dip gave the highest number of runners (146), but the lowest fruit yield (1,748 grams). The high storage temperature (12.7° C) in combination with long storage period (21 days) and preplant fungicide dip (benomyl) resulted in fewer number of runners and highest fruit yield. The same temperature combined with the shorter storage period (8 days) and water dip reduced runner development. In general there were no clear trends to these interaction effects.

The interactions between storage temperature and preplant fungicide dip had significant ($p = 0.05$) influence on runner development but not on fruit yield (Table 16). Plants held at 7.2° C storage and benomyl dipped, resulted in the most runners (123) and generally the lowest yield (2,760 grams). The highest fruit yield (4,269 grams) was recorded from treatment interactions between storage temperature at 12.7° C and benomyl dip, and had fewer runners. The lowest fruit yield was from 1.2° C storage and preplant benomyl dip. Storage temperature of 12.7° C and

water dip interactions yielded the lowest number of runners (88) with moderately higher fruit yield (3,272 grams).

There were no significant treatment interaction effects between cold storage period and preplant fungicide dip on fruit yield or runner development (Table 17).

The interactions between storage temperature and storage period treatments had significant ($p = .05$) effects on runner development but not on yield (Table 18). Interactions between storage at 1.7° C for 8 days and 7.2° C for 8 days significantly increased number of runners produced (127 and 131 respectively). Cold storage at 12.7° C for 8 days resulted in the lowest number of runners. Although there were no significant effects between treatment interactions on fruit yield, but cold storage at 12.7° C for 21 days resulted in fewer runners (111) and highest fruit yield (4,627 grams). There are no clear trends but the lower temperatures and short storage periods tended to increase runner development and reduced fruit yields.

Table 19 represents the analysis of variance structure for treatment effects and interactions on fruit yield and runner development of the 1985 field tests. There were significant interaction effects between cold storage temperatures and preplant fungicide dips on both fruit yield and runner development (Table 20). A combination of low storage temperature and preplant fungicide dip increased fruit yield and runner development. Storage at 1.7° C with preplant fosetyl-Al dip gave the highest fruit yield (320 grams) and number of runners (29). While the lowest yield (167 grams) was obtained from treatment interaction between 10° C and preplant benomyl dip, the lowest number of runners (14) were

obtained from the 10° C treatment and preplant fosetyl-Al dip interactions.

Field tests in 1983 indicated that plants stored at 1.7° and 7.2° C had higher ($p = .05$) number of runners develop (111 and 121 respectively) than from those plants stored at 12.7° C . In contrast, the yield from plants decreased with storage temperature (Table 21). Figure 1 shows a quadratic temperature effect on runner development. Cold storage temperature treatments had significant linear effect on fruit yield as shown Figure 2.

Cold storage temperatures in the 1985 tests also had significant effect on runner development (Table 22). The 1.7° C temperature treatment resulted in 25 runners compared to the 10° C treatment with 18 runners. Plot size and plant population were smaller in these studies than those of 1983 hence, the difference in number of runners. Temperature did not have a significant effect on fruit yield. The blossoms were not removed during the 1985 test for the purpose of treatment evaluation.

In 1983, the length of cold storage did not significantly affect runner development or fruit yields (Table 23), although there was a clear trend for the plants to produce fewer runners and higher fruit yields as the storage period increased.

The preplant benomyl dip in 1983 significantly increased ($p = .05$) runner development but did not have an effect on fruit yields (Table 24). In 1985, preplant fungicide dip treatments (fosetyl-Al and benomyl) did not affect fruit yield or runner development (Table 25).

Table 1. Percentage of Fungi Isolated from Root and Crown Tissues of Strawberry Plants held in Cold Storage Chambers at 1.7° and 10° C for 14 Days--1985.

	Frequency of Isolations (%)[x]			
	1.7° C[y]		10° C[z]	
Genera Isolated	Root	Crown	Root	Crown
Alternaria	29.0	18.0	49.0	31.1
Aspergillus	1.1	--	--	1.1
Fusarium	11.1	16.0	4.4	20.0
Penicillium	3.3	--	6.0	4.4
Pythium	--	--	1.1	--
Rhizoctonia	1.1	--	2.2	2.2
Trichoderma	10.0	4.4	17.0	3.3
Others*	44.4	61.6	20.3	37.9

* No fungi isolated from root or crown sample or genera of fungi not determined.

[z][y]Plants held at a constant temperature in the dark.

[x]Based on 90 specimens of roots and crowns from which isolations were made.

Table 2. Analysis of Variance Structure for Final Dry Weight of Strawberry Plants Grown in the Greenhouse After Cold Storage and Pre-Plant Fungicide Treatments--1983.

Source of Variation	Degrees of Freedom	F Value for Dry Weight	PR > F
Fungicide	1	2.94	0.095
Temperature	2	1.41	NS
Days	2	1.40	NS
Fung. * Temp.	2	0.60	NS
Fung. * Days	2	0.45	NS
Temp. * Days	4	1.92	0.1
Fung. * Temp. * Days	4	1.09	NS

NS = Nonsignificant ($p > .10$).

Table 3. Influence of Cold Storage Temperature, Storage Period, and Pre-Plant Fungicide Dip Interactions on Growth of Strawberry Plants Grown in the Greenhouse--1983.

Treatments			
Temp. (° C)	Storage Period (Days)	Fung. Dip	Dry Wt. of Plants (gm)[y]
1.2	3	Water	18.0
1.2	3	Benomyl	20.0
1.2	8	Water	16.1
1.2	8	Benomyl	19.1
1.2	15	Water	19.0
1.2	15	Benomyl	21.1
7.2	3	Water	16.0
7.2	3	Benomyl	20.0
7.2	8	Water	18.1
7.2	8	Benomyl	18.2
7.2	15	Water	16.0
7.2	15	Benomyl	16.2
12.7	3	Water	20.0
12.7	3	Benomyl	18.1
12.7	8	Water	15.4
12.7	8	Benomyl	14.0
12.7	15	Water	16.3
12.7	15	Benomyl	20.3
		HSD[z]	NS

[z] Tukey's Test = 0.10; NS = Nonsignificant.

[y] Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

Table 4. Influence of Cold Storage Temperature and Pre-Plant Fungicide Dip Interactions on Growth of Plants Grown in the Greenhouse-- 1983.

Treatments		
Temp. (°C)	Fung. Dip	Dry Wt. of Plants (gm)[Y]
1.7	Water	17.5
1.7	Benomyl	20.0
7.2	Water	16.5
7.2	Benomyl	18.0
12.7	Water	17.1
12.7	Benomyl	17.3
	HSD[Z]	NS

[Z] Tukey's Test = 0.10; NS = Nonsignificant.

[Y] Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

Table 5. Influence of Cold Storage Temperature and Storage Period Interactions on Growth of Strawberry Plants Grown in the Greenhouse--1983.

Treatments		
Temperature (°C)	Storage Period (Days)	Dry Wt. of Plants (gm)[y]
1.7	3	19.0ab
1.7	8	18.0ab
1.7	15	20.0a
7.2	3	18.0ab
7.2	8	18.2ab
7.2	15	16.0ab
12.7	3	19.0ab
12.7	8	14.5b
12.7	15	18.3ab
	HSD[z]	5.3

[z]Tukey's Test = 0.10.

[y]Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

Table 6. Influence of Cold Storage Period and Pre-Plant Fungicide Dip Interactions on Growth of Strawberry Plants Grown in the Greenhouse--1983.

Treatments		
Storage Period (Days)	Fungicide Dip	Dry Wt. of Plants (gm)[y]
3	Water	18.0
3	Benomyl	19.1
8	Water	16.5
8	Benomyl	17.0
15	Water	17.0
15	Benomyl	19.2
	HSD[z]	NS

[z]Tukey's Test = 0.10; NS = Nonsignificant.

[y]Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

Table 7. Analysis of Variance Structure for Blossom Development, Fruit Yield and Dry Weight of Strawberry Plants Grown in the Greenhouse After Cold Storage and Pre-Plant Fungicide Treatments--1985.

Source of Variation	Degrees of Freedom	F-Value for 8-Day Blossom Count	PR > F	F-Value for Total Blossom Count	PR > F	F-Value for Frt. Yield	PR > F	F-Value for Dry Wt.	PR > F
Fungicide	2	0.28	NS[z]	0.47	NS	1.15	NS	0.29	NS
Temperature	1	47.66	0.0001	4.98	0.04	1.15	NS	7.29	0.01
Fung. * Temp.	2	0.13	NS	0.20	NS	0.34	NS	0.56	NS

[z]NS = Non sinificant (p > .05)

Table 8. Effects of Pre-Plant Fungicide Dips and Cold Storage Temperature Interactions on Blossom Development, Fruit Yield and Growth of Strawberry Plants Grown in the Greenhouse--1985.

Treatments		Number of	Total		Dry Wt. of
Fungicide	Temperature (°C)	Blossoms at End of 7 Days	Number of Blossoms[x]	Yield (gm)	Plants (gm)[y]
Water	1.7	5.0b	11.0	49.2	11.0
Fosetyl-Al	1.7	4.0b	13.0	52.0	11.0
Benomyl	1.7	9.0b	14.0	60.0	11.2
Water	10	32.0a	16.0	54.0	9.3
Fosetyl-Al	10	29.0a	16.0	61.2	10.1
Benomyl	10	31.0a	16.0	60.0	9.0
	HSD[z]	19.3	NS	NS	NS

[z]Tukey's Test = 0.05; NS = Nonsignificant.

[y]Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

[x]Mean Final count per treatment.

Table 9. Influence of Cold Storage Temperatures on Growth of Strawberry Plants in the Greenhouse--1983.

Temperature (°C)	Dry Weight of Plants (gm)[y]
1.7	18.70
7.2	17.24
12.7	17.21
HSD[z]	NS

[z] Tukey's Test = 0.10; NS = Nonsignificant.

[y] Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

Table 10. Influence of Cold Storage Temperature on Blossoms, Fruit Yield and Growth of Strawberry Plants grown in the Greenhouse--1985.

Temp. (°C)	Blossom Count After 7 Days	Total Blossom Count[x]	Yield (gm)	Dry Wt. of Plants (gm)[y]
1.7	6.0b	13.0b	53.5	11.1a
10	31.0a	16.0a	58.3	9.3b
HSD[z]	7.4	3.0	NS	1.3

[z]Tukey's Test = 0.05; NS = Nonsignificant.

[y]Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

[x]Mean final count per treatment.

Table 11. Effect of Cold Storage Period on Growth of Strawberry Plants in the Greenhouse--1983.

Storage Period (Days)	Dry Weight of Plants (gm)[y]
3	18.39
8	16.76
15	18.00
HSD[z]	NS

[z] Tukey's Test = 0.10; NS = Nonsignificant.

[y] Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

Table 12. Effect of a Preplant Fungicide Dip on Growth of Cold Stored Strawberry Plants in the Greenhouse--1983.

Fungicide	Dry Weight of Plants (gm)[y]
Water	17.0b
Benomyl	18.4a
HSD[z]	1.4

[z] Tukey's Test = 0.10.

[y] Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

Table 13. Effects of Pre-Plant Fungicide Dips on Blossoms, Fruit Yield and Growth of Strawberry Plants in the Greenhouse--1985.

Fungicide	Blossom Count After 7 Days	Blossom Count[x]	Yield (gm)	Dry Wt. of Plants (gm)[y]
Water	18.0	13.0	51.5	10.1
Fosetyl-Al	17.0	14.0	56.5	10.5
Benomyl	20.0	15.0	60.0	10.0
HSD[z]	NS	NS	NS	NS

[z]Tukey's Test = 0.10; NS = Nonsignificant.

[y]Mean Dry Weight of whole plants per treatment after growth for 10 weeks.

[x]Mean Final count per treatment.

Table 14. Analysis of Variance Structure for Runner Development and Fruit Yield of Strawberry Plants Grown in the Field After Cold Storage and Pre-Plant Fungicide Treatments--1983.

Source of Variation	Degrees of Freedom	F Value for Yield	PR > F	F Value for Runners	PR > F
Fungicide	1	0.00	NS[z]	4.15	0.049
Temperature	2	2.39	0.1	4.79	0.015
Days	2	1.14	NS	0.63	NS
Fung. * Temp.	2	1.40	NS	0.68	NS
Fung. * Days	2	0.66	NS	0.31	NS
Temp. * Days	4	1.02	NS	2.33	0.076
Fung. * Temp. * Days	4	1.37	NS	4.49	0.005
Replication	2	0.17	NS	1.56	NS
Temp. Linear	1	4.62	0.04	3.05	0.089
Temp. Quad.	1	0.15	NS	6.54	0.015

[z]NS = Nonsignificant ($p > .10$)

Table 15. Effects of Cold Storage Temperature, Storage Period, and Pre-Plant Fungicide Dip Interactions on Fruit Yield and Runner Development of Strawberry Plants in the Field--1983.

Treatment				
Temperature (°C)	Storage Period (Days)	Fung. Dip	Yield (gm)[x]	Number of Runners[y]
1.7	8	Benomyl	2190.0	107.0abc
1.7	8	Water	1748.0	146.0a
1.7	14	Benomyl	2564.0	126.0ab
1.7	14	Water	3975.0	85.0abc
1.7	21	Benomyl	2541.0	122.0ab
1.7	21	Water	2911.0	81.0bc
7.2	8	Benomyl	2388.0	135.0ab
7.2	8	Water	4233.0	127.0ab
7.2	14	Benomyl	3170.0	112.0abc
7.2	14	Water	2585.0	114.0abc
7.2	21	Benomyl	2723.0	121.0ab
7.2	21	Water	3143.0	118.0abc
12.7	8	Benomyl	3438.0	111.0abc
12.7	8	Water	2237.0	58.0c
12.7	14	Benomyl	3413.0	96.0abc
12.7	14	Water	4282.0	101.0abc
12.7	21	Benomyl	5955.0	117.0abc
12.7	21	Water	3298.0	105.0abc
		HSD[z]	NS	63.0

[z]Tukey's test = 0.05; NS = Nonsignificant.

[y]Means of runners per treatment interaction.

[x]Mean weight per treatment interaction.

Table 16. Effects of Pre-Plant Fungicide Dip and Cold Storage Temperature Interactions on Fruit Yield and Runner Development of Strawberry Plants in the Field--1983.

Treatment			
Fungicide	Temperature (°C)	Yield (gm)	Number of Runners[y]
Benomyl	1.2	2432.0	118.0ab
Water	1.2	2878.0	104.0ab
Benomyl	7.2	2760.0	123.0a
Water	7.2	3320.0	120.0ab
Benomyl	12.7	4269.0	108.0ab
Water	12.7	3272.0	88.0b
	HSD[z]	NS	31.6

[z]Tukey's Test = 0.05; NS = Nonsignificant.

[y]Means of runners per treatment interaction.

Table 17. Effects of Pre-Plant Fungicide Dip and Cold Storage Period Interactions on Fruit Yield and Runner Development of Strawberry Plants in the Field--1983.

Treatment			
Fungicide	Cold Storage Period (Days)	Frt. Yield (gm)	Number of Runners[y]
Benomyl	8	2672.0	118.0
Water	8	2739.2	110.0
Benomyl	14	3049.0	111.0
Water	14	3614.0	100.0
Benomyl	21	3740.0	120.0
Water	21	3117.0	101.0
	HSD[z]	NS	NS

[z]Tukey's Test = 0.10; NS = Nonsignificant.

[y]Means of runners per treatment interaction.

Table 18. Effects of Cold Storage Temperature and Storage Period Interactions on Fruit Yield and Runner Development of Strawberry Plants in the Field--1983.

Treatment			
Temperature (°C)	Storage Period (Days)	Frt. Yield (gm)	Number of Runners[y]
1.7	8	1969.0	127.0a
1.7	14	3270.0	106.0ab
1.7	21	2726.0	102.0ab
7.2	8	3310.0	131.0a
7.2	14	2878.0	113.0ab
7.2	21	2933.0	119.0ab
12.7	8	2837.0	85.0b
12.7	14	3848.0	99.0ab
12.7	21	4627.0	111.0ab
	HSD[z]	NS	39.0

[z] Tukey's Test = 0.05; NS = Nonsignificant.

[y] Means of runners per treatment interaction.

Table 19. Analysis of Variance Structure for Fruit Yield and Runner Development of Strawberry Plants Grown in the Field After Cold Storage and Pre-Plant Fungicide Treatments--1985.

Source of Variation	Degrees of Freedom	F Value for Yield	PR > F	F Value for Runners	PR > F
Fungicide	2	1.74	NS[z]	0.49	NS
Temperature	1	1.01	NS	25.05	0.001
Fung. * Temp.	2	4.09	0.03	7.29	0.004
Replication	4	0.09	NS	0.36	NS

[z]NS = Nonsignificant (p > .05)

Table 20. Influence of Pre-Plant Fungicide Dip and Cold-Storage Temperature Interactions on Fruit Yield and Runner Development of Strawberry Plants in Field--1985.

Treatment			
Fungicide	Temperature (°C)	Yield (gm)[x]	Number of Runners[y]
Water	1.7	209.0ab	25.0ab
Fosetyl-Al	1.7	320.0a	29.0a
Benomyl	1.7	262.0ab	22.0ab
Water	10.0	297.0ab	20.0bc
Fosetyl-Al	10.0	241.0ab	14.0c
Benomyl	10.0	167.0b	20.0bc
	HSD[z]	140.01*	8.0**

[z]Tukey's Test = 0.05 (**); and 0.10 (*).

[y]Means of runners per treatment interaction (counted in mid-August).

[x]Yield from first season for treatment evaluation.

Table 21. Influence of Cold Storage Temperatures on Runner Development and Fruit Yield of Strawberry Plants in Field--1983.

Temperature (°C)	Number of Runners[x]	Yield (gm)[y]
1.7	111.0ab	2655.0b
7.2	121.0a	3040.0ab
12.7	98.0b	3771.0a
HSD[z]	18.0**	1102.0*

[z] Tukey's Test = 0.05 (**); 0.10 (*).

[y] Means of 3 replications.

[x] Means of runners per treatment.

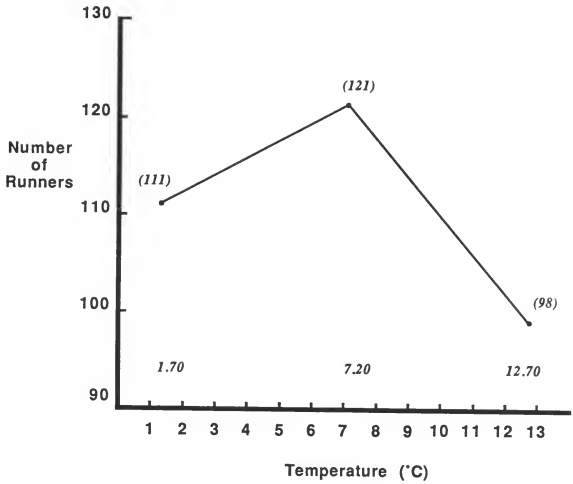

Fig. 1. Effect of Cold Storage Temperature on Runner Development, 1983

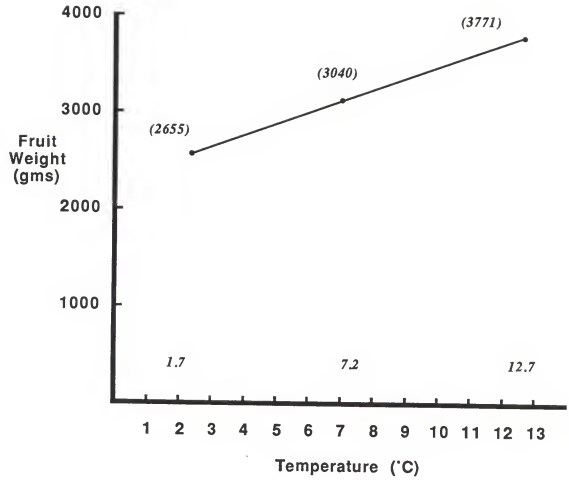

Fig. 2. Effect of Cold Storage Temperature on Fruit Yield, 1983

Table 22. Influence of Cold Storage Temperatures on Fruit Yield and Runner Development of Strawberry Plants in the Field--1985.

Temperature (°C)	Yield (gms)[x]	Number of Runners[y]
1.7	263.9	25.0a
10	234.8	18.0b
HSD[z]	NS	3.1

[z] Tukey's Test = 0.05; NS = Nonsignificant .

[y] Runners counted in mid-August.

[x] Yield from first season for evaluation of treatments.

Table 23. Effects of Cold Storage Periods on Runner Development and Fruit Yield of Strawberry Plants in the Field--1983.

Storage Period (Days)	Number of Runners[x]	Yield (gm)[y]
8	114.0	2706.0
14	106.0	3332.0
21	111.0	3429.0
HSD[z]	NS	NS

[z]Tukey's Test = 0.10; NS = Nonsignificant

[y]Means of 3 replications.

[x]Means of runners per treatment.

Table 24. Effect of a Pre-Plant Fungicide Dip on Runner Development and Fruit Yield of Cold Stored Strawberry Plants in the Field--1983.

Fungicide	Number of Runners[x]	Yield (gm)[y]
Water	104b	3157
Benomyl	116a	3154
HSD[z]	12.0	NS

[z]Tukey's Test = 0.05; NS = Nonsignificant.

[y]Means of 3 replications.

[x]Means of runners per treatment.

Table 25. Effects of Pre-Plant Fungicide Dips on Fruit Yield and Runner Development of Cold Stored Strawberry Plants in the Field--1985.

Fungicide	Number of Runners[x]	Yield (gm)[y]
Water	23.0	253.0
Fosetyl-Al	21.0	281.0
Benomyl	21.0	215.0
HSD[z]	NS	NS

[z] Tukey's Test = 0.10; NS = Nonsignificant.

[y] Yield of First season (Blossoms not removed for the purpose of treatment evaluation).

[x] Runners counted in mid-August.

DISCUSSION AND CONCLUSIONS

Isolations

The results of the isolation tests from the two years of this study (pre-storage and post-storage isolations) did not indicate any significant populations of root infecting fungal pathogens or storage molds. The fungi isolated from plant tissues in both years were similar in both type and nonsignificant populations present. In the 1983 prestorage tests, few fungi were isolated from crowns and roots but neither Botrytis cineria nor Rhizoctonia solani, the fungi usually implicated in storage of strawberry transplants (20, 27, 29, 30, 32, 33, 37) were detected. Both media (PDA/4 and APDA) used should have encouraged growth of these fungi if they were present within tissues. However, in the 1985 post-storage tests, the fungi genera most frequently isolated from root and crown tissues were Alternaria spp. which are saprophytic by nature (subsist on dead matter) and are probably not important in terms of pathogenicity or plant survival (32). Fusarium spp. were also frequently isolated from root and crown tissues (more on crown, 16 and 20 percent) at both cold storage temperatures of 1.7° and 10° C respectively. Graham et. al. (20) found that Fusarium, Rhizoctonia, Botrytis and some other fungi are capable of good growth at 1.7° and 4.4° C.

Nevertheless, the populations of Fusarium in the present studies, were probably not sufficiently high to be detrimental to the survival or vigor of plants as observed after greenhouse and field plantings. Similarly, Daubeny et. al. (17) cited that the presence of fungi did not

affect plant survival or vigor. In contrast, Mass and Scott (34) and Guttridge and Montgomerie (21) reported that post-storage survival was adversely affected by presence of fungi. They suggested that under unfavorable growing conditions the presence of fungi could have affected survival and vigor of plants (21). Furthermore, the short storage period (14 days) in the 1985 test may have influenced the low populations of fungi isolated and subsequently their effects on survival and vigor. Even in the 1983 tests where isolations were carried out before storage for 3, 8, 15 days (greenhouse planting) and 8, 15, 21 days (field planting), there was no evidence of reduced survival or vigor after planting. Daubeny et.al. (17), cited that long storage for five and one-half months with the incidence of fungi did not affect plant survival (plants were pretreated with fungicide before storage).

From both tests it could be deduced that there was no relationship between plant health and fungi isolated. There were no significant populations of root infecting fungi or storage molds.

Greenhouse Studies

There were no significant treatment interactions on plant growth in the 1983 tests except between cold storage temperatures and storage periods ($p = 0.1$). The most effective treatment was obtained from the 1.7° C storage for 15 days (20 grams dry weight). The least effect was from the 12.7° C storage for 8 days while the rest of the interactions (seven treatments) gave intermediary effects. Hence, there is no clear biological trends to the treatment effects. Analysis of variance indicated a low significance level ($p = 0.1$).

In the 1985 study the only interaction effect that was significant

was between cold storage temperature and preplant fungicide dip on initial blossom development (7 days). There was no significant difference within each group of temperature interactions except between the two temperature groups. Thus, it is evident that the main effect here was temperature and not an interaction effect. Analysis of variance indicated no significant interaction effect but significant temperature effect, $p = 0.0001$.

Cold storage temperatures in the 1983 greenhouse study did not influence plant development as expressed by plant dry weight. However, plants from the 1.7° C storage were slower to begin growth after planting than those from 7.2° and 12.7° C. Way (47), attributed a low temperature effect (-1° C) to the fact that stored plants are dormant when planted and therefore have a low initial transpiration rate after planting. Similarly, plants from the 1.7° C were still dormant at the time of planting in comparison to those held at 7.2° and 12.7° C which had initiated growth in the storage chambers. But after the initial plant establishment period there was a full stand of plants regardless of preplanting treatments and there were no observed differences in plant growth to suggest treatment responses. Hence, it is not surprising that statistical analysis indicated no significant difference between these temperatures.

The 1985 study demonstrated the significant influence of cold storage temperature on plant performance as expressed by blossom development and dry weight, but not on yield. The influence on increased dry weight of the 1.7° C treatment over that of the 10° C was probably due to the fact that they had more food reserve. Bringhurst et. al. (6),

suggested that starch reserves appeared to influence performance of plantings mostly in relation to the plant's ability to survive and grow vigorously after transplanting. Also, Guttridge (23) cited that reduced carbohydrate reserves tended to restrict full expression of post-chilling vigor, but had much less effect on plant performance than did the chilling history per se. Thus, there are two factors involved in plants' performance here; the starch reserve and chilling effect. Since the plants held at 1.7° C were chilled, they remained dormant in storage and therefore an absence of respiration (27). Consequently, they retained their food reserve. Also, as had been mentioned earlier, these plants had a slow initial transpiration rate (47), therefore less carbohydrate was utilized. The plants held at 10° C could be said to have utilized some of their food reserve in storage because they started sprouting (broken dormancy) before transplanting.

The significant influence of the 10° C treatment over 1.7° C on increased blossom development was not unexpected because those plants at the higher temperature had broken dormancy and initiated growth in storage, thus started to bloom earlier. However, the yield data indicated that there was no significant difference between temperatures even though plants held at 10° C started to bloom earlier. This shows that the plants held at 1.7° C caught up and could be attributed to the role played by the food reserve and chilling effect. Freeman and Pepin (19) suggested that a positive relationship between starch content of strawberry roots and subsequent survival and growth was only apparent when growing conditions were unfavorable. This also explains why the 1.7° C treatment did not have an advantage over the 10° C treatment despite the

potential higher food reserve.

The cold storage period was possibly too short to make any differences between the periods employed (3, 8 and 15 days) in the 1983 study. On the other hand, these may be adequate short-term storage periods, since plants were in good condition before and after storage. Voth and Bringhurst (42) compared 30 days to 15 days storage and found that 15 days had advantage over the other. But Albregts and Howard (2 and 3) reported detrimental effects of storage at 2° C for two weeks or longer on Dover plants. This was reported to delay fruit production, increase plant size and occasionally reduced total fruit yield. In another study however, Albregts and Howard (1) cited that plant storage for 7 days at 2° C gave significant fruit yields as compared to non-stored plants. Most other studies based their investigations on longer storage periods that can not be directly compared to the present study. Such studies involved storage periods ranging between 6 weeks and 12 months (7, 20, 25, 26, 27, 34, 35, 37, 44, 47, 50, 51, 52).

The result of the preplant fungicide dip in 1983 was effective on increased plant dry weight while the 1985 results indicated no effect of the fungicide treatments. The significant benomyl effect from the former study is suspected not to be a direct effect of fungicide because there was considerable variability among treatment replications. Also, the analysis of variance for the dry weight (Table 7) showed a low probability level ($p = 0.095$). The results obtained from these studies (1983 and 1985) however, were not unexpected since plants were in good condition as was demonstrated by the culture tests. Mass and Scott (35), cited that benomyl is especially effective against Botrytis cineria. It

is important to note the different cultivar responses in both studies (Redchief for 1983, and Honeoye for 1985). The fungicide treatment had significant effect on Redchief cultivar (1983) and no effect on Honeoye (1985). Mass (33) reported that 4 out of 19 strawberry cultivars treated with benomyl showed no advantage over non-sprayed plants. It was also suggested that since considerable variation is often encountered when fungicides are used to control diseases of strawberry and since every cultivar is genetically unique, variation in response to treatment may be expected (33).

Field Studies

Plant response did not show any trends in the treatment interaction effects. All the interaction effects only had significant influence on runner development and not on yield. However, it can be deduced from the various interactions that storage at 12.7° C for 21 days with benomyl treatment was most effective, as regards moderate number of runners and highest fruit yield. It is notable from these treatment interactions that the treatments that induced the most runners produced about the lowest yields. This is in agreement with the findings of Albregts and Howard (2 and 3); Voth and Bringhurst (43); Worthington and Scott (51). Nevertheless, there is so much inconsistency between these treatments that it is not possible to follow a particular trend.

Also, in 1985 results, there were no clear trends to the interactions between cold storage temperatures and pre-plant fungicide treatments.

The results of the 1983 cold storage treatment indicated that storage at 12.7° C yielded the lowest number of runners but the highest

fruit yield the following season. Since plants at this temperature initiated growth in storage, this was possibly due to earlier plant growth, early runner establishment (plants were deblossomed), but were not excessive to be detrimental to plant performance. However, several studies have shown that the chilling history of the plants affect the growth rate and performance (6, 23, 42, 43). This implies that plants held at this high temperature had already received enough chilling either in the nursery before digging and/or in holding conditions after digging and during shipping, before they were recieved and stored for these studies. Hence, even though dormancy was broken in storage, they still produced adequate number of runners and subsequent high fruit yields. Bringhurst et. al. (6), suggested that differences in chilling history had a much greater influence on strawberry plant performance than differences in starch reserve. They also stated that the response in vigor of mature plants to a given period of chilling in storage was essentially equal to that of plants left in the nursery and receiving same chilling period in the field.

The 1.7° and 7.2° C treatments produced more runners but lower fruit yields as compared to that of the 12.7° C. This seems to agree with the study of Worthington and Scott (50), who reported that plants stored at 2.2° C were very vigorous and produced plant beds that were too dense (vegetative) for optimum yields. Also, Albregts and Howard (2 and 3) found that cold storage of transplants at 2° C made plant establishment difficult, in that it increased plant size, delayed fruit production and occasionally reduced total yield. Furthermore, Voth and Bringhurst (43), cited that when plants received too much chilling, they were very

vigorous producing more runners than fruits, but adequate chilling gave enough vigor to produce adequate runners and high fruit yields. Therefore, it is possible that preplant chilling was a principal factor concerned in vegetative versus sexual response, otherwise all plantings should have responded similarly since they were subjected to the same growing conditions (43).

In the 1985 field results, although there was no significant effect of temperature on fruit yield, there was apparent effect on runner development. This is similar to the 1983 result in which the lower temperature induced more runners than the higher temperature. Thus, this may be interpreted also as effect of chilling earlier cited (6, 23, 42, 43). On the other hand, since these 1985 plantings were not deblossomed (for treatment evaluation purposes), this low temperature effect could also be attributed to more carbohydrate reserve in these plants (6, 23). In addition, Worthington and Scott (51), in their study, compared April-, May- and June-set plantings and suggested that the planting with less runners (June-set) were superior in yield and fruit size. But where excess runners were removed from the April- and May-set plots, plant density was unified and there was no significant difference between the different plantings. Hence, it is evident that too many runners may reduce yield.

The lack of difference between the cold storage periods (8, 14, 21 days) in runner development, and fruit yield may be due to the fact that the plants were in a vigorous condition. This is similar to the greenhouse test result with no difference between 3, 8, and 15 days. Therefore, it could be suggested that any of these storage periods may be

appropriate for short-term storage requirements.

The field studies gave similar results as those of the greenhouse studies indicating a significant preplant fungicide effect in the 1983 study and no effect in that of 1985. Again, this might be due to the variability in strawberry cultivar response to treatments (33). Benomyl in the 1983 experiment seemed to promote runner development and did not influence fruit yield, this may be an adverse rather than a beneficial effect. Various studies have indicated that conditions that favor runner production tend to reduce fruit yield (2, 3, 43, 50, 51). This is probably due to the absence of storage pathogens that the fungicide could act on and so it induced some stimulatary effects that promoted runner development. This is contrary to the 1985 results, though the fungicide treatments were not significantly different from one another. Benomyl treatment seemed to produce the same number of runners as that of fosetyl-Al, but lower fruit yield, even lower than that of the control treatment (water dip) with slightly more runners. This seem to be a phytotoxic effect from the benomyl since there was no storage organism to act on. Fosetyl-Al, on the contrary, tended to influence fruit yield and could be attributed to its effect on the soil-borne pathogens in the field, especially Phytophthora fragariae causing red core disease of strawberries (36). However, since plants were in good condition before and after storage, it is not unexpected that there were no striking beneficial effects from the fungicide treatments. Previous studies that have indicated benefits from fungicide treatments were with diseased or deteriorated plants from storage, or treated before storage to prevent deterioration in long-term storage (4, 17, 20, 21, 33, 34, 35).

It is evident however, from both studies that temperature had the most influence on plant performance compared to storage period or preplant fungicide treatment.

In conclusion , it was deduced from these studies that obtaining good quality plants is of primary importance as indicated by low pathogen populations before and after storage. It is apparent that good handling during farm storage is important to maintain plant quality. Furthermore, none of the treatments drastically caused excessive plant damage and generally growing conditions were considerably good. Consequently there was no added stress after treatments and transplanting.

SUMMARY

Since plants in these studies were in good condition before and after cold storage as indicated by the pre- and post-storage isolations in 1983 and 1985 respectively, vigor and survival in both greenhouse and field plantings were exceptionally good. Cold storage temperatures between 10° and 12.7° C seemed to be suitable for plants that were received in March and stored for short periods between 7 to 21 days and still achieve good plant performance. Preplant fungicide dips did not prove to be beneficial in these tests and so may not be recommended for plants that are received from nurseries that provide optimum storage conditions prior to shipping good quality plants.

The main treatment effect, as has been deduced from these studies, is cold storage temperature. This is evident from the significant influence of cold storage temperature at 1.7° C on increased plant dry weight and 10° C on blossom development in the 1985 greenhouse studies. Also, both 1983 and 1985 field studies showed significant effects of cold storage temperature on runner production. The higher temperature treatments (10° and 12.7° C) induced fewer runners than the lower temperatures (1.7° and 7.2° C), indicating more vegetative plants at lower temperatures.

Within the range of conditions of these studies, it is evident that obtaining good quality plants as ascertained by pre- and post-storage isolations, and subjecting them to adequate preplant storage conditions will consequently result in optimum growth and yields with optimum growing conditions prevailing.

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EVALUATION OF PREPLANT STORAGE TREATMENTS AND SUBSEQUENT GROWTH RESPONSES OF STRAWBERRY PLANTS AFTER TRANSPLANTING

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ABSTRACT

Dormant strawberry plants of the cultivars 'Redchief' and 'Honeoye' were evaluated to determine the effects of various farm storage conditions on plants prior to spring transplanting. Comparisons involved greenhouse and field studies in 1983 and 1985 of preplant fungicide dips (water, benomyl and fosetyl-Al); cold storage temperatures (1.7°, 7.2° 10° and 12.7° C); and storage periods of 3, 8 15 days for greenhouse plants and 8, 15, 21 days for field plants (1983), and 10 days (1985). Pre- and post-storage isolation tests were also carried out and some organisms were isolated, but subsequent plant growth indicated no influence of such storage organisms.

Cold storage temperatures at 12.7° and 10° C in the 1983 and 1985 studies respectively reduced runner development and increased fruit yield. Cold storage period had no significant effect on any of the parameters measured. Preplant fungicide dip had no significant effect on plant performance, except in the 1983 study where benomyl dip increased plant dry weight and promoted runner development in the greenhouse and field tests respectively. This effect on runner development may not be desirable since plants were more vegetative at the expense of being fruitful.