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INTRODUCTION

The Oregon small fruits industry supplies fresh berries for local consumption and is the principal source for several fruits processed and marketed nationally and internationally. The blackberry/raspberry industry is comprised of approximately 800 growers and 20 packers who provide 98 percent of the black raspberries, 50 percent of the red raspberries, 85 percent of the blackberries, 50 percent of the Boysenberries, and 100 percent of the Loganberries harvested in the United States for processing (Schroeder, 1990). California overwhelmingly dominates the strawberry fresh market. However, commercial packers who provide a year-round supply of strawberry products are dependent upon 460 Oregon growers to provide 3,000 tons of superior quality strawberries (Anonymous, 1990).

Obviously, a disruption in the Northwest supply of berries affects the national supply. The fact that these crops are grown in such a limited geographic area reflects their specific climatic requirements. Unusual conditions, such as severe cold, have affected the crops periodically. For instance, cold injury reduced the blackberry harvest 64 percent in 1950, 27 percent in 1969, 70 percent in 1973, 30 percent in 1979, and 31 percent in 1989 (Brown, 1981; Brown, 1989; Sheets, 1974). Such severe injury has had unfortunate consequences for individual growers, suppliers, and end users.

Early assessment of winter injury would greatly benefit the industry. Growers could determine the advisability of further inputs (Brown, 1989; MacConnell, 1991; A. Sheets, pers. comm.) and packers could estimate supply and price. Unfortunately, early injury assesssment has not been reliable in strawberries and caneberries. The reasons for this include the subtlety of symptoms when plants are dormant and the unpredictability of subsequent weather. Also, the plants have the ability to regenerate a limited amount of healthy tissue, and/or may compensate with production from secondary and tertiary buds under favorable conditions (Jennings, 1988; Crandall, 1974).

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A review of literature available concerning cold hardiness of small fruit provides some indication of both the complexity of plant response to cold stress and the factors that influence subsequent attempts to assess damage to these crops.

REVIEW OF LITERATURE

The perceived solution to winter injury in berry crops is the breeding of hardier cultivars. This is a legitimate goal with numerous stumbling blocks, including the 10- to 15-year period from crossing to introduction. However, even hardier cultivars are not absolutely hardy.

The term "hardy" is misleading because it suggests an absolute (Proebsting and Mills, 1978). Hardiness, or specifically "cold hardiness," is actually a potential tolerance for cold, which can be achieved at some time during the year and sustained for some period of time if certain environmental conditions prevail. Winter injury to raspberries, blackberries, and strawberries in Oregon seldom occurs simply as the result of exposure to a low temperature, below the tolerance of the crop. Instead, damage occurs because the plants are stressed when they are not at their maximum level of hardiness.

In strawberries, cultivar differences in hardiness are primarily differences in ultimate mid-winter hardiness or absolute cold tolerance (Moore et al., 1990). Day-neutral cultivars tend to be less hardy than June-bearing cultivars, partly because of reduced accumulation of carbohydrates (Gagnon et al., 1990). Hardiness in *Rubus* genotypes is more complex and involves consideration of several components of cold tolerance: the ability to harden rapidly, the retention of cold resistance through deeper dormancy and longer rest, and the ability to reharden if initial resistance is lost. These characteristics are separate from, but just as important as, tolerance to absolute low temperature (Brierley and Landon, 1946; Baily, 1948; VanAdrichem, 1970) and ranking cultivars by cold tolerance can be enhanced by distinguishing between cultivars more vulnerable in fall, midwinter, and spring (MacConnell, 1991).

A plant becomes hardy by the cessation of extension growth in response to shorter days. Weiser (1970) describes acclimation after the cessation of growth as an active process, a sequence of metabolic and physical changes which occur as a plant becomes dormant, not "just something that happens when growth stops." The plant enters a rest period, when it must be exposed to a given number of hours in a specific temperature range before growth can recommence. This chilling requirement varies among species and cultivars of both *Fragaria* and *Rubus*. Rest is normally completed in most raspberry-producing regions in mid-December (Brierley and Landon, 1946; Jennings et al., 1972), although severe weather may hasten the cessation of rest (Baily, 1948).

After rest, the plant is generally responsive to ambient temperature, and mild spells in midwinter can lead to loss of hardiness, predisposing plants to injury by subsequent cold weather (Baily, 1948; Brierley and Landon, 1946; VanAdrichem, 1970). Rapid drops in temperature can be more injurious than the absolute minimum reached (Daniell and Crosby, 1971; Galletta and Bringhurst, 1990). Short-term changes in cold resistance in apple (Howell and Weiser, 1970), strawberry (Darrow, 1966; Galletta and Bringhurst, 1990), peach (Quamme, 1983), raspberry (Brierley and Landon, 1949; Brierley et al., 1954), and blackberry (Warmund et al., 1986) have been related to air temperatures immediately preceding injury. Red raspberries have been shown to lose hardiness after exposure to only a few hours at or above 39° F (Brierley and Landon, 1946) and show bud activity at 50° F (Baily, 1948). In some strawberries, plant functions increase rapidly when temperatures rise above 32° F, after hardening is completed (Darrow, 1966).

All plant parts are not equally hardy at a given time (Warmund et al., 1989; Cain and Andersen, 1979). Buds in terminal sections of the raspberry cane may break rest earlier and be more susceptible to winter injury than basal buds (Brierley and Landon, 1946; Jennings et al., 1972; Måge, 1975). Brierley and Landon (1946) showed that raspberry buds developed cold resistance more rapidly than cane tissue. Cane damage has been attributed primarily to injury to cambium and phloem tissue, which are less hardy than bud and xylem tissue (Warmund et al., 1986), and are not regenerated. Consequently, if the xylem is intact, fruiting laterals develop and grow until nutrient reserves are depleted. Collapse follows, when damaged phloem and cambium cannot meet demands of the rapidly growing tissues (Moore and Brown, 1971; Brierley and Landon, 1946).

Bud and xylem hardiness may be due to the ability to supercool (Warmund et al., 1989). The relationship between water within the plant and winter injury was recognized early, but has not been fully explained. Ice formation within the plant was initially thought to damage cell membranes. Another hypothesis was that intercellular water froze and precipitated the migration of intracellular water across membranes, dehydrating the cell. Recent evidence suggests that intracellular water in bud and xylem tissues can supercool, remaining in a viscous state below the freezing point and so preserving cell viability (Quamme, 1985; Warmund et al., 1989). Bud supercooling may be partially dependent on an absence of xylem cells within the bud, preventing migration of ice crystals into the bud, without which nucleation of water cannot occur (Ashworth, 1984; Quamme, 1983). Phloem and cambium tissues have not shown this ability to supercool.

Environmental conditions and cultural practices may influence hardiness. Both premature defoliation (Jennings et al., 1964; Jennings et al., 1972; Doughty et al., 1972) and prolonged fall growth (Måge, 1975; Crandall, 1974; Jennings et al., 1964) of red raspberry reduce potential hardiness. Late season application of nitrogen has been shown to prolong growth and delay dormancy (Crandall, 1974), and excess tissue nitrogen has been implicated in high water content of canes susceptible to winter injury (Jennings et al., 1964; Jennings et al., 1972; Jennings and Cormack, 1969). Weak raspberry plants without sufficient carbohydrate reserves show reduced hardiness (Doughty et al., 1972). In a study of deciduous fruit species, Proebsting and Mills (1978) attributed some variability in freeze injury to "unknown cultural factors."

Assessment of winter injury is nearly as complex as determination of the cause(s). Many diagnostic techniques have been developed, ranging in complexity from simple evaluations of regrowth to tissue-specific biochemical assays. Regrowth capacity, measured as percent budbreak and development, is a reliable procedure, but is slow and cumbersome because samples must be collected in the field and forced indoors (Calkins and Swanson, 1990; VanAdrichem, 1970). Regrowth in the field may not give an accurate measure of damage until late in the season, so it is useless as a management tool. For example, blackberries may exhibit seemingly healthy vegetation and flowers as late as April, but these can then fail as the demands of flowering and fruiting exceed the supply capabilities of damaged tissues (Moore and Brown, 1971).

In some plant materials, a single visual symptom, such as bud browning in grapes, may be an accurate indicator of degree of damage (Brusky-Odneal, 1983; Proebsting et al., 1980). However, in many cases assessment will focus on damage to the cambium, since this tissue is considered critical to the survival of the plant (Weiser, 1970). Strawberry pith browns readily in response to cold injury without apparent long-term damage, but browning of the narrow cambium layer outside the pith may kill the plant (Darrow, 1966). Because new growth and primary roots must develop from the crown, the adjacent cambium is critical (Crandall, 1974; Moore et al., 1990). Stress which does not kill the plant may result in alterations of growth patterns and lead to deformation of leaves (Marini and Boyce, 1979). Injury assessment in strawberry is primarily an assessment of the extent and location of cambial browning, the cambium at the crown being the most important.

In raspberries and blackberries, the interpretation of cold injury symptoms is not as clear. Doughty et al. (1972) ranked raspberry tissue from most to least vulnerable: pith at the bud base, cane pith, vascular cylinder at the bud base, and floral primordia. However, pith browning, as in the case of strawberry, has little effect on production, whereas browning of the cambium is destructive (Crandall, 1974). Secondary buds may compensate for injured buds, but cambial regeneration is limited in raspberry floricanes (Brierley, 1930). The cambium and associated tissues may sustain injury independently, and evaluation is complicated because the xylem, cambium, phloem, cortex, and periderm are difficult to separate visually (Quamme, 1985). Nevertheless, scales for rating the severity of cold injury have been developed. Brierley and Landon (1949) devised a typical scale for raspberry symptoms. Similar scales have been made more meaningful by accompanying photographs and/or drawings (Darrow, 1966). Variations in cultivar, sampling method, and sampling time must be taken into consideration when scales are developed.

The development of strawberry, raspberry, and blackberry cultivars with all desirable horticultural and fruit qualities and the ability to sustain maximum hardiness throughout a prolonged period (December-March) would be ideal, but seems unlikely. For the present, the small fruits industry must concentrate on manipulating cultural practices to maximize hardiness of existing plantings. The need for injury assessment, as well as damage control, is apparent.

WINTER INJURY IN OREGON 1990-91

Cold injury became an issue again in the Oregon small fruits industry during the winter of 1990/91. Mild conditions during the first half of December preceded a precipitous drop in temperature to extreme lows during the middle of the month, followed by unusual warming in January. According to National Weather Service data gathered at ten sites throughout the small fruits production area, early and mid-December minimum temperatures were slightly above the ten-year average (George Taylor, pers. comm.). The minimum temperature at the North Willamette Research and Extension Center (NWREC) on December 18 was 40° F, compared to a ten-year average of 32° F. Minimum temperatures at the NWREC fell 17, 13, and 10° in the following three days to reach a minimum of 0° F on December 21, compared to a ten-year average of 29° F on that date (Figure 1).

After four days of sustained cold, a quick warming trend (33° F in two days) was followed by quick cooling (32° F in two days). This pattern was typical of all small fruit production areas within the Willamette Valley and was followed by a period of warm temperatures in mid-January. At the NWREC on January 13, minimum and maximum temperatures were 52 and 60° F, respectively. Active plant growth is expected in that temperature range, provided the chilling requirement has been satisfied.

The extreme low temperature during mid-December could in itself cause injury in strawberry, raspberry, and blackberry, and the extent of injury may have been increased by both the mild conditions early in the month and the variability later. Examination of strawberry, raspberry, and blackberry plant parts indicated some damage. Both cultural and marketing issues arose. Should raspberry and blackberry fields be trained? Should old or marginal strawberry fields be removed? Should fertilizers and pesticides be applied? Should customers be notified and/or marketing activities suspended? Decisions would have been much easier if reliable estimates of yield potential were available to the industry (Brown, 1989; MacConnell, 1991; Sheets, pers. comm.)

The apparent extent of the injury suggested that blackberry and raspberry growers might qualify for federal disaster assistance. However, to qualify for such assistance, crop loss must be documented within ninety days of the occurrence of injury. This is an impossibility with existing assessment methods. Under these circumstances, we conducted a broad survey of injury in commercial fields of strawberry, red and black raspberry, and trailing blackberry in the spring of 1991. The objectives were to characterize the 1990 freeze and to establish the feasibility of early assessment of yield potential of winter-damaged fields. The survey was designed to cover representative growing areas, major cultivars, young and mature plantings, and the most common planting and training systems.

STRAWBERRY

Methods

Processor fieldmen selected 48 strawberry fields to represent major growing areas and cultivars proportionately: 27 'Totem', 11 'Benton', 3 'Sumas', 2 'Redcrest', and 1 each of 'Shuksan', 'Shuswap', 'Hood', 'Olympus', and 'Tioga'. Fields were sampled during cool wet weather from March 12 to 29, 1991.

Samples were taken along an average mid-field row or diagonally across rows to account for site variation. Samples were primarily mother plants in first-year fields and daughters in older fields. Twelve plants at each site were dug and cut with sharp pruners lengthwise from the growing point through the core to produce half sections with 1) primary bud (growing point), 2) core (pith), and 3) cambium/vascular tissue exposed for rating on a 5-point scale: 1 = intact/healthy to 5 = dead.

A healthy growing point exhibited light green firm tissue, immature leaves, and occasionally immature flowers. Healthy core tissue was uniformly creamy or pink, depending on cultivar, and neither watery nor dry; damaged pith was mottled or uniformly dark brown, sometimes water-soaked and sometimes dry. Healthy cambium/vascular tissue was an almost continuous firm, light band surrounding the core, not brown, watery, or exfoliating.

Information on age, site, weather, cultural practices, and yield was obtained by interviews with processor fieldmen and/or growers. The planting system, single- or double-matted row, or double-row-raised-bed, was noted.

Results

Means of injury ratings and yield for the major commercial cultivars across all fields and planting systems indicate that all strawberry plants sustained some injury to core pith, growing point, and vascular tissue. With the rating system used, the growing point consistently exhibited least injury and the vascular system most.

There were no meaningful differences between 'Totem' and 'Benton' in injury symptoms, but differences in both yield and percent crop reduction were observed. There was no correlation between injury and yield. Growers expected and realized greater yield from 'Totem' than from 'Benton'. Yields of 'Benton' were reduced more than those of 'Totem' (Table 1).

Planting age had no significant effect on injury of 'Totem' and 'Benton'. Actual yield was not correlated with any injury symptoms. Although growers did not anticipate yield differences based on age, first-year fields out-produced older fields (Table 2). Planting system had a significant effect on core discoloration and cambium/vascular tissue injury of

'Totem' and 'Benton'. Plants in the double row-raised bed system had more injury than the matted single or double row. However, planting system had no effect on yield and there was no correlation between injury and yield (Table 3).

Discussion

In 1991, Oregon strawberry production was down 16 percent from 1990. The relatively small crop reduction following severe winter conditions has been attributed to good plant recovery during a cool, wet spring and to a thorough harvest. Plants were exposed to little stress from April through June. Weather data recorded at NWREC is representative of conditions across the growing area. Daily maximum temperatures were consistently in the 50's and 60's, and minimums in the high 30's and 40's through early June. Precipitation was adequate and well distributed: 4.6 in. over 17 days in April, 4.6 in. over 13 days in May, and 2.4 in. over 12 days in June. To some extent, the effects of winter injury may have been overcome, rendering potential correlations between injury ratings and yield insignificant.

In summary, injury ratings did not differ between cultivar and age groups. Injury ratings in the double row-raised bed system were not correlated with yield, perhaps because of the advantages for recovery provided by the same system. The crowns of plants in raised beds are exposed to more severe temperature fluctuations than crowns planted in level field. However, raised beds may allow greater opportunity for recovery, in that they warm faster and drain better in cool wet spring weather. Differences in actual yield in 'Totem' and 'Benton' reflected both a greater yield potential for 'Totem' and a smaller yield reduction resulting from winter injury.

Although the number of 'Redcrest' fields was too small to allow statistical analysis, observations suggest that this cultivar may have good potential for recovery from winter injury. First-year fields performed better in 1991, even though second-year fields traditionally out-produce first-year fields. The additional canopy in young fields may have protected the crown from injury.

BLACK RASPBERRY

Methods

Twenty-five 'Munger' black raspberry fields identified by processor fieldmen as representative of the Willamette Valley production area were sampled during cool wet weather from March 18 to April 9, 1991.

Samples were taken from ten plants along representative rows or diagonally across a field to account for variation. Individual plants were discernible although all fields were pruned to hedges approximately 3 ft. x 3 ft. (1 m x 1 m). The number of canes was recorded, and a single representative cane was cut at 18 in. (45 cm) above ground for evaluation of the cambium in cross section on a 1 to 5 scale (lower vascular tissue). A continuous ring of uniform, firm, light green tissue was rated 1 and a continuous ring of dark tissue or dry white tissue was rated 5.

A 1.5 in. (3.75 cm) bud section was taken from the main bearing area of each of three canes from the same plant. Two cuts were made with sharp pruners through the bud to expose the growing point, the pith at the base of the same bud, and the vascular tissue near the bud base (upper vascular tissue): 1) transversely on a diagonal through the cane from below and opposite the bud up through the bud base and 2) longitudinally through the bud and cane to produce halves with exposed growing point, pith, and cambium. In some cases, a secondary bud was developing in conjunction with a failing/failed primary.

The growing point, the pith, and the vascular tissue of each bud section were again rated on a 1 to 5 scale. A healthy growing point exhibited a firm bright green bud or breaking lateral and was rated 1; dead buds were papery dry, shrunken, and brown or black and were rated 5. The characteristic shield-shaped pith at the bud base ranged from a creamy color almost indiscernible from healthy cane pith, to dark brown and watery. The cane bark was scraped to expose the underlying vascular tissue. This exposed tissue ranged from moist and bright green and purple to dark brown or dry, stringy, and pale.

Information on age, site, weather, cultural practices, and yield was obtained from processor fieldmen and/or the growers themselves.

Results

Oregon black raspberry production is fairly standardized with 'Munger' grown in continuous hedgerows. Age and exposure are the major variables from field to field.

Older plantings had greater lower vascular discoloration and growing point damage than young fields (Table 4). Older fields also exhibited greater percent yield reduction. Cane number showed a significant negative correlation with upper vascular tissue discoloration ($r = -0.51$) while upper vascular tissue discoloration was negatively correlated with yield ($r = -0.55$) and positively correlated with percent yield reduction ($r = 0.35$).

Discussion

In 1991, Oregon black raspberry production was down 48 percent from 1990. Low yield in black raspberry was attributed primarily to winter injury, but also to reduced bee activity and poor pollination because of cool, wet weather during bloom. Poor pollination results in crumbly fruit which cannot be harvested.

The negative correlation between cane number and upper vascular tissue damage suggests that a more vigorous plant may be more tolerant of low temperature. The negative correlation between upper vascular tissue discoloration and yield reduction suggests that this symptom can be used as an predictor of yield. Refining the sampling procedure and defining symptoms for consistency and easy recognition could provide a dependable tool for rating winter injury.

The failure of black raspberry to recover from winter injury under favorable spring conditions in 1991 makes early assessment promising.

RED RASPBERRY

Methods

Processor fieldmen selected 48 red raspberry fields distributed throughout the Willamette Valley production area for evaluation: 23 'Willamette' and 25 'Meeker'. Samples were taken during cool wet weather from March 12 to April 8, 1991, and again from April 23 to May 10, 1991. Sampling method was identical to that used in black raspberry (see above).

The same fields were sampled again during fruit lateral development and flower bud break. Three canes from each of ten plants were evaluated for number of buds in the main bearing area, the number of lateral buds developing normally, and the number of buds both broken and failed in the same section.

Information on age, site, weather, cultural practices, and yield was obtained by interviews with processor fieldmen and/or growers. Training system was noted: bundles cut above the wire, bundles looped and tied to the wire, or individual canes secured at the wire and topped.

Results

'Willamette' had a higher average cane number per plant than 'Meeker', although yield and cane number were not related. There was a significant difference between cultivars in percent yield reduction. 'Meeker' produced 70 percent of the estimated crop; 'Willamette' produced only 56 percent of the expected yield (Table 5).

There were few differences in injury attributable to field age. Older fields had more lower vascular tissue damage and more canes, but fewer buds per cane section than younger fields. Younger fields had more upper vascular system damage and a greater percent bud failure. However, young and old fields did not differ in yield or percent yield reduction.

There were no differences in injury attributable to training system. Yield from looped bundles was not significantly different from yield from topped bundles or individually secured canes, but individually secured canes produced more than topped bundles.

The correlation analyses showed a highly significant negative correlation between percent unhealthy canes per hill and yield (r = -0.44) and between both upper and lower vascular tissue discoloration and yield (r = -0.50 and r = -0.49, respectively). Bud pith discoloration, another early symptom, correlated negatively with yield (r = -0.36). Percent bud break and yield were positively correlated (r = 0.59).

Percent yield reduction was correlated with percent unhealthy canes (r = 0.53), lower and upper vascular system damage (r = 0.43 and r = 0.41, respectively), and bud pith discoloration (r = 0.30). Percent bud break and percent yield reduction were negatively correlated (r = -0.46).

Discussion

In 1991, Oregon red raspberry production declined 27 percent from 1990. As in the case of strawberry, crop loss in red raspberry may have been reduced by moderate spring temperatures and adequate rainfall, which may have allowed some compensation to occur. Plants were exposed to little stress from April through June.

Several injury variables which may be useful assessment tools were identified. Although unhealthy canes were clearly associated with yield reduction, the number of obviously unhealthy canes is limited and did not account for all injury. Bud base pith evaluation could easily be standardized, but the relationship to yield reduction was not as strong as the relationship of upper vascular tissue discoloration with yield reduction. Lower vascular tissue damage was consistent and easily quantified, but limited in comparison with upper vascular tissue damage. Upper vascular tissue discoloration was more variable and more difficult to standardize, but appears in more samples, possibly because upper cane sections are thinner and may be more easily damaged.

Although percent bud break is a reliable indicator of yield, it occurs too late in the season. By bud break, a grower may have made many investments in fertilizer, pesticides, and labor.

In summary, upper vascular tissue discoloration and bud base pith show promise as early indicators of yield and deserve further study and refinement.

TRAILING BLACKBERRY

Methods

Between 15 March and 19 April 1991, freeze damage to 'Marion', 'Thornless Evergreen' and 'Boysen' trailing blackberry was assessed. An attempt was also made to assess damage to the newer cultivars 'Kotata' and 'Waldo'. A total of 34 'Marion', 14 'Thornless Evergreen', 18 'Boysen', 4 'Kotata', and 5 'Waldo' fields were selected by processor fieldmen and rated individually. These fields were all commercial operations located in four principal growing regions: Hillsboro/Forest Grove, Woodburn, Dundee-Independence (west of the Willamette River), and Sandy.

Each field was categorized by region, cultivar, age of the plants (4 harvest seasons or fewer, and more than 4 harvests), time of training to the trellis (summer or winter), alternate year (AY) or every year (EY) production system, and whether plants were trained to a single wire or multiple wire trellis. Within each field, regardless of size, 10 individual plants were selected for evaluation. The field was sampled in a diagonal pattern, although if large topographical variations existed, the sampling pattern was adjusted to reflect the field variation.

Plants were selected randomly, and rated individually for cane number per plant and the number of dead canes per plant. A cane was considered dead if it was obviously shrivelled and discolored. Damage to the lower vascular tissue was rated by scraping away the bark about 12 inches (30 cm) above ground level, and estimating the percentage of the tissue that was discolored, regardless of severity. The bud base, growing point, and upper vascular tissue were rated by selecting three buds per plant along the length of the canes, splitting them longitudinally, and rating the tissues on the 1 to 5 scale.

Between 21 and 24 May, the same fields were rated for percent budbreak. Because growth was well advanced at this time, this was done by a simple visual estimation on 10 individual plants. The percentage of the elongating laterals that had wilted was also assessed. In addition to the injury ratings, the "normal" or average yield was obtained for each field, as were details about winter conditions and any other observations on field performance that the fieldman or grower was able to provide. Following harvest, yield data for each field was obtained, if possible. These data were unavailable for 13 of the fields, usually because the canes were mowed off prior to harvest. In some other cases, an accurate estimate of yield for a given field was impossible to make because of specific harvest practices.

Results

Table 6 summarizes the effect of region on the variables measured. While there was no difference among regions in cane number, the percentage unhealthy canes varied significantly. Generally speaking, the Sandy and Hillsboro-Forest Grove regions showed the highest cane death, while the west river region had the lowest. This trend was also evident for damage to the lower and upper cambium and bud base.

The west river region showed the highest budbreak and the Sandy region the lowest. Normal yields were found to be highest in the Hillsboro region, intermediate in the west river and Woodburn regions, and lowest in the Sandy region. It was not possible to show a significant difference between regions for actual yield in 1991, nor percentage reduction in yield at the 10 percent level (Table 6).

Table 7 summarizes the performances of the five cultivars over all growing regions. The percentage dead canes varied from 22 and 21 percent for 'Marion' and 'Waldo', to 0 percent for 'Thornless Evergreen'. Discoloration of the lower cambium was generally greatest on 'Waldo' compared to the other cultivars. Ratings of growing point discoloration tended to show that 'Waldo' and 'Thornless Evergreen' exhibited the most discoloration. The bud base of these cultivars also exhibited greater discoloration than the others, followed by 'Marion', 'Boysen', and 'Kotata'. This pattern was also evident in the rating of upper cambium discoloration, which was greatest in 'Waldo', 'Thornless Evergreen', and 'Marion', and less evident in 'Boysen' and 'Kotata' (Table 7).

Despite notable differences in percent budbreak for each cultivar, these were not significant at the 10 percent level. 'Thornless Evergreen' had the highest percent budbreak and tended to have the highest yield. Differences amongst cultivars in percent reduction in yield were not significant at the 10 percent level (Table 7).

Results for field age, time of training, AY or EY production, and trellis type produced few significant differences. The young fields produced slightly fewer canes and had slightly higher budbreak (Table 8). Time of training had an effect on the percent dead canes, with winter-trained having less damage (Table 9). Normal yield was also higher on the summer-trained fields, but there was no significant difference in percent reduction in yield (Table 9). There were no significant differences in injury attributable to either AY or EY production, or to the type of trellis used.

Percent yield reduction in 'Marion' was positively correlated with percent dead canes ($r = 0.54$), lower and upper vascular discoloration ($r = 0.63$ and $r = 0.55$, respectively), and negatively correlated with percent budbreak ($r = -0.64$). Results of the correlation analyses were less satisfactory for the other cultivars, particularly 'Kotata' and 'Waldo', probably because, for each of these, full data were only available for a few fields.

<u>Discussion</u>

The results of the regional analysis show that, generally speaking, the west river area suffered less damage than other regions, and that damage tended to be worse around Hillsboro and particularly the Sandy region. Within a given region, however, the damage to individual fields of a given cultivar could be quite variable. The Sandy region had some of the most heavily damaged fields of all cultivars, including 'Thornless Evergreen', but possibly the worst field of this cultivar was found in a bowl-shaped depression east of Salem in the Waldo Hills. Damage to 'Marion' in the Woodburn area varied noticeably from field to field.

This variability suggests that the microclimate of a given field determines in large part the extent of injury. Low temperature and windspeed varied considerably from field to field in each region, although accurate data are not available in most cases. Informal observations suggest that many other factors can play a role in determining injury. In the

Sandy region, many fields are situated in hilly areas and have noticeable depressions and valleys where damage was obviously worse. The presence of a substantial windbreak around a field seemed to reduce injury in some cases, while merely serving as a trap for cold air in others, and hence increasing damage.

Another factor which may influence the degree of injury is the drainage of the field. Several of the most heavily damaged fields showed evidence of poor drainage. An example of this was a field of 'Waldo' that had an area of standing water near its edge. Cane growth in this area was comparable, while budbreak was only a fraction of that in the rest of the field. Disease control also seems to be important. Several of the fields visited had severe cane disease problems which represented some yield loss, but in combination with the cold may have significantly increased damage. In some cases, it was difficult to differentiate between cold injury and disease. Both 'Marion', and especially 'Waldo', seem susceptible to fungal cane pathogens, and may benefit the most from a comprehensive disease control program.

The comparison of the cultivars over all regions shows that 'Thornless Evergreen' exhibits the greatest cold hardiness of the cultivars examined. 'Marion' and 'Waldo' generally showed the least hardiness, while 'Kotata' and 'Boysen' were similar. Field age had essentially no effect on cold hardiness. However, time of training did have some effect on winter injury. Aside from the slightly higher cane death in summer-trained fields, observations suggested that those trained in mid-September and even October could suffer more damage than August trained plants. The care with which the canes were trained by the crews also seemed to be part of this--sloppily trained sections of a field could suffer more injury than carefully trained sections. The EY fields seemed to suffer no more injury than AY fields. Trellis type also had little effect, although it did appear in many cases that those parts of the cane below the trellis wire had higher budbreak than the section wrapped about the wire(s).

The results of the correlation analyses illustrate the benefits of an adequate sample size. The sample size for 'Marion' was by far the largest of the five cultivars, and the correlations were the strongest. Percent dead canes, lower cambium discoloration, and upper cambium discoloration were all well correlated with percent yield reduction. With refinement, these could serve as the basis for an system of early damage assessment for this cultivar. The estimates of primary bud discoloration, and bud base discoloration, are probably unsuitable unless sample numbers per plant were to be radically increased. The reason for this is that bud performance varies considerably on a given plant, or even a given cane, and it is difficult to sample randomly in this situation, since the eye is inevitably drawn to those buds that are most prominent. A reasonably small sample that is representative of plant performance is, therefore, difficult to obtain.

The success of this procedure with the other cultivars was less obvious. In the case of 'Thornless Evergreen', this cultivar could benefit from a later sampling date than the other cultivars. The structure of the buds, which are more compressed before elongation than the other cultivars, makes evaluation of their viability more difficult. Cane coloration of 'Thornless Evergreen' also tends to be somewhat different than the other cultivars, so it is important not to be misled by characteristics specific to a cultivar. Nonetheless, the ratings of upper cambium damage were well correlated with subsequent yield reduction. The sample size of 'Boysen' was comparable to that of 'Thornless Evergreen', yet none of the variables were related to yield reduction.

SUMMARY

Statewide losses to freeze damage in small fruit crops varied widely in 1991. Strawberry production declined 16 percent, red raspberry 27 percent, and black raspberry 48 percent. Losses in trailing blackberry production depended on the cultivar: 'Marion' production declined 70 percent, 'Boysen' 17 percent, and 'Thornless Evergreen' 15 percent. The figures illustrate the vulnerability of these crops to cold injury and the value of a means to accurately assess damage during early spring.

The methods used for this survey show potential for forming part of a system for accurately predicting yield potential of fields based on symptoms in early spring. The most promising results with these methods were obtained with black and red raspberry and 'Marion' blackberry. It should be possible to refine the procedures to produce more efficient sampling and consistent and accurate yield prediction. An effort should also be made to develop methods for strawberry and the other trailing blackberry cultivars. In the case of blackberry, this may simply involve a larger sample size, but strawberry may require alternative sampling methods.

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Figure 1. Daily air temperature at the NWREC, December 1990 and January 1991.

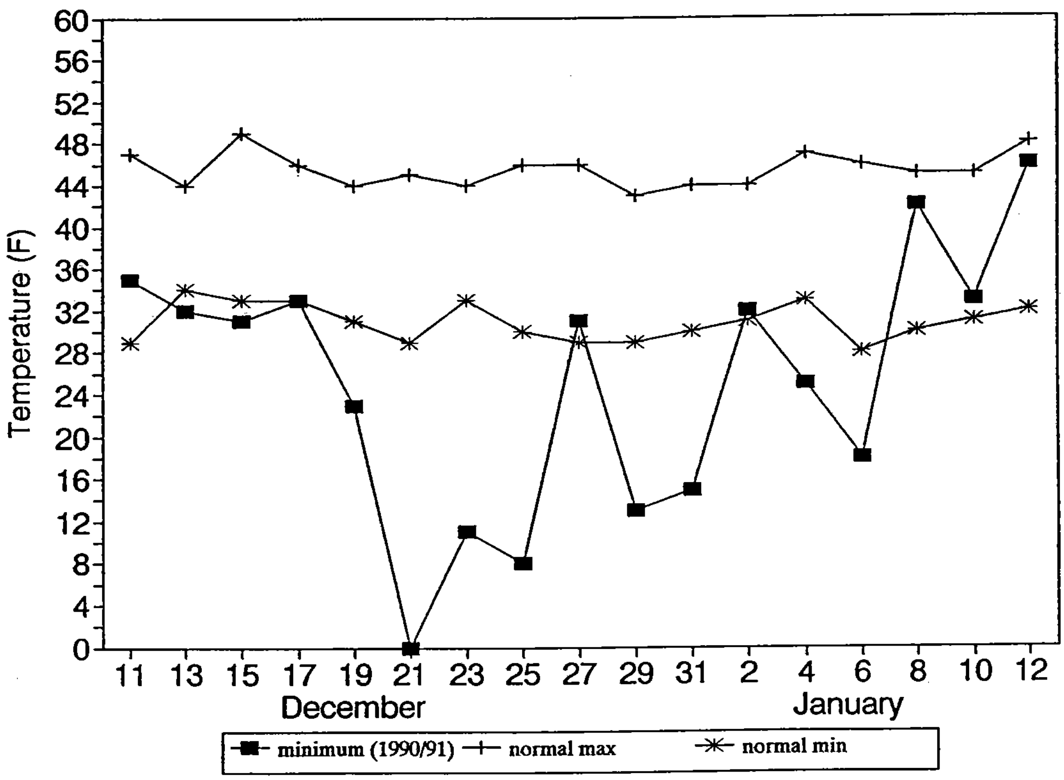

Table 1. **Injury and yield in strawberry cultivars, 1991.**

Cultivar	N	CORE	GPT	CAM	NYL	AYL	% RED
Totem	29	1.8	1.1	2.5	8.7	7.1	21
Benton	11	1.8	1.4	2.3	6.5	4.3	33
Sig.		NS	**	NS	**	**	**

Table 2. **Injury and yield in strawberry cultivars 'Benton' and 'Totem' by field age, 1991.**

Age	N	CORE	GPT	CAM	NYL	AYL	% RED
1 yr	14	1.7	1.1	2.4	8.6	7.9 a	15
2+3 yr	15	1.8	1.2	2.5	8.0	5.8 b	27
≥4 yr	11	1.9	1.3	2.5	7.5	5.0 b	32
Sig.		NS	NS	NS	NS	**	NS

CORE = core discoloration, GPT = growing point discoloration, CAM = cambium discoloration, NYL = normal yield, AYL = actual yield in 1991, % RED = percent yield reduction from normal. **, NS = significant at 5 percent level or not significant, respectively.

Table 3. **Injury and yield in strawberry cultivars 'Benton' and 'Totem' by planting system, 1991.**

System	N	CORE	GPT	CAM	NYL	AYL	% RED
MSR	31	1.6 b	1.2	2.2 b	8.1	6.5	23
DRB	6	2.9 a	1.1	3.6 a	8.1	6.3	18
MDR	3	1.6 b	1.1	2.3 b	8.0	4.8	44
Sig.		**	NS	**	NS	NS	NS

Planting system: MSR = matted single row, DRB = double row raised bed, MDR = matted double row. CORE = core discoloration, GPT = growing point discoloration, CAM = cambium discoloration, NYL = normal yield, AYL = actual yield in 1991, % RED = percent yield reduction from normal. **, NS = significant at 5 percent level or not significant, respectively.

Table 4. **Injury and yield in black raspberry by field age, 1991.**

Age	N	LCM	GPT	BP	UCM	NYL	AYL	% RED
1+2 yr	6	1.1	1.1	2.4	2.7	1.3	1.0	29
≥ 3 yr	19	1.4	1.3	2.5	2.7	1.5	0.8	49
Sig.		***	***	NS	NS	NS	NS	*

LCM = lower cambium discoloration, GPT = growing point discoloration, BP = bud pith discoloration, UCM = upper cambium discoloration, NYL = normal yield, AYL = actual yield in 1991, % RED = percent yield reduction from normal. ***, *, NS = significant at 1 percent or 10 percent level, or not significant, respectively.

Table 5. Injury and yield in red raspberry cultivars, 1991.

Cultivar	N	CNS	LCM	GPT	BP	UCM	% BF	NYL	AYL	% RED
Meeker	25	12	1.3	1.4	2.8	3.0	14	3.8	2.7	30
Willamette	23	15	1.6	1.3	2.9	3.3	17	2.8	1.6	44
Sig.		**	NS	NS	NS	NS	**	***	***	**

CNS = cane number, LCM = lower cambium discoloration, GPT = growing point discoloration, BP = bud pith discoloration, UCM = upper cambium discoloration, % BF = percent bud failure, NYL = normal yield, AYL = actual yield in 1991, % RED = percent yield reduction from normal. ***, **, NS = significant at 1 percent or 5 percent level, or not significant, respectively.

Table 6. **Injury and yield in trailing blackberry cultivars 'Marion', 'Thornless Evergreen', 'Boysen', 'Kotata', and 'Waldo' by region, 1991.**

Region	N	CNS	% DEAD	LCM	GPT	BP	UCM	% BB	NYL	AYL	% RED
H/FG	12	14	22 a	38 a	1.2	2.9 bc	2.2 ab	50 b	6.8 a	3.0	55
W	35	12	14 ab	35 a	1.5	2.8 b	2.1 bc	54 b	4.6 bc	3.0	34
D-I	20	15	6 b	26 b	1.3	2.6 c	1.9 c	70 a	5.3 b	3.4	36
S	8	13	27 a	45 a	1.5	3.3 a	2.5 a	36 c	3.9 c	1.8	57
Sig.		NS	***	**	NS	***	**	**	***	NS	NS

Regions: H/FG = Hillsboro/Forest Grove, W = Woodburn, D-I = Dundee to Independence, S = Sandy. CNS = cane number, % DEAD = percent dead canes, LCM = percent of lower cambium discolored, GPT = growing point discoloration, BP = bud pith discoloration, UCM = upper cambium discoloration, % BB = percent budbreak, NYL = normal yield, AYL = actual yield in 1991, % RED = percent yield reduction from normal. ***, **, NS = significant at 1 percent or 5 percent level, or not significant, respectively.

Table 7. **Injury and yield in trailing blackberry cultivars, 1991.**

Cultivar	N	CNS	% DEAD	LCM	GPT	BP	UCM	% BB	NYL	AYL	% RED
Marion	27	13 b	22 a	31 b	1.3 b	2.9 b	2.2 ab	45	4.9 b	2.5 b	49
T. Evergreen	12	12 b	0 c	33 b	2.0 a	3.2 a	2.3 a	71	6.4 a	4.7 a	30
Boysen	14	16 a	9 b	37 ab	1.1 b	2.5 c	1.8 b	64	4.0 c	2.6 b	35
Kotata	4	18 a	12 b	30 b	1.0 b	2.3 c	1.7 b	68	5.7 ab	3.4 ab	34
Waldo	3	9 b	21 ab	48 a	2.1 a	3.0 ab	2.3 a	43	6.8 a	2.6 b	54
Sig.		**	***	*	***	***	*	NS	***	***	NS

CNS = cane number, % DEAD = percent dead canes, LCM = percent lower cambium discolored, GPT = growing point discoloration, BP = bud pith discoloration, UCM = upper cambium discoloration, % BB = percent budbreak, NYL = normal yield, AYL = actual yield in 1991, % RED = percent yield reduction from normal. ***, **, *, NS = significant at 1 percent, 5 percent, or 10 percent level, or not significant, respectively.

Table 8. **Injury and yield in trailing blackberry cultivars 'Marion', 'Thornless Evergreen', 'Boysen', 'Kotata,' and 'Waldo' by field age, 1991.**

Age	N	CNS	% DEAD	LCM	GPT	BP	UCM	% BB	NYL	AYL	% RED
≤4 Harvests	21	11	12	39	1.6	2.8	2.1	62	5.5	3.5	35
>4 Harvests	49	14	15	32	1.3	2.9	2.1	54	5.0	2.8	44
Sig.		***	NS	NS	**	NS	NS	*	NS	NS	NS

Table 9. **Injury and yield in trailing blackberry cultivars 'Marion', 'Thornless Evergreen', 'Boysen', 'Kotata', and 'Waldo' by training time, 1991.**

Time	N	CNS	% DEAD	LCM	GPT	BP	UCM	% BB	NYL	AYL	% RED
Summer	42	13	17	33	1.3	2.9	2.1	56	5.5	3.1	43
Spring	28	12	9	34	1.5	2.8	2.0	56	4.4	2.8	37
Sig.		NS	*	NS	NS	NS	NS	NS	***	NS	NS

CNS = cane number, % DEAD = percent dead canes, LCM = percent lower cambium discolored, GPT = growing point discoloration, BP = bud pith discoloration, UCM = upper cambium discoloration, % BB = percent budbreak, NYL = normal yield, AYL = actual yield in 1991, % RED = percent yield reduction from normal. ***, *, NS = significant at 1 percent or 10 percent level, or not significant, respectively.