THESIS

EFFECTS OF SIMULATED HAIL INJURY ON POTATO STEM ANATOMY AND YIELD

Submitted by

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY JERRY WAYNE GOUGH ENTITLED EFFECTS OF SIMULATED HAIL INJURY ON POTATO STEM ANATOMY AND YIELD BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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ABSTRACT OF THESIS

EFFECTS OF SIMULATED HAIL INJURY ON POTATO STEM ANATOMY AND YIELD

The principle objective of this study was to define the effects of defoliation and stem bruising on potato tuber yield. Secondary objectives were to determine difference in cultivar response and the influence of bruising on the potato stem vascular system. The work was supported in part by the National Crop Insurance Association. The data obtained will be used by insurance personnel in conjunction with loss tables to estimate losses.

The influence of defoliation, bruising and plant age on potato yield was determined in a factorial experiment with three replications. Four potato cultivars were compared with a standard cultivar ('Russet Burbank') involving injury at three stages of growth. Injury treatments were applied by hand. Yield loss relative to non-injured plants was determined at the end of the season. Photomicrographs were taken of bruises on stem sections at one, three, five and seven weeks after bruising to follow changes in the vascular system.

Defoliation resulted in the removal of active photosynthetic leaf area. Bruising disrupted the plant canopy and interrupted the vascular transport system. Both types of injury reduced total and market yields with larger losses resulting from more severe injury.

However, losses were not linearly related to the degree of injury. This was attributed to the physiological and morphological regenerative potential of the potato plant. When defoliation and bruising were applied in different combinations losses were additive. Within the scope of this study, the most sensitive stage of plant development was about six to seven weeks after emergence.

Three early maturing cultivars responded to injury significantly different than the 'Russet Burbank' cultivar when injured three weeks from emergence. However, they responded similarly when injured six and nine weeks from emergence. Thus, loss charts prepared for the 'Russet Burbank' cultivar could be used later in the season with the three early maturing cultivars.

Photomicrographs taken of bruised stem sections showed that the potato plant was able to withstand injury and still maintain a certain amount of functional vascular system. This is because the vascular system is well protected by various support cells, and most of the damage to the stem was absorbed by these cells. The vascular system is also complex with a high degree of anastomosing between its leaf traces.

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CHAPTER I

INTRODUCTION

In the field, the potato plant is influenced by all climatic factors. Hail is an adverse factor which may delay plant growth and therefore lower tuber yields.

To reduce financial losses due to hail, growers purchase crop insurance. Following hail storms insurance adjusters are expected to give unbiased evaluations of plant damage occurring in insured fields. Plant damage and plant age are then used in conjunction with previously prepared loss charts to estimate yield losses. Predicting the effect of plant damage (defoliation, bruising, etc.) is difficult. One reason is a lack of understanding how specific types of plant damage influence yield.

It has been postulated that estimated losses often exceed the actual losses. Part of the reason for this may be over emphasis on plant damage resulting from defoliation and/or bruising.

Bruising may break epidermal tissues and disrupt the vascular system of the plant, thus reducing yield. Defoliation may also reduce yield, through removal of active photosynthetic leaf area. The stage of plant growth at which injury occurs is also important in estimating yield reductions.

Simulated hail damage studies have been done in the San Luis Valley of Colorado and in other states as well. San Luis Valley plants were injured with hand held flails or high velocity ice blowers. Injury resulted in defoliation, bruising and broken stems. Plants were injured on various dates, and the percentage damage was estimated and losses determined at the end of the season. Loss charts for use in Colorado have been prepared from these studies for 'Russet Burbank' and 'Red McClure'. More work has been done with 'Russet Burbank'. Other cultivars are grown in Colorado, but their volume does not warrant the extensive work previously conducted with 'Russet Burbank'.

In the studies reported here defoliation and/or bruising treatments were applied by hand to several cultivars to compare their response with 'Russet Burbank' and to define the influence of these two types of injury on yield reduction. In addition stem sections through bruised regions were selected at various times and prepared for microscopic evaluation. This was done with 'Russet Burbank' to determine what changes occur in the vascular system following severe stem injury.

The objectives were the following:

A. To differentiate between the effects of bruising and defoliation on potato yields and to evaluate their interactions.

B. To compare the injury response of other cultivars to 'Russet Burbank'.

C. Develop a better understanding of the influence of bruising injury on the vascular transport system.

CHAPTER II

REVIEW OF LITERATURE

Anatomy

The nightshade family, Solanaceae, contains many important crops including: potato, _Solanum tuberosum_; eggplant, _Solanum melogena_; tobacco, _Nicotiana tabacum_ and tomato, _Lycopericum esculentum_.

Dimond _et al._ (14) have described the vascular network and anatomy of the tomato plant. Except for leaf arrangement, the vascular system is similar to that of the potato (51).

The potato is an annual, herbaceous dicotyledon as far as vegetative habits are concerned, but it may be regarded as a perennial owning to its capacity for vegetative reproduction by mean of tubers (2, 15, 18).

The mature stem of the potato is subtriangular or quadrangular in transection. This results from the development of three large vascular bundles and the wing-like projections of the leaf which extends down the stem from each node (18). Between each pair of major bundles are three smaller ones, and in the mature stem, a continuous cylinder of vascular tissue is formed by the development of an interfascicular cambium.

According to Artschwager (2) the vascular tissue of the potato shows bicollateral type arrangement with phloem on both sides of the xylem. This may be seen in the larger bundles of the stem as shown in Figure 1. Most striking in this figure is a wedge shaped mass of rather large, dark staining cells, the xylem. At more or less equal distances to the outside and the inside of the xylem are small groups of thin walled cells which make up the phloem. The external phloem is separated from the xylem by a layer of uniform, rectangular cells, the cambium. The internal phloem is also separated from the xylem, but in this case by thin walled irregular cells. These cells are much smaller than those of the pith and form what is called the perimedullary zone of the vascular cylinder. The internal phloem abuts directly on the pith, and many of its groups are completely surrounded by pith cells. The external phloem groups are separated from one another and from the endodermis by parenchymatous cells of irregular size, which together constitute the pericyclic region of the stele. The phloem in both regions is made up of cell groups which in the outer zone are small and form a more or less continuous band and which in the inner region are variable in size and more scattered.

According to Esau (15) the leaf traces constitute a prominent part of the vascular system of the aerial stem. This system shows variable structure related to the position of the leaves.

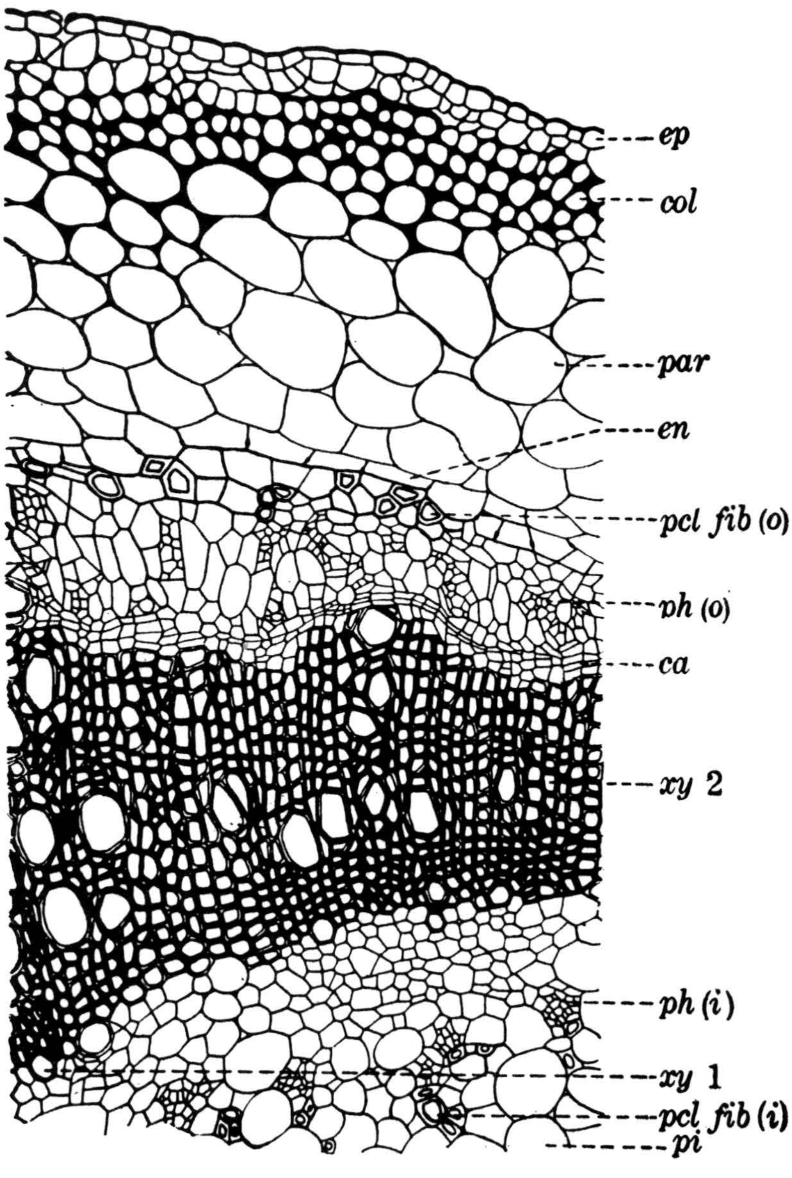

Figure 1. Transection of sector or mature stem: ca, cambium; col, collenchyma; en, endodermis; ep, epidermis; par, parenchyma; pcl fib (i), inner pericyclic fibers; pcl fib (o), outer pericyclic fibers; ph (i), inner phloem; ph (o), outer phloem; pi, pith; xy 1, primary xylem; xy 2, secondary xylem. (From Hayward, H. E., Structure of economic plants, 1st ed. New York. MacMillian Co., 1938).

Artschwager (2) stated that vascular bundles from one leaf are not necessarily restricted to the same side of the stem, but that they traverse the stem between nodes, and in addition anastomosing of the vascular bundles occurs at the nodes. This can be seen in some detail in Figure 2.

Gray and Smith (17) supplied potato leaves (on separate plants) at nodes 5, 7 and 9 with $^{14}CO_2$ at flowering and 20 and 40 days after flowering. Twenty percent of the tubers arose from that portion of stem in the vicinity of the supply leaf. These tubers contained 47 percent of the activity detected in all of the tubers. This would suggest that there is a high degree of vascular continuity between tubers and supplying leaves.

Translocation

Translocation is the movement of solutes throughout the plant. As photosynthesis proceeds, the products must move from the leaves to other parts of the plant. This takes place in the vascular bundles with the phloem being the primary conducting system.

Crafts (10) stated that continuous differentiation and ontogeny of tissue are characteristic of the phloem, and in a living plant maturing sieve tubes are available to function in conduction. Crafts (11) also reported that sucrose is the major sugar transported in the sieve tube elements of the phloem, although other sugars may be present.

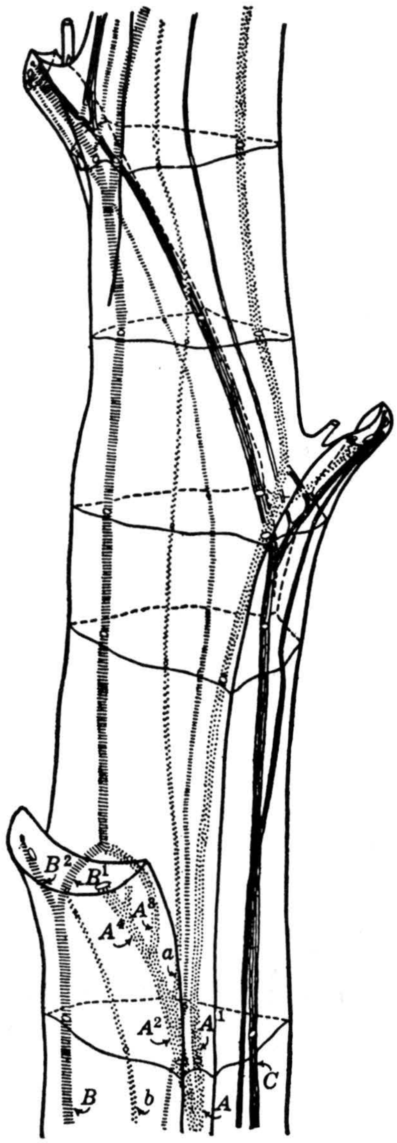

Figure 2. Diagrammatic longisection of stem showing course of vascular bundles and vascular supply to leaves: A, B, C, large vascular bundles; a, b, small vascular bundles. (From Hayward, H. E., Structure of economic plants, 1st ed. New York. MacMillian Co., 1938).

Jones _et al._ (24) studying translocation from single leaves of tobacco plants found that of the $^{14}CO_2$ assimilated 20-30 percent of the radioactivity was incorporated into the presentation leaf while some 3 percent reached the upper leaves and stem apex. Import into leaves above the presentation leaf was completed in about six hours. No activity appeared in leaves below the presentation leaf, therefore the balance of the exported activity was retained in the stem and roots. The distribution of radioactivity in the leaves followed a well defined pattern determined by the vascular inter-connections.

Khan and Sagar (25) using reciprocal grafts between potato and tomato found a higher proportion of radioactive assimilates exported from both tomato and potato leaves when potato was used as the root-stock. This was attributed to the size and activity of the potato tuber as a photosynthetic sink which is greater than the roots of the tomato. Thorne and Evans (53) found similar results when working with grafts between sugar beet and spinach. They observed higher assimilation rates when sugar beet roots were used as the rootstock. This was considered an example of the sink effect on photosynthesis.

The change from vegetative growth to the production of flowers and fruits or a rapidly developing storage organ will markedly alter the pattern of assimilate distribution. Such development changes both the intensity of the demand for assimilates and in many instances the position of this demand in relation to the leaves (56). It is clear from work on tomatoes that developing fruit has priority of assimilates from adjacent leaves.

Milthorpe and Moorby (30) stated that storage organs such as the potato appear to dominate vegetative growth in a manner similar to fruits. The flow of carbohydrates appears to be determined by sink activity, unless conditions for photosynthesis are unfavorable. The rate of increase in dry weight per unit leaf area or the net assimilation of the potato plant appears to be closely associated with the rate of tuber growth. Net assimilation rate falls from emergence to tuber initiation. At tuber initiation it increases for a short time, but falls again late in the season.

Burt (7) showed that any factor which reduced tuber growth, such as removal of tubers, reduced net assimilation rate. On removing tubers, dry matter accumulation in the leaves and stems was considerably increased. This suggests that in the potato plant net assimilation rate is dependent upon the ability of the tubers to accumulate dry matter.

Nosberger and Humphries (38), in a similar experiment, stated that removing tubers immediately had a smaller effect on net assimilation rate than later removal.

Moorby (35) pointed out that the rate of tuber growth is often greater than the rate of top growth. This suggests the transfer of large amounts of dry matter from the vine top to the tubers. Moorby

(36) followed this by saying that any increase in tuber dry weight comes from the accumulation of carbohydrates and there is probably competition between tubers for carbohydrates from the tops.

The maintenance of a uniform tuber growth rate is dependent on a constant supply of carbohydrates. But since both net assimilation rate and leaf area decrease over much of the period of tuber growth current photosynthesis cannot supply the required amount. Calculations have shown that in some instances, the dry matter lost by the vine is sufficient to supply deficiencies (34). This situation is similar to that found in maize where materials may be stored for a period in the stems and other organs before transfer into the grain.

Mokronsov and Bubenshehikova (32) showed that along with a slow (20-80 cm/hr) movement of the main stream of assimilates there also exists a rapid diffuse distribution of labelled compounds throughout the stem to the stem tip in the potato plant. Radial translocation of assimilates from the vascular bundles to the cortex and pith also occurs in the potato plant. The flow rate of products from the leaf to the conducting structures is higher in young plants. However, the overall mass of assimilates flowing from the leaf increases with plant age and enlargement of consuming organs.

Baker and Moorby (3) suggested that the pathways of sugar and ion movement into tubers are in agreement with generally accepted ideas on transport in plants. The developing tubers obtain their water through the xylem, while ions such as phosphate, and other ions which move in the phloem, enter the tuber with assimilates.

According to Crafts (9) diffusion along plasmodesma of cross walls and acceleration by protoplasmic streaming within non-vascular tissues, combined with pressure flow through permeable sieve tubes and phloem walls within specialized conducting organs, seemed most satisfactory to explain translocation in the potato.

Defoliation Stress

Defoliation is the removal of expanding or mature leaves or leaflets from a plant's lateral branches. Experiments in which the size of the source (leaf area) has been decreased, instead of the sink (tuber) have yielded interesting results.

Thrower (54) reported that defoliation of soybeans alters the distribution of assimilate between leaf and root, so that a greater proportion moved to the root. This was considered not due to the removal of leaf sinks which compete with the roots, but that leaf removal resulted in a greater sugar deficit in the roots. The lower leaves export mainly to the root and their removal may deprive the roots of assimilate.

Davidson and Milthorpe (13) found with non-severe defoliation of a grass, cocksfoot (*Dactylis glomerata*), that the changes in reserve carbohydrates could account for net respiratory losses and amount of new growth made. When defoliation was severe, even high concentrations of reserve carbohydrates were inadequate and other substances, presumably proteins, must have been remobilized for use in respiration and new growth. Defoliation of pasture plants normally produces a temporary carbohydrate shortage which results in a portion of the accumulated soluble carbohydrate being used in growth and respiration.

Stoy (46) reported that removing part of the leaves of various plants very markedly increases the rate of photosynthesis in the remaining leaves. This increase may compensate for the loss of parts of the green foliage, and is regarded as a response of the source to the demands of the sink. Removal of part of the leaves stimulates the synthesis of proteins by reducing the competition between leaves for nutrients or growth substances.

Defoliation of sugar beets increased the size of older leaves on plants that are still growing, and accelerated the onset of rapid growth of the unfolding leaves (16). The growth rate of leaves was increased, although the fraction of the photosynthate going to leaves may not change if the plant is young and investing a larger fraction of new growth in leaves anyway.

Soine (43) also working with sugar beet showed that weight of tops after 50 percent leaf removal caught up with the non-defoliated control after 75 days.

Sweet and Wareing (48) found that removal or partial removal of fully expanded leaves of 11 week old *Pinus radiata* conifer seedlings had two effects: (1) there was an increase in the photosynthetic activity of the remaining leaves and (2) an increase in the growth rate of the remaining leaves when compared to a control.

In defoliation experiments with corn and field beans Wareing, Khalifa and Treharne (57) reported that partial defoliation not only increased the relative demand for photosynthates on the remaining leaves, but also increased the photosynthetic efficiency of the remaining leaves by reducing the competition between leaves for mineral nutrients and also for specific hormonal factors, such as cytokinins, supplied by the roots.

Defoliation of wheat when the fifth, sixth and seventh leaves were unfolded on the main axis reduced the grain yield by 15 percent compared with a control (28). Removal of two leaves reduced the rate of stem growth up to the flag leaf stage, but thereafter remarkable recovery occurred in the growth rate of the stem and ear.

Kittock and Williams (26) found that removal of leaves of castor beans at four stages of growth at the rates of 1/4, 1/2, 3/4 and total removal resulted in lower yields than that of the control. However, yield differences between the control and most partial removal treatments were not large enough to be significant. Stages of growth when partial removal treatments were applied had no significant effect on yield. Total leaf removal at each of the dates resulted in yields that were significantly lower than the check. Regrowth following the first two total leaf removals produced yields that were adequate to justify continuation of fields under farm conditions.

Teigen and Vorst (50) found that leaf removal from soybeans in the vegetative stage reduced seed yield a maximum of 6 percent. Plant height at maturity and lodging were reduced by defoliation, but not significantly. Defoliation during the reproductive stage reduced seed yield, number of pods per plant and lodging more than similar treatments applied at the vegetative stage. Reduction in seed yield was small in all instances when compared to the amount of photosynthetic area removed.

In potatoes, Mokronsov and Ivanova (33) reported that elimination of 30-50 percent of the leaf area increased the intensity of photosynthesis of the remaining leaves while an 80 percent loss of leaves depressed photosynthesis.

Milthorpe and Moorby (31) found that a reduction in the photosynthetic system by partial defoliation did not reduce the rate of potato tuber growth due to an increase in the efficiency of the remaining leaves. However, losses in yield are possible from an early maturing cultivar when 25 percent of the foliage is removed and from a medium maturing cultivar when 50 percent is lost (55).

Takatori *et al.* (49) concluded that defoliation involving loss of leaves of 25 percent or more will reduce yield. Defoliation when tubers are being initiated reduced the grade of potatoes in direct proportion to the amount of foliage removed. Early damage had little effect upon potato grade. Late damage occurring as senility approaches did not reduce potato grade, but reduced total yield since small potatoes will result. Renewal of growth took place rapidly when foliage was lost either in the 6 or 12 inch stage of growth; the time required being directly related to the amount of foliage removed.

Sparks *et al.* (44) reported that defoliation of potatoes when the plants are beginning to bloom (12 to 15 in. tall) gave a 25 percent increase in the percentage of U.S. No. 2 tubers. Defoliation when the plants were beginning to bloom and set tubers gave the greatest increase in malformed and off type tubers.

The percentage loss in yield of U.S. No. 1 tubers resulting from defoliation increased up to the full bloom stage, then decreased as the plants develop beyond this stage (45).

The later in development that defoliation takes place the greater is the loss in tuber starch content (44, 45). This may indicate that some starch is converted to sugar and used to regenerate foliage. When injured late in the season, time is insufficient for the plant to replace the starch in the tubers.

Snyder and Michelson (42) reported a 12 percent loss in potato yield following light defoliation, 17 percent for medium and 21 percent loss for heavy. Losses were less than expected, due to the rapid recovery of the potato plant.

Murphy and Goven (37) reported that the yield of two potato cultivars decreased as degree of defoliation increased. Greatest loss in yield occurred at the full bloom stage of growth. Occasionally defoliation applied to plants at 8 to 10 inches in height slightly increased yield and quality.

Beresford (5) reported both total and yields of U.S. No. 1 size tubers decreased as the degree of defoliation increased from 25 percent to 100 percent. Twenty-five percent damage applied when 50 percent of the plants were past full bloom reduced total yields by 10 percent, whereas 100 percent reduced yields 56 percent on the average. As the degree of defoliation increased the percentage of smaller sized tubers increased and the percentage of larger sized tubers decreased.

Bruising and Vascular Regeneration

Murphy (37) reported that damage to the stem vascular tissues from bruising reduced yield, quality and tuber size more than a large amount of leaf removal. However, Snyder and Michelson (42) reported that bruising sufficient to cut the vascular tissue applied early in the season had very little effect on either yield or grade of tubers. Yield was reduced when older plants were bruised. In seven years no increase in disease was found; damaged tissue healed quickly and the potato plant recovered rapidly from stem damage.

Busch and Salveson (8) reported that the location of the bruise on the wheat stem had a variable effect on yield. Stem bruising either near the spike (head) or near the soil surface caused the greatest yield loss; stem bruising near the spike (head) was the more serious.

Crafts and Crisp (12) reported that excessive loss of assimilates is prevented when a plant is cut or mutilated. If the wound effects only a part of a stem, wound phloem will be differentiated around the injury and translocation reestablished. If the stem is cut off, an axillary bud at the node below the cut may break into growth and take over the function of apical growth. If the secondary phloem is injured, wound callus may be formed and new phloem developed through or below the injury to reestablish food distribution.

MacKay and Weatherly (29) placed both single and double overlapping transverse cuts on the stems of transpiring plants (Acer pseudoplatanus and Gossypium hirsutum) and measured transpiration and water stress in the leaves. Single cuts severing as much as 90 percent of the cross sectional area of the stem had no detectable effect on the rate of transpiration or on stress in the leaves above. Double overlapping cuts resulted in increased stress and cessation of sap flow only if their vertical separation was less than a critical distance. This distance was specific for each species and related to the respective vessel lengths. Cuts separated by more than this distance had no detectable effect on stress or transpiration rate.

Benayoun, Aloni and Sachs (4) attempted to determine whether vascular regeneration around wounds included a replacement of damaged tissues or only new vascular strands, which normally form from the cambium and are diverted around wounds. In coleus and cucumis the new vascular strands forming around the wounds were completely new, and did not join any mature strands. No connections were formed to damaged sieve tubes and vessels, so that their continuity around wounds was not restored.

Aloni (1) reported that during the regeneration of conducting cells of coleus that parenchyma cells redifferentiate to vessels, sieve tube elements and phloem fibers. The redifferentiation of conducting cells takes only a few days. LaMotte and Jacobs (27) found that after only two to seven days coleus stems regenerated approximately ten sieve tube members per strand following a wound 2-3 mm deep and 1-2 mm wide.

One phase in the differentiation of the original tissue pattern is the thickening of the walls in cells of specific layers of cells around the wound surface. Bloch (6) studied the regeneration of xylem in various plants and noted that the regenerating strand formed mostly in a polar fashion from the upper margin toward the lower part of the cut.

Jacobs (19) found that the local IAA (auxin) concentration in cells adjoining cut sieve tubes builds up enough to initiate the differentiation of wound sieve tube elements. There seems to be agreement that the healing of wounds is stimulated or initiated by the formation of a hormone or hormones (41). Since the cells which are stimulated to activity are necessarily somewhat removed from the site of injury, the wound produced substances which evoke the new cell activity must move within the plant.

Sussex *et al.* (47) have shown that the response to pith cells redifferentiating in two systems -- isolated pith cultured on a defined medium, and a stem wound regenerating after vascular tissue had been severed -- is dependent on auxin supply. In both systems there was an initial period during which cell division was resumed. This was followed by redifferentiation of some of the divided cells as xylem elements and by the formation of a cambial meristem that produced further xylem and phloem.

Thompson and Jacobs (52) stated that transport of IAA in excised internodes of coleus is strictly basipetal, judging by regeneration bio-assay involving both sieve tube strands and xylem cells. Similar results were also obtained with tomato. If isolated coleus internodes are not treated with hormone, no xylem cells and only a small number of sieve tube strands are regenerated. With increasing concentration of IAA added apically, the number of regenerated sieve tube strands increased progressively up to 1 percent IAA, the highest concentration applied.

CHAPTER III

MATERIALS AND METHODS

The presentation of experimental procedures is divided into two parts: (I) Effects of simulated hail injury on potato tuber yield and number, and (II) Anatomical studies of stem bruises.

Part I: Effects of Simulated Hail Injury on Potato Tuber Yield and Number

Experiments were conducted during 1976 with three cultivars in Northern Colorado (Gilcrest area) and with two cultivars in Southern Colorado (San Luis Valley). 'Norgold', 'Superior' and 'Norchip' were grown in Northern Colorado on commercial farms and 'Russet Burbank' and Russet Seedling 'BC 8370-4' were grown in Southern Colorado at the C.S.U. Research Center near Center, Colorado. 'Superior' (39) and 'Norchip' (23) are white skinned chipping cultivars, while 'Norgold' (22), 'Russet Burbank' and Russet Seedling 'BC 8370-4' are russeted cultivars, usually marketed fresh. Cultural practices were optimized as far as possible in all locations to avoid any additional stress beyond that resulting from defoliation and bruising.

The planting, emergence and harvest dates are listed for each cultivar in Table 1. These dates are representative for commercially grown potatoes in the two areas.

Plants were injured three times during the season. Table 2 lists the dates when each cultivar was injured. The first injury date (A) was intended to coincide with tuber set or about three or four weeks from emergence. The second date (B) was from two to three weeks later around the full bloom stage of plant development and the third date (C) was about three weeks after the second injury date. Roughly, the plants could be considered to be three, six and nine weeks from emergence. The time period from the last injury date to harvest varied from two to four weeks.

Table 3 lists the nine defoliation and/or bruising treatments applied on each of the three dates, thus, there were a total of 27 treatments per cultivar. Bruising was applied by striking each stem with a stone against a flat surface on a second stone. The single bruise was placed in the center portion of each stem and three bruises were spaced at equal intervals along the stem. Bruising intensity varied somewhat, but was sufficient to collapse the plant canopy. Occasionally stems were nearly severed. The general appearance of bruises is shown in Figure 3.

For defoliation, leaflets were clipped with a pair of scissors from each leaf on all stems. Leaflets were removed randomly to

Table 1. Dates of planting, emergence and harvest.

	'Russet Burbank'	'BC 8370-4'	'Norgold'	'Superior'	'Norchip'
Planting	5-10-76	5-10-76	4-20-76	5-1-76	5-1-76
Emergence	6-5-76	6-5-76	5-10-76	5-20-76	5-20-76
Harvest	9-12-76	9-12-76	8-10-76	8-10-76	8-31-76

Table 2. Dates when plants were injured.

	'Russet Burbank'	'BC 8370-4'	'Norgold'	'Superior'	'Norchip'
A 1st date	7-1-76	7-2-76	6-12-76	6-15-76	6-22-76
B 2nd date	7-20-76	7-21-76	7-3-76	7-5-76	7-8-76
C 3rd date	8-13-76	8-12-76	7-22-76	7-26-76	8-7-76

Table 3. Bruising and/or defoliation treatments applied on each date.

Treatment No.	Percent Defoliation	No. of Bruises Per Stem
1	0	0
2	0	1
3	0	3
4	25	0
5	25	1
6	25	3
7	75	0
8	75	1
9	75	3

Figure 3. Appearances of bruised stems: upper - fresh bruise; lower - two to three week old bruise.

achieve either 25 percent or 75 percent defoliation. Figure 4 is an example to show 25 percent (2 leaflets per leaf) and 75 percent (6 leaflets per leaf) leaf removal, as compared to a control.

For each cultivar, a three factor (date, defoliation, bruising) randomized complete block design with three blocks was used. Each treatment factor was applied to six plants per block and was separated from adjoining treatments by the removal of three or four plants. A larger buffer zone separated each block.

The potatoes were harvested with a C.S.U. one row mechanical harvester on the dates shown in Table 1 and later graded into various size and grade classifications.

Part II: Anatomical Studies of Stem Bruises

The influence of bruising on stem anatomy was studied only with the cultivar 'Russet Burbank' grown in the San Luis Valley. Plants for this experiment were grown adjacent to plants used in the previously described experiments (Part I). Bruises were also applied in the manner as described in Part I. Plants were injured on just one date, July 2, 1976, and sections of injured stems were collected on July 9 and 22 and August 4 and 19. The stem was cut above and below the bruised region and the sections were immediately placed in a fixative consisting of 5 ml glacial acetic acid, 10 ml formaldehyde, 50 ml 95 percent ethanol and 35 ml water. This solution is known as formalin-aceto-alcohol-F.A.A. (21).

Figure 4. Examples of defoliation: left, control; center, 25 percent defoliation; right, 75 percent defoliation.

Upon completion of fixing, stem sections were stored and later sectioned transversely, beginning in the undamaged tissue at the apical edges of the bruises and proceeding to the basal edges. Sections were taken in this manner so that photographs could be made through the entire bruised area.

The tissue sections were placed in small round tissue holders and put through a dehydration series. The tert-butyl-alcohol method of tissue dehydration was employed. Tissue was passed from a low concentration tert-butyl-alcohol solution through continuing higher concentrations to complete dehydration with 100 percent tert-butyl-alcohol.

After dehydration, tissue was transferred to glass vials, partially filled with tert-butyl-alcohol. These vials were placed in a micro-technique oven, which had been pre-heated to 53 degrees C. Melted paraffin was added to the vials to gradually replace the alcohol. This was done in graded 24 hour series of 25 percent, 50 percent, 75 percent and 48 hours in 100 percent paraffin. This insured that the alcohol was removed and that the tissue was completely infiltrated with paraffin.

The tissue was placed in plastic casting molds and covered with warm paraffin (tissuemat) for embedding. After embedding, plastic molds were placed in a refrigerator for storage. The molds were clamped to a rotary microtome and cut into ribbons ten microns thick.

Ribbons coming off of the microtome blade have a shiny and a dull side. Ribbons were placed shiny side down on a clean slide which had been previously coated with Haupt's gelatinous adhesive. The slides were put on a warming tray and held for five days at 43 degrees C. The paraffin melted slowly from around the tissue and fixed the tissue to the slide.

Tissue was stained with safranin-fast green stain, made up according to histochemical specifications (20, 40). This stains the lignified xylem cells red and other cells, such as parenchyma, green.

After staining, the tissue was covered with three or four drops of permount mounting media, and covered with a clean glass cover slip. The cover slips were pressed down slightly so as to eliminate air bubbles and insure proper adhesion. Care was taken not to crack the cover slip.

Slides were allowed to dry for one week in a clean dry place. After drying, slides were examined under a microscope using a low power objective. This was done so that whole sections could be observed for cellular detail and continuity of the vascular system through bruised regions.

Photomicrographs were taken of desired regions using a Zeiss II photomicroscope using 35 millimeter film. Enlargements were then made to permit observation of cellular organization.

Photographs were chosen on the basis of cellular organization and clarity. The purpose was to obtain photographs showing the effects of bruising injury on vascular organization and continuity and change with time.

CHAPTER IV

RESULTS

Results for Part I are presented in the following order: (1) Response of individual cultivars to injury, (2) Comparison of cultivars in response to injury, and (3) Mean effects of injury when cultivars are averaged. Part II presents results of the anatomical studies of stem bruises.

Part I: Effects of Simulated Hail Injury on Potato Tuber Yield and Number

Response of Individual Cultivars

'Russet Burbank'

The total yield response of the 'Russet Burbank' cultivar to injury is shown in Table 4. The lowest mean total yield resulted when plants were injured on the second injury date. The yield reduction was significantly different from the first date, but not from the third date. Wide variations in total yield reduction resulted from the same percentage of defoliation. However, the mean differences between none, 25 percent and 75 percent defoliation were not significantly different. Wide variations in total yield reduction also followed the same degree of bruising, but in this case the mean differences in total

Table 4. Influence of injury date, defoliation and bruising on total yield of 'Russet Burbank' tubers. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Injury Dates: Second	Injury Dates: Third	Means
		Grams Per 6 Plants			
0%	none	5341 (9)	5596 (5)	6687 (+14)	5875[a]
	one	5877 (0)	5249 (11)	5736 (2)	5621 (4)
	three	5390 (8)	4858 (17)	5685 (3)	5311 (10)
25%	none	5759 (2)	5836 (1)	6186 (+5)	5927 (+1)
	one	6407 (+9)	4436 (24)	5886 (+1)	5575 (5)
	three	5907 (+1)	4571 (22)	4321 (26)	4934 (16)
75%	none	5780 (2)	5654 (3)	4807 (18)	5414 (8)
	one	6403 (+9)	4858 (17)	4735 (19)	5332 (9)
	three	5560 (5)	4326 (26)	4575 (22)	4820 (18)
Date Means		5825 (a)	5043 (b)	5402 (ab)	5423
Defoliation Means	none	5536 (0)	5234 (0)	6036 (0)	5602 (0)
	25%	6025 (+9)	4947 (5)	5463 (9)	5479 (2)
	75%	5914 (+7)	4946 (5)	4706 (22)	5189 (7)
Bruising Means	none	5627 (0)	5696 (0)	5894 (0)	5739 (0)(a)
	one	6229 (+11)	4848 (15)	5451 (7)	5509 (4)(ab)
	three	5619 (0)	4585 (19)	4861 (17)	5022 (12)(b)

Analysis of Variance[b]

	F ratio	Signif.
Date	3.866	0.05
Defoliation	1.135	N.S.
Bruising	3.380	0.05
Date x Def	1.695	N.S.
Date x Bru	1.368	N.S.
Def x Bru	0.146	N.S.

Error mean square	1071082
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

[b]Where a significant F test occurred the means were compared using the H.S.D. mean separation test. Means not followed by the same letter differ significantly at the 5 percent level.

yield between none, one and three bruises were significant. One bruise did not differ significantly from no bruises. Three bruises differed significantly from no bruises, but not from one bruise. No significant factor interactions occurred.

'Russet Burbank' market yield response to injury is shown in Table 5. The overall market yield response was similar to that for total yield, in that wide variations in market yield occurred within the same injury. Significant differences in mean market yield reduction occurred between the bruising treatments. One bruise did not differ significantly from none or three bruises. Three bruises reduced market yield the most and differed significantly from no bruises, but not from one bruise.

Both defoliation and bruising had a slight, but non-significant effect on the total number of tubers on 'Russet Burbank' plants (Table 6). A small, but significant difference in mean total number of tubers occurred between injury dates. Plants injured on the first injury date had significantly more tubers than those injured on the other two injury dates. No significant factor interactions were observed. The mean total number of tubers for six plants was 44.

The influence of injury on the number of market tubers produced by plants of the 'Russet Burbank' cultivar is shown in Table 7. Some variations in market tuber numbers occurred within and between injury factors. However, no significant mean differences or

Table 5. Influence of injury date, defoliation and bruising on market yield of 'Russet Burbank' tubers. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates First	Injury Dates Second	Injury Dates Third	Means
		Grams Per 6 Plants			
0%	none	3618 (18)	4153 (6)	5443 (+23)	4405[a]
	one	4964 (+13)	3763 (15)	3831 (13)	4186 (5)
	three	3301 (25)	3228 (27)	4276 (3)	3602 (18)
25%	none	4702 (+2)	4825 (+9)	4512 (+2)	4615 (+5)
	one	4815 (+9)	3301 (25)	4364 (1)	4159 (6)
	three	4116 (7)	3331 (24)	3034 (31)	3493 (21)
75%	none	4115 (7)	4588 (+4)	3544 (19)	4082 (7)
	one	4692 (+6)	3415 (22)	2826 (36)	3644 (17)
	three	3515 (20)	2702 (39)	3407 (23)	3208 (28)
Date Means		4182	3701	3915	3933
Defoliation Means	none	3961 (0)	3715 (0)	4517 (0)	4064 (0)
	25%	4479 (+13)	3819 (+3)	3970 (12)	4089 (+1)
	75%	4107 (+4)	3569 (4)	3258 (28)	3645 (10)
Bruising Means	none	4080 (0)	4522 (0)	4500 (0)	4367 (0)(a)
	one	4824 (+18)	3493 (23)	3674 (18)	3997 (8)(ab)
	three	3644 (11)	3087 (32)	3573 (21)	3434 (21)(b)

Analysis of Variance[b]

	F ratio	Signif.
Date	1.483	N.S.
Defoliation	1.587	N.S.
Bruising	5.615	0.05
Date x Def	1.265	N.S.
Date x Bru	2.122	N.S.
Def x Bru	0.083	N.S.
Error mean square	1060738	
Error degrees of freedom	54	

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

[b]Where significant F test occurred the means were compared using the H.S.D. mean separation test. Means not followed by the same letter differ significantly at the 5 percent level.

Table 6. Influence of injury date, defoliation and bruising on total tuber numbers of the 'Russet Burbank' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Tubers Per 6 Plants			
0%	none	46 (+7)	44 (+2)	41 (5)	43[a]
	one	39 (9)	38 (12)	44 (+2)	41 (5)
	three	50 (+16)	46 (+7)	39 (9)	45 (+5)
25%	none	48 (+12)	40 (7)	50 (+16)	46 (+7)
	one	43 (0)	38 (12)	43 (0)	41 (5)
	three	46 (+7)	42 (2)	38 (12)	42 (2)
75%	none	49 (+14)	39 (9)	40 (7)	43 (0)
	one	51 (+18)	42 (2)	43 (0)	45 (+5)
	three	55 (+28)	41 (5)	39 (9)	45 (+5)
Date Means		48 (b)	41 (a)	42 (a)	44
Defoliation Means	none	45 (0)	42 (0)	41 (0)	43 (0)
	25%	46 (+2)	40 (5)	43 (+5)	43 (0)
	75%	52 (+16)	41 (2)	41 (0)	44 (+2)
Bruising Means	none	48 (0)	41 (0)	44 (0)	44 (0)
	one	45 (6)	39 (5)	43 (2)	42 (5)
	three	51 (+6)	43 (+5)	39 (11)	44 (0)

Analysis of Variance[b]

	F ratio	Signif.
Date	5.204	0.05
Defoliation	0.269	N.S.
Bruising	0.382	N.S.
Date x Def	1.082	N.S.
Date x Bru	1.124	N.S.
Def x Bru	0.718	N.S.
Error mean square	65.29	
Error degrees of freedom	54	

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

[b]Where a significant F test occurred the means were compared using the H.S.D. mean separation test. Means not followed by the same letter differ significantly at the 5 percent level.

Table 7. Influence of injury date, defoliation and bruising on market tuber numbers of the 'Russet Burbank' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Tubers Per 6 Plants			
0%	none	20 (9)	22 (0)	24 (+9)	22[a]
	one	25 (+14)	21 (4)	17 (23)	21 (4)
	three	17 (23)	18 (18)	22 (0)	19 (14)
25%	none	24 (+9)	22 (0)	24 (+9)	23 (+5)
	one	23 (+5)	18 (18)	22 (0)	21 (4)
	three	23 (+5)	19 (14)	17 (23)	20 (9)
75%	none	22 (0)	24 (+9)	20 (9)	22 (0)
	one	26 (+18)	20 (9)	16 (27)	20 (9)
	three	22 (0)	16 (27)	20 (9)	19 (14)
Date Means		22	20	20	21
Defoliation Means	none	21 (0)	20 (0)	21 (0)	21 (0)
	25%	23 (+9)	19 (5)	21 (0)	21 (0)
	75%	23 (+9)	20 (0)	19 (9)	21 (0)
Bruising Means	none	22 (0)	23 (0)	23 (0)	22 (0)
	one	25 (+14)	19 (17)	19 (17)	21 (4)
	three	21 (4)	18 (22)	20 (13)	19 (14)

Analysis of Variance

	F ratio	Signif.
Date	1.898	N.S.
Defoliation	0.145	N.S.
Bruising	2.236	N.S.
Date x Def	0.640	N.S.
Date x Bru	1.190	N.S.
Def x Bru	0.017	N.S.

Error mean square	27.889
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

significant factor interactions occurred. The mean number of marketable tubers per six plants was 21. This was about 50 percent of the total tuber number.

Data taken on undersized (less than 112 grams) and cull tubers is shown in Appendix Tables A-1 and A-2, respectively. No significant mean differences in either class resulted from injury or injury date. No significant factor interactions occurred except the date x bruising interaction in Table A-1.

Russet Seedling 'BC 8370-4'

The total yield response to injury and factor interactions for Russet Seedling 'BC 8370-4' are shown in Table 8. The lowest mean total yield resulted from injury on the second date. A significant difference occurred between the first and second injury dates, but not between the second and third injury dates. No significant differences existed between defoliation means or between bruising means. Also, no significant factor interactions occurred.

Russet Seedling 'BC 8370-4' market yield response to injury is shown in Table 9. Injury on the second date resulted in market yields significantly lower than the other two injury dates. Seventy-five percent defoliation significantly reduced market yield compared to none and 25 percent defoliation. No significant mean differences occurred between bruising factors, nor were there any significant factor interactions.

Table 8. Influence of injury date, defoliation and bruising on total yield of Russet Seedling 'BC 8370-4' tubers. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	5020 (1)	5206 (+2)	5032 (1)	5086[a]
	one	4922 (3)	4369 (14)	4741 (7)	4678 (8)
	three	5339 (+5)	4377 (14)	5408 (+6)	5041 (1)
25%	none	5419 (+7)	4970 (2)	4663 (8)	5017 (1)
	one	5090 (0)	4810 (5)	5041 (1)	4981 (2)
	three	4765 (6)	3921 (23)	5104 (+1)	4597 (10)
75%	none	5565 (+9)	4064 (20)	4360 (14)	4663 (8)
	one	5249 (3)	4015 (21)	4375 (14)	4546 (11)
	three	5255 (+3)	3966 (22)	4547 (11)	4589 (10)
Date Means		5180 (a)	4411 (b)	4808 (ab)	4799
Defoliation Means	none	5094 (0)	4651 (0)	5060 (0)	4935 (0)
	25%	5092 (0)	4567 (2)	4936 (2)	4865 (1)
	75%	5356 (+5)	4015 (14)	4427 (12)	4599 (7)
Bruising Means	none	5536 (0)	4747 (0)	4685 (0)	4922 (0)
	one	5087 (5)	4398 (7)	4719 (+1)	4735 (4)
	three	5120 (4)	4088 (14)	5019 (+7)	4742 (4)

Analysis of Variance[b]

	F ratio	Signif.
Date	9.418	0.05
Defoliation	1.992	N.S.
Bruising	0.715	N.S.
Date x Def	1.705	N.S.
Date x Bru	1.344	N.S.
Def x Bru	0.787	N.S.

Error mean square	424610
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

[b]Where a significant F test occurred the means were compared using the H.S.D. mean separation test. Means not followed by the same letter differ significantly at the 5 percent level.

Table 9. Influence of injury date, defoliation and bruising on market yield of Russet Seedling 'BC 8370-4' tubers. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	4089 (+6)	3712 (3)	3723 (3)	3841[a]
	one	3753 (2)	3541 (8)	3826 (1)	3707 (4)
	three	3935 (+2)	3168 (17)	4144 (+8)	3749 (2)
25%	none	4472 (+16)	2411 (37)	3563 (7)	3482 (9)
	one	4253 (+11)	3353 (13)	3617 (6)	3741 (3)
	three	3347 (13)	2639 (31)	4119 (+7)	3368 (12)
75%	none	3667 (4)	2411 (37)	3389 (12)	3156 (18)
	one	3584 (7)	2546 (34)	2670 (30)	3033 (21)
	three	3403 (11)	2005 (48)	2669 (30)	2693 (30)
Date Means		3834 (a)	2865 (b)	3556 (a)	3418
Defoliation Means	none	3925 (0)	3474 (0)	3898 (0)	3765 (0)(a)
	25%	4024 (+2)	3801 (19)	3767 (3)	3530 (6)(a)
	75%	3551 (9)	2321 (33)	3009 (23)	2960 (21)(b)
Bruising Means	none	4076 (0)	2845 (0)	3558 (0)	3493 (0)
	one	3863 (5)	3147 (+11)	3471 (2)	3494 (0)
	three	3562 (13)	2604 (8)	3644 (+2)	3270 (6)

Analysis of Variance[b]

	F ratio	Signif.
Date	11.545	0.05
Defoliation	7.953	0.05
Bruising	0.771	N.S.
Date x Def	0.876	N.S.
Date x Bru	0.760	N.S.
Def x Bru	0.378	N.S.

Error mean square	582049
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

[b]Where significant F test occurred the means were compared using the H.S.D. mean separation test. Means not followed by the same letter differ significantly at the 5 percent level.

The total number of tubers produced by Russet Seedling 'BC 8370-4' in response to injury is shown in Table 10. No significant differences occurred between factors, nor were there significant interactions. Russet Seedling 'BC 8370-4' produced 41 tubers per six plants.

The number of market tubers produced by Russet Seedling 'BC 8370-4' is shown in Table 11. Significant mean differences occurred between injury dates and between defoliation treatments. Plants injured on the second date yielded significantly fewer market tubers than plants injured on the first and third dates. Seventy-five percent defoliation reduced market tuber numbers significantly compared to none and 25 percent defoliation. Bruising did not significantly change the number of market tubers. No significant factor interactions occurred. Market tuber number was about 50 percent of total tuber number (cf. Tables 10 and 11).

Russet Seedling 'BC 8370-4' yield of tubers under 112 grams and yield of cull tubers in response to injury are presented in Appendix Tables A-3 and A-4, respectively. A wide variation in small tubers resulted within the same injury. Seventy-five percent defoliation increased the mean yield of small tubers significantly compared to none and 25 percent defoliation. Cull tuber yields were not significantly increased by defoliation or bruising.

Table 10. Influence of injury date, defoliation and bruising on total tuber numbers of the Russet Seedling 'BC 8370-4' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Tubers Per 6 Plants			
0%	none	34 (15)	45 (+12)	40 (0)	40[a]
	one	39 (2)	35 (15)	38 (5)	37 (8)
	three	41 (+2)	38 (5)	42 (+5)	40 (0)
25%	none	43 (+7)	41 (+2)	37 (7)	41 (+3)
	one	39 (2)	45 (+12)	44 (+10)	43 (+8)
	three	41 (+2)	38 (5)	38 (5)	39 (3)
75%	none	50 (+25)	40 (0)	34 (15)	41 (+3)
	one	47 (+18)	40 (0)	41 (+2)	43 (+8)
	three	49 (+22)	43 (+7)	46 (+15)	46 (+15)
Date Means		43	40	40	41
Defoliation Means	none	38 (0)	39 (0)	40 (0)	39 (0)
	25%	41 (+8)	42 (+8)	40 (0)	41 (+5)
	75%	49 (+30)	41 (+5)	40 (0)	43 (+11)
Bruising Means	none	42 (0)	42 (0)	37 (0)	40 (0)
	one	42 (0)	39 (7)	41 (+11)	41 (+3)
	three	44 (+5)	40 (5)	42 (+14)	42 (+5)

Analysis of Variance

	F ratio	Signif.
Date	0.733	N.S.
Defoliation	1.777	N.S.
Bruising	0.150	N.S.
Date x Def	1.089	N.S.
Date x Bru	0.531	N.S.
Def x Bru	0.677	N.S.
Error mean square	74.198	
Error degrees of freedom	54	

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table 11. Influence of injury date, defoliation and bruising on market tuber numbers of the Russet Seedling 'BC 8370-4' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Tubers Per 6 Plants			
0%	none	21 (0)	22 (+5)	21 (0)	21[a]
	one	21 (0)	19 (9)	23 (+9)	21 (0)
	three	22 (+5)	19 (9)	22 (+5)	21 (0)
25%	none	25 (+19)	20 (5)	20 (5)	22 (+5)
	one	25 (+19)	20 (5)	22 (+5)	22 (+5)
	three	19 (9)	17 (19)	24 (+14)	20 (5)
75%	none	21 (0)	15 (29)	20 (5)	18 (14)
	one	21 (0)	17 (19)	18 (14)	19 (9)
	three	20 (5)	13 (38)	16 (24)	16 (24)
Date Means		22 (a)	18 (b)	21 (a)	20
Defoliation Means	none	21 (0)	20 (0)	22 (0)	21 (0)(a)
	25%	23 (+9)	19 (5)	22 (0)	21 (0)(a)
	75%	21 (0)	15 (25)	18 (18)	18 (14)(b)
Bruising Means	none	22 (0)	19 (0)	20 (0)	20 (0)
	one	22 (0)	19 (0)	21 (+5)	21 (+5)
	three	20 (9)	16 (16)	21 (+5)	19 (5)

Analysis of Variance[b]

	F ratio	Signif.
Date	6.132	0.05
Defoliation	6.075	0.05
Bruising	1.086	N.S.
Date x Def	0.838	N.S.
Date x Bru	0.368	N.S.
Def x Bru	0.233	N.S.
Error mean square	27.889	
Error degrees of freedom	54	

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

[b]Where a significant F test occurred the means were compared using the H.S.D. mean separation test. Means not followed by the same letter differ significantly at the 5 percent level.

'Norgold'

The total yield response of the 'Norgold' cultivar to the injury factors and factor interactions is shown in Table 12. No significant mean differences occurred between injury dates. Seventy-five percent defoliation significantly reduced total yield compared to no injury. Twenty-five percent defoliation did not differ significantly from none or 75 percent defoliation. No significant differences occurred between bruising treatments, nor were there significant factor interactions.

'Norgold' market yield response to injury is shown in Table 13. Significant differences did not occur between injury dates. Mean market yields were reduced by defoliation and bruising, but the reductions were not significant. No significant interactions were observed.

Wide variations in the total tuber numbers resulted from the same degree of defoliation and/or bruising (Table 14). However, no significant differences occurred between factor means, nor were there significant factor interactions. The mean total number of tubers per six plants produced by the 'Norgold' cultivar was 49.

The number of market tubers produced by the 'Norgold' cultivar (Table 15) varied less between treatments than total tuber number. No significant differences in mean market tuber numbers occurred between factors, nor were there significant factor interactions.

Table 12. Influence of injury date, defoliation and bruising on total yield of 'Norgold' tubers. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	6940 (+3)	6311 (6)	6948 (+3)	6733[a]
	one	5585 (17)	7416 (+10)	6787 (+1)	6596 (2)
	three	5701 (15)	6962 (+3)	5563 (17)	6075 (10)
25%	none	7221 (+7)	5528 (18)	5393 (20)	6047 (10)
	one	5038 (25)	6315 (6)	7073 (+5)	6142 (9)
	three	5413 (20)	4904 (27)	6649 (1)	5655 (16)
75%	none	5225 (22)	5642 (16)	6174 (8)	5680 (16)
	one	5800 (14)	4700 (30)	5934 (12)	5478 (19)
	three	4165 (38)	5337 (21)	6060 (10)	5187 (23)
Date Means		5676	5902	6287	5955
Defoliation Means	none	6076 (0)	6896 (0)	6433 (0)	6468 (0)(a)
	25%	5890 (3)	5582 (19)	6372 (1)	5948 (8)(ab)
	75%	5063 (17)	5226 (24)	6056 (6)	5448 (16)(b)
Bruising Means	none	6462 (0)	5827 (0)	6172 (0)	6154 (0)
	one	5475 (15)	6144 (+5)	6598 (+7)	6072 (1)
	three	5093 (21)	5734 (2)	6090 (1)	5639 (8)

Analysis of Variance[b]

	F ratio	Signif.
Date	1.428	N.S.
Defoliation	3.895	0.05
Bruising	1.146	N.S.
Date x Def	0.812	N.S.
Date x Bru	0.975	N.S.
Def x Bru	0.048	N.S.

Error mean square	1801893
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

[b]Where a significant F test occurred the means were compared using the H.S.D. mean separation test. Means not followed by the same letter differ significantly at the 5 percent level.

Table 13. Influence of injury date, defoliation and bruising on market yield of 'Norgold ' tubers. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	5518 (+8)	4438 (13)	5369 (5)	5108[a]
	one	4347 (15)	5451 (+7)	5094 (1)	4963 (3)
	three	4191 (18)	5840 (+14)	3918 (23)	4650 (9)
25%	none	5996 (+18)	4397 (14)	3934 (23)	4776 (6)
	one	3801 (26)	5131 (+1)	5663 (+11)	4865 (5)
	three	3956 (23)	3517 (31)	4908 (4)	4127 (19)
75%	none	4010 (21)	4250 (17)	5244 (3)	4501 (12)
	one	3980 (22)	3341 (35)	4843 (5)	4055 (21)
	three	3027 (41)	4052 (21)	4822 (6)	3967 (22)
Date Means		4314	4491	4866	4557
Defoliation Means	none	4685 (0)	5243 (0)	4793 (0)	4907 (0)
	25%	4585 (2)	4349 (17)	4835 (+1)	4589 (6)
	75%	3672 (22)	3881 (26)	4970 (+4)	4174 (15)
Bruising Means	none	5174 (0)	4362 (0)	4849 (0)	4795 (0)
	one	4043 (22)	4641 (+6)	5200 (+7)	4628 (3)
	three	3725 (28)	4470 (+2)	4549 (6)	4248 (11)

Analysis of Variance

	F ratio	Signif.
Date	1.409	N.S.
Defoliation	2.395	N.S.
Bruising	1.395	N.S.
Date x Def	1.163	N.S.
Date x Bru	1.392	N.S.
Def x Bru	0.188	N.S.

Error mean square	1522716
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table 14. Influence of injury date, defoliation and bruising on total tuber numbers of the 'Norgold' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Tubers Per 6 Plants			
0%	none	54 (+6)	50 (2)	48 (6)	51[a]
	one	44 (14)	68 (+33)	63 (+23)	58 (+14)
	three	52 (+2)	50 (2)	49 (4)	50 (+2)
25%	none	48 (6)	41 (20)	47 (8)	45 (12)
	one	44 (14)	44 (14)	52 (+2)	47 (8)
	three	48 (6)	48 (6)	68 (+33)	55 (+8)
75%	none	45 (12)	49 (4)	37 (27)	43 (16)
	one	50 (2)	49 (4)	43 (16)	48 (6)
	three	39 (23)	46 (9)	48 (6)	44 (14)
Date Means		47	50	50	49
Defoliation Means	none	50 (0)	56 (0)	53 (0)	53 (0)
	25%	47 (6)	44 (21)	56 (+5)	49 (7)
	75%	45 (10)	48 (14)	43 (19)	45 (15)
Bruising Means	none	49 (0)	47 (0)	44 (0)	46 (0)
	one	46 (6)	54 (+15)	53 (+20)	51 (+10)
	three	46 (6)	48 (+2)	55 (+25)	50 (+9)

Analysis of Variance

	F ratio	Signif.
Date	0.561	N.S.
Defoliation	2.898	N.S.
Bruising	0.963	N.S.
Date x Def	1.308	N.S.
Date x Bru	1.100	N.S.
Def x Bru	1.054	N.S.
Error mean square	147.8	
Error degrees of freedom	54	

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table 15. Influence of injury date, defoliation and bruising on total tuber numbers of the 'Norgold' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Injury Dates: Second	Injury Dates: Third	Means
		Tubers Per 6 Plants			
0%	none	25 (+4)	23 (4)	24 (0)	24[a]
	one	22 (8)	25 (+4)	23 (+17)	25 (+4)
	three	23 (4)	28 (+17)	21 (13)	24 (0)
25%	none	29 (+21)	21 (13)	20 (17)	23 (4)
	one	20 (17)	24 (0)	29 (+21)	25 (+4)
	three	21 (13)	22 (8)	27 (+13)	23 (4)
75%	none	22 (8)	26 (+8)	24 (0)	24 (0)
	one	22 (8)	21 (12)	24 (0)	22 (8)
	three	18 (25)	22 (8)	26 (+8)	22 (8)
Date Means		22	24	25	24
Defoliation Means	none	23 (0)	25 (0)	24 (0)	24 (0)
	25%	23 (0)	23 (8)	25 (+4)	23 (4)
	75%	21 (9)	23 (8)	24 (0)	23 (4)
Bruising Means	none	25 (0)	24 (0)	23 (0)	24 (0)
	one	21 (19)	23 (4)	27 (+17)	24 (0)
	three	21 (19)	24 (0)	25 (+9)	23 (4)

Analysis of Variance

	F ratio	Signif.
Date	0.860	N.S.
Defoliation	0.503	N.S.
Bruising	0.158	N.S.
Date x Def	0.306	N.S.
Date x Bru	1.085	N.S.
Def x Bru	0.165	N.S.
Error mean square	41.420	
Error degrees of freedom	54	

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Market tuber number was about 50 percent of total tuber number (cf. Tables 14 and 15).

No significant mean differences in yield of tubers less than 112 grams, or in yield of cull tubers, resulted from the injury factors or their interactions (Tables A-5 and A-6).

'Superior'

The total yield response of the 'Superior' cultivar to injury date is summarized in Table 16. Plants injured on the second date yielded significantly less than plants injured on the third date. Neither defoliation or bruising significantly decreased total yield. No significant factor interactions occurred.

Table 17 shows the market yield response of the 'Superior' cultivar. Market yields were about 90 percent of total yields. The mean market yield of plants injured on the second date was significantly less than that of plants injured on the third date. Significant differences in market yields did not occur between defoliation or bruising factors. No significant factor interactions occurred.

No significant differences in total tuber number (Table 18), or in market tuber number (Table 19), occurred between treatment factors. A significant interaction in total tuber numbers occurred between the date and bruising factors (Table 18). The mean total tuber number produced per six plants was 37 of which 75 percent were marketable.

Table 16. Influence of injury date, defoliation and bruising on total yield of 'Superior' tubers. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	8642 (4)	8995 (0)	9377 (+4)	9005[a]
	one	9992 (+11)	8211 (9)	6429 (29)	8210 (9)
	three	7365 (18)	7341 (18)	9109 (+1)	7938 (12)
25%	none	8287 (8)	6999 (22)	10923 (+21)	8737 (3)
	one	7425 (17)	7185 (20)	7647 (16)	7419 (18)
	three	7085 (21)	7235 (20)	10184 (+13)	8168 (9)
75%	none	7373 (18)	8966 (1)	8633 (4)	8324 (8)
	one	7029 (22)	7449 (17)	8309 (8)	7596 (16)
	three	7685 (14)	5819 (35)	8852 (2)	7452 (17)
Date Means		7876 (ab)	7578 (b)	8829 (a)	8094
Defoliation Means	none	8666 (0)	8182 (0)	8305 (0)	8384 (0)
	25%	7599 (12)	7140 (13)	9585 (+15)	8108 (3)
	75%	7362 (15)	7411 (9)	8598 (+3)	7790 (7)
Bruising Means	none	8101 (0)	8320 (0)	9655 (0)	8688 (0)
	one	8149 (+1)	7615 (8)	7462 (23)	7742 (11)
	three	7378 (9)	6798 (18)	9382 (3)	7853 (10)

Analysis of Variance[b]

	F ratio	Signif.
Date	3.171	0.05
Defoliation	0.655	N.S.
Bruising	1.987	N.S.
Date x Def	1.187	N.S.
Date x Bru	1.710	N.S.
Def x Bru	0.196	N.S.

Error mean square	3639543
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

[b]Where a significant F test occurred the means were compared using the H.S.D. mean separation test. Means not followed by the same letter differ significantly at the 5 percent level.

Table 17. Influence of injury date, defoliation and bruising on market yield of 'Superior' tubers. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Injury Dates: Second	Injury Dates: Third	Means
		Grams Per 6 Plants			
0%	none	8202 (5)	8660 (+1)	8901 (+4)	8588[a]
	one	8905 (+4)	7466 (13)	6032 (30)	7468 (13)
	three	6899 (20)	6698 (22)	8579 (0)	7392 (14)
25%	none	7573 (12)	6571 (23)	10268 (+20)	8137 (5)
	one	6504 (24)	6668 (22)	7075 (18)	6749 (21)
	three	6299 (27)	6517 (24)	9686 (+13)	7501 (13)
75%	none	6822 (21)	8364 (3)	8185 (5)	7790 (9)
	one	6234 (27)	6886 (20)	7701 (10)	6940 (19)
	three	6977 (19)	5459 (36)	7742 (10)	6726 (22)
Date Means		7157 (ab)	7032 (b)	8241 (a)	7477
Defoliation Means	none	8002 (0)	7608 (0)	7838 (0)	7816 (0)
	25%	6792 (15)	6586 (13)	9010 (+15)	7462 (4)
	75%	6677 (17)	6903 (9)	7876 (+1)	7152 (9)
Bruising Means	none	7532 (0)	7865 (0)	9118 (0)	8172 (0)
	one	7214 (4)	7007 (11)	6936 (24)	7052 (14)
	three	6725 (11)	6225 (21)	8669 (5)	7206 (12)

Analysis of Variance[b]

	F ratio	Signif.
Date	3.566	0.05
Defoliation	0.891	N.S.
Bruising	2.970	N.S.
Date x Def	1.244	N.S.
Date x Bru	1.428	N.S.
Def x Bru	0.193	N.S.
Error mean square	3346877	
Error degrees of freedom	54	

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

[b]Where significant F test occurred the means were compared using the H.S.D. mean separation test. Means not followed by the same letter differ significantly at the 5 percent level.

Table 18. Influence of injury date, defoliation and bruising on total tuber numbers of the 'Superior' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Tubers Per 6 Plants			
0%	none	41 (+8)	36 (5)	37 (3)	38[a]
	one	48 (+26)	35 (8)	28 (26)	37 (3)
	three	36 (5)	33 (13)	40 (+5)	37 (3)
25%	none	40 (+5)	39 (+3)	42 (+11)	40 (+5)
	one	42 (+11)	32 (16)	34 (11)	36 (5)
	three	32 (16)	38 (0)	42 (+11)	37 (3)
75%	none	37 (3)	41 (+8)	42 (+11)	40 (+5)
	one	43 (+13)	37 (3)	37 (3)	39 (+3)
	three	39 (+3)	26 (32)	35 (8)	33 (13)
Date Means		40	35	37	37
Defoliation Means	none	42 (0)	35 (0)	35 (0)	37 (0)
	25%	38 (9)	36 (+3)	39 (+11)	38 (+3)
	75%	40 (5)	35 (0)	38 (+8)	37 (0)
Bruising Means	none	39 (0)	38 (0)	40 (0)	39 (0)
	one	45 (+15)	35 (8)	33 (18)	37 (5)
	three	36 (8)	32 (16)	39 (3)	36 (8)

Analysis of Variance

	F ratio	Signif.
Date	2.661	N.S.
Defoliation	0.030	N.S.
Bruising	1.608	N.S.
Date x Def	0.659	N.S.
Date x Bru	2.674	0.05
Def x Bru	0.634	N.S.
Error mean square	55.309	
Error degrees of freedom	54	

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table 19. Influence of injury date, defoliation and bruising on market tuber numbers of the 'Superior' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates First	Second	Third	Means
		Tubers Per 6 Plants			
0%	none	32 (+7)	30 (0)	28 (7)	30[a]
	one	30 (0)	27 (10)	19 (37)	25 (17)
	three	26 (13)	23 (23)	28 (7)	26 (13)
25%	none	26 (13)	27 (10)	31 (+3)	28 (7)
	one	28 (7)	24 (20)	24 (20)	25 (17)
	three	23 (23)	27 (10)	33 (+10)	28 (7)
75%	none	27 (10)	29 (3)	31 (+3)	29 (3)
	one	27 (10)	25 (17)	29 (3)	27 (10)
	three	27 (10)	21 (30)	25 (17)	24 (20)
Date Means		27	26	28	27
Defoliation Means	none	29 (0)	26 (0)	25 (0)	27 (0)
	25%	26 (10)	26 (0)	29 (+16)	27 (0)
	75%	27 (7)	25 (4)	28 (+12)	27 (0)
Bruising Means	none	28 (0)	29 (0)	30 (0)	29 (0)
	one	28 (0)	25 (14)	24 (20)	26 (10)
	three	25 (11)	24 (17)	29 (3)	26 (10)

Analysis of Variance

	F ratio	Signif.
Date	0.831	N.S.
Defoliation	0.010	N.S.
Bruising	2.957	N.S.
Date x Def	1.267	N.S.
Date x Bru	1.461	N.S.
Def x Bru	0.606	N.S.

Error mean square	31.321
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Significant differences in yield of tubers weighing less than 112 grams or cull tubers did not occur between injury dates, degree of defoliation or number of bruises (Tables A-7 and A-8). Also, significant factor interactions did not occur.

'Norchip'

The influence of injury to 'Norchip' plants on total and market yields is shown in Tables 20 and 21, respectively. No significant differences in total yield or market yield occurred between injury dates, defoliation treatments or number of bruises. No significant factor interactions occurred. Approximately, 80 percent of the total yield was marketable.

The influence of injury on total and market tuber number is summarized in Tables 22 and 23, respectively. No significant differences in total or market tuber numbers occurred between levels of defoliation, bruising or date of injury. A significant interaction in total tuber number resulted between injury date and degrees of defoliation (Table 22). The mean total tuber number was 56. Approximately, 65 percent of the mean total tuber number was marketable.

Seventy-five percent defoliation significantly increased the yield of tubers weighing less than 112 grams (Table A-9). A significant interaction was observed between injury date and defoliation.

Table 20. Influence of injury date, defoliation and bruising on total yield of 'Norchip' tubers. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Injury Dates: Second	Injury Dates: Third	Means
		Grams Per 6 Plants			
0%	none	11734 (+11)	11052 (+5)	8864 (16)	10550[a]
	one	10575 (+1)	9003 (15)	7303 (30)	8961 (15)
	three	8277 (21)	9014 (15)	7956 (25)	8416 (20)
25%	none	8077 (23)	9128 (13)	9285 (12)	8830 (16)
	one	8044 (24)	8525 (19)	7555 (28)	8041 (24)
	three	8344 (21)	8657 (18)	8606 (18)	8536 (19)
75%	none	9401 (11)	8329 (21)	9678 (8)	9136 (13)
	one	7747 (29)	7481 (29)	9820 (7)	8349 (21)
	three	8655 (18)	8493 (19)	8877 (16)	8675 (18)
Date Means		8984	8854	8660	8833
Defoliation Means	none	10195 (0)	9698 (0)	8041 (0)	9308 (0)
	25%	8155 (20)	8770 (9)	8482 (+5)	8469 (9)
	75%	8601 (16)	8101 (16)	9458 (+18)	8720 (6)
Bruising Means	none	9737 (0)	9503 (0)	9276 (0)	9505 (0)
	one	8789 (10)	8336 (12)	8226 (11)	8450 (11)
	three	8425 (14)	8722 (8)	8480 (9)	8542 (10)

Analysis of Variance

	F ratio	Signif.
Date	0.197	N.S.
Defoliation	1.381	N.S.
Bruising	2.539	N.S.
Date x Def	2.176	N.S.
Date x Bru	0.108	N.S.
Def x Bru	0.645	N.S.

Error mean square	3630256
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table 21. Influence of injury date, defoliation and bruising on market yield of 'Norchip' tubers. Percentage decrease or increase (+) resulting from injury is shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	10198 (+11)	9790 (+6)	7635 (17)	9208[a]
	one	9244 (+1)	7727 (16)	7023 (24)	7998 (13)
	three	6725 (27)	7975 (13)	6963 (24)	7221 (22)
25%	none	7509 (18)	7666 (17)	7951 (14)	7709 (16)
	one	7132 (22)	7283 (21)	6973 (24)	7129 (23)
	three	7246 (21)	7076 (23)	7488 (19)	7270 (21)
75%	none	7743 (16)	7416 (19)	8358 (9)	7839 (15)
	one	6442 (30)	6747 (27)	8182 (11)	7124 (23)
	three	6727 (27)	7073 (23)	7432 (19)	7011 (24)
Date Means		7641	7639	7556	7612
Defoliation Means	none	8723 (0)	8497 (0)	7206 (0)	8142 (0)
	25%	7296 (16)	7342 (13)	7471 (+4)	7369 (10)
	75%	6904 (21)	7079 (17)	7991 (+11)	7324 (10)
Bruising Means	none	8483 (0)	8291 (0)	7981 (0)	8252 (0)
	one	7606 (10)	7252 (12)	7393 (7)	7417 (10)
	three	6833 (19)	7375 (11)	7294 (9)	7167 (13)

Analysis of Variance

	F ratio	Signif.
Date	0.018	N.S.
Defoliation	1.665	N.S.
Bruising	2.542	N.S.
Date x Def	1.328	N.S.
Date x Bru	0.229	N.S.
Def x Bru	0.430	N.S.

Error mean square	3426968
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table 22. Influence of injury date, defoliation and bruising on total tuber numbers of the 'Norchip' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Tubers Per 6 Plants			
0%	none	75 (+17)	61 (5)	57 (11)	64[a]
	one	64 (0)	52 (19)	48 (25)	54 (16)
	three	59 (8)	56 (12)	48 (25)	54 (16)
25%	none	42 (34)	61 (5)	53 (17)	52 (19)
	one	50 (22)	52 (19)	46 (28)	49 (23)
	three	57 (11)	55 (14)	52 (19)	54 (16)
75%	none	64 (0)	48 (25)	70 (+9)	60 (6)
	one	55 (14)	41 (36)	65 (+2)	53 (17)
	three	66 (+3)	62 (3)	60 (6)	63 (2)
Date Means		59	54	55	56
Defoliation Means	none	66 (0)	56 (0)	51 (0)	57 (0)
	25%	49 (26)	56 (0)	50 (2)	52 (9)
	75%	62 (6)	50 (11)	65 (+27)	59 (+3)
Bruising Means	none	60 (0)	57 (0)	60 (0)	59 (0)
	one	56 (7)	48 (16)	53 (12)	52 (12)
	three	61 (+2)	57 (0)	53 (12)	57 (3)

Analysis of Variance

	F ratio	Signif.
Date	1.398	N.S.
Defoliation	2.941	N.S.
Bruising	2.375	N.S.
Date x Def	3.931	0.05
Date x Bru	0.521	N.S.
Def x Bru	1.053	N.S.

Error mean square	125.95
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table 23. Influence of injury date, defoliation and bruising on market tuber numbers of the 'Norchip' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Tubers Per 6 Plants			
0%	none	48 (+12)	44 (+2)	38 (12)	43[a]
	one	43 (0)	34 (21)	33 (23)	37 (14)
	three	36 (16)	39 (9)	32 (26)	35 (19)
25%	none	36 (16)	38 (12)	34 (21)	35 (19)
	one	35 (19)	34 (21)	38 (12)	36 (16)
	three	39 (9)	34 (21)	34 (21)	36 (16)
75%	none	38 (12)	34 (21)	48 (+12)	40 (7)
	one	32 (26)	31 (28)	39 (9)	34 (21)
	three	33 (23)	39 (9)	38 (12)	37 (14)
Date Means		37	36	37	37
Defoliation Means	none	42 (0)	39 (0)	34 (0)	39 (0)
	25%	35 (17)	35 (10)	35 (+3)	35 (10)
	75%	35 (17)	35 (10)	42 (+23)	36 (8)
Bruising Means	none	39 (0)	39 (0)	40 (0)	39 (0)
	one	37 (5)	33 (15)	37 (8)	35 (10)
	three	36 (8)	37 (5)	34 (15)	36 (8)

Analysis of Variance

	F ratio	Signif.
Date	0.134	N.S.
Defoliation	1.164	N.S.
Bruising	1.995	N.S.
Date x Def	2.455	N.S.
Date x Bru	0.504	N.S.
Def x Bru	1.083	N.S.

Error mean square	57.50
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

No significant differences in yield of cull potatoes occurred between dates of injury, defoliation levels or number of bruises (Table A-10).

Cultivar Comparisons

The following is a comparison of the response to injury of the four cultivars to that of the 'Russet Burbank' cultivar. A loss table relating percent yield loss, injury date and injury severity has been prepared for the 'Russet Burbank' cultivar. Of interest was whether insurance adjusters could use the 'Russet Burbank' loss table to evaluate yield reduction in other cultivars. To compare cultivars, the percentage loss or gain in total and market yield for each cultivar has been compiled in Tables 24 and 25, respectively. Each cultivar was compared to the 'Russet Burbank' cultivar using the unpaired t test.

On the first injury date, the mean percent reduction in total yield of 'Norgold', 'Superior' and 'Norchip' in response to injury was significantly greater than that for 'Russet Burbank' (Table 24). Russet Seedling 'BC 8370-4' responded the same as 'Russet Burbank'. Significant differences in yield reduction did not occur between 'Russet Burbank' and the four other cultivars when injured on the second and third dates.

Table 24. Percentage decrease or increase (+) in total yield for each cultivar. Percentages are based on non-injured control.

Defoliation	Bruising	Russet Burbank	BC 8370-4	Norgold	Superior	Norchip
		First Injury Date				
0%	one	0	3	17	+11	+1
	three	8	+5	15	18	21
25%	none	2	+7	+7	8	23
	one	+9	0	25	17	24
	three	+1	6	20	21	21
75%	none	2	+9	22	18	11
	one	+9	3	14	22	27
	three	5	+3	38	14	18
Mean		+.25	+1.5	18	13	18
t statistic		-	0.42424	3.63428	3.12618	4.71828
Significance		-	(N.S.)	(0.05)	(0.05)	(0.05)
		Second Injury Date				
0%	one	11	14	+10	9	15
	three	17	14	+3	18	15
25%	none	1	2	18	22	13
	one	24	5	6	20	19
	three	22	23	27	20	18
75%	none	3	20	16	1	21
	one	17	21	30	17	29
	three	26	22	21	35	19
Mean		15	15	13	19	18
t statistic		-	0.03747	0.37315	0.51366	0.88004
Significance		-	(N.S.)	(N.S.)	(N.S.)	(N.S.)
		Third Injury Date				
0%	one	2	7	+1	29	30
	three	3	+6	17	+1	25
25%	none	+5	8	20	+21	12
	one	+1	1	+5	16	28
	three	26	+1	1	+13	18
75%	none	18	14	8	4	8
	one	19	14	12	8	7
	three	22	11	10	2	16
Mean		10	6	7	3	18
t statistic		-	0.9355	0.52806	1.12943	1.40588
Significance		-	(N.S.)	(N.S.)	(N.S.)	(N.S.)

Table 25. Percentage decrease or increase (+) in market yield for each cultivar. Percentages are based on non-injured control.

Defoliation	Bruising	Russet Burbank	BC 8370-4	Norgold	Superior	Norchip
			First Injury Date			
0%	one	+13	2	15	+4	+1
	three	25	+2	18	20	27
25%	none	+2	+16	+18	12	18
	one	+9	+11	26	24	22
	three	7	13	23	27	21
75%	none	7	4	21	21	16
	one	+6	7	22	27	30
	three	20	11	41	19	27
Mean		4	1	19	18	20
t statistic		-	0.43493	1.95142	2.42349	2.75953
Significance		-	(N.S.)	(0.05)	(0.05)	(0.05)
			Second Injury Date			
0%	one	6	8	+7	13	16
	three	15	17	+14	22	13
25%	none	27	37	14	23	17
	one	+9	13	+1	22	21
	three	25	31	31	24	23
75%	none	24	37	17	3	19
	one	22	34	35	20	27
	three	39	48	21	36	23
Mean		19	28	12	20	20
t statistic		-	1.33056	0.081417	0.28390	0.23065
Significance		-	(N.S.)	(N.S.)	(N.S.)	(N.S.)
			Third Injury Date			
0%	one	13	1	1	30	24
	three	3	+8	23	0	24
25%	none	+2	7	23	+20	14
	one	1	6	+11	18	24
	three	31	+7	4	+13	19
75%	none	19	12	3	5	9
	one	36	30	5	10	11
	three	23	30	6	10	19
Mean		16	9	7	5	18
t statistic		-	0.91733	1.36252	1.38341	0.45862
Significance		-	(N.S.)	(N.S.)	(N.S.)	(N.S.)

Market yield response of the four cultivars relative to 'Russet Burbank' was the same as that for total yield (Table 25).

Mean Effects of Treatments -- Cultivars Averaged

The response of the five cultivars was averaged to obtain the mean response to defoliation, bruising and date of injury. In each figure the relationship between two factors is shown with the third factor averaged.

The relationship between date of injury and defoliation on mean total and mean market yields is shown in Figures 5 and 6, respectively. Defoliation on the second injury date resulted in slightly greater reductions in total and market yields than injury on the first or third date.

Twenty-five percent defoliation depressed mean total yield to 10 percent and mean market yields to 13 percent depending on the injury date. Seventy-five percent defoliation depressed mean total yields from 2 to 14 percent and mean market yields from 4 to 17 percent.

The relationship between injury date and bruising on mean total and mean market yields is shown in Figures 7 and 8, respectively. Slightly greater reductions in total and market yield resulted when plants were bruised on the second date. An interaction between date and bruising occurred on the third injury date due to a reverse

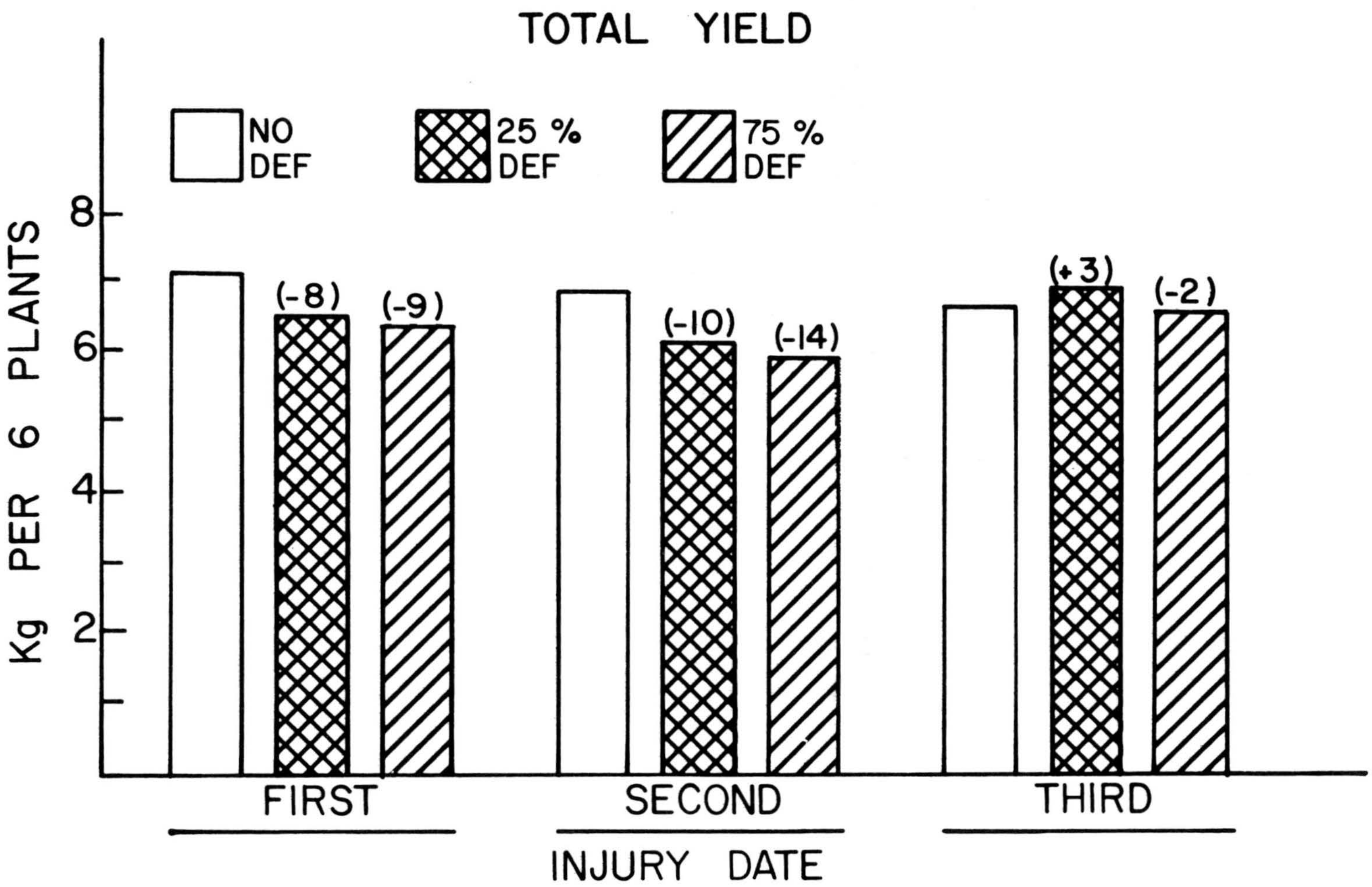

Figure 5. Effects of injury date and defoliation on total yield; each bar is the mean of five cultivars, three bruising treatments and three replications. Number in parenthesis is the percent loss or gain relative to the non-defoliated treatment on each date.

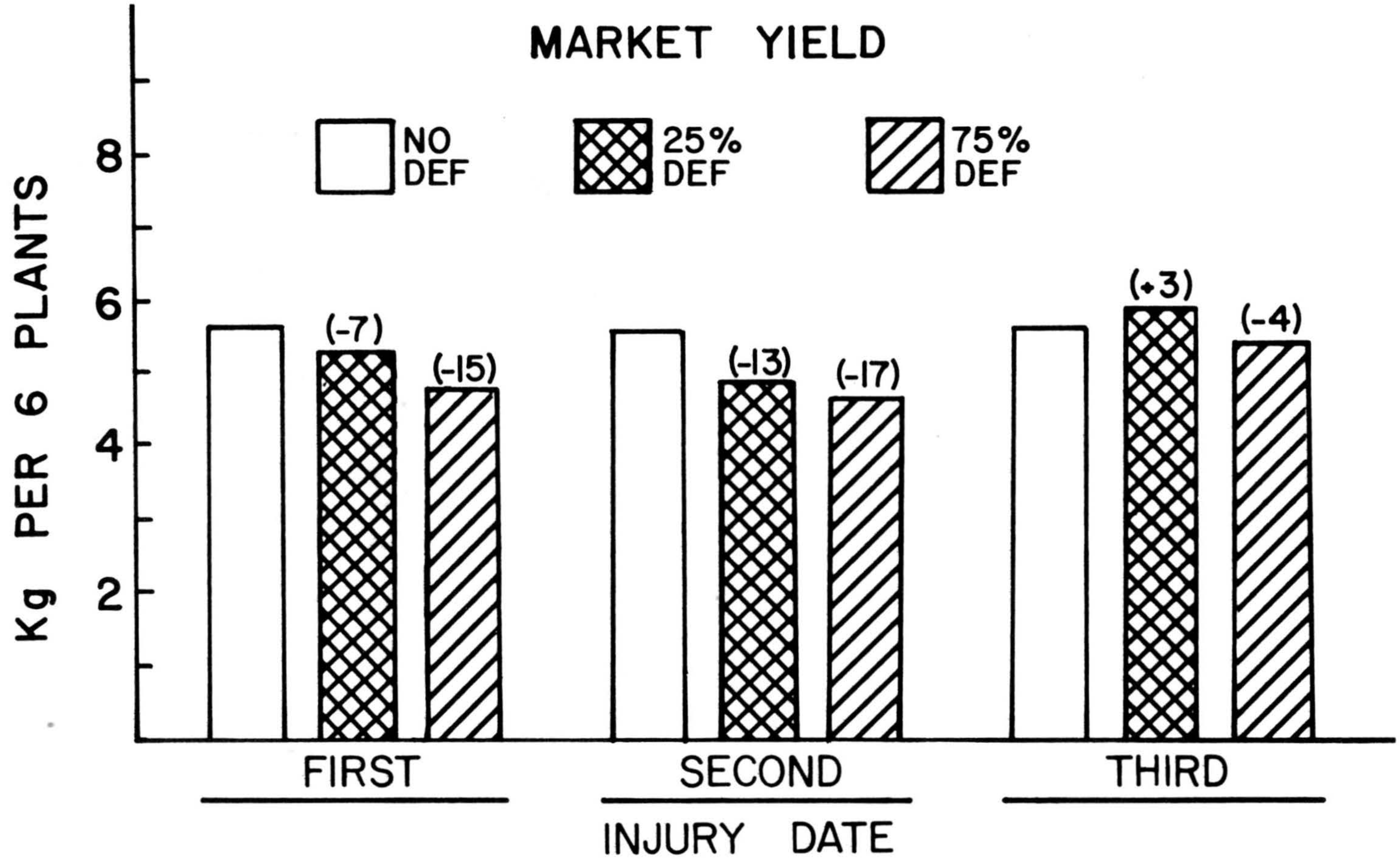

Figure 6. Effects of injury date and defoliation on market yield; each bar is the mean of five cultivars, three bruising treatments and three replications. Numbers in parenthesis is the percent loss or gain relative to the non-defoliated treatment on each date.

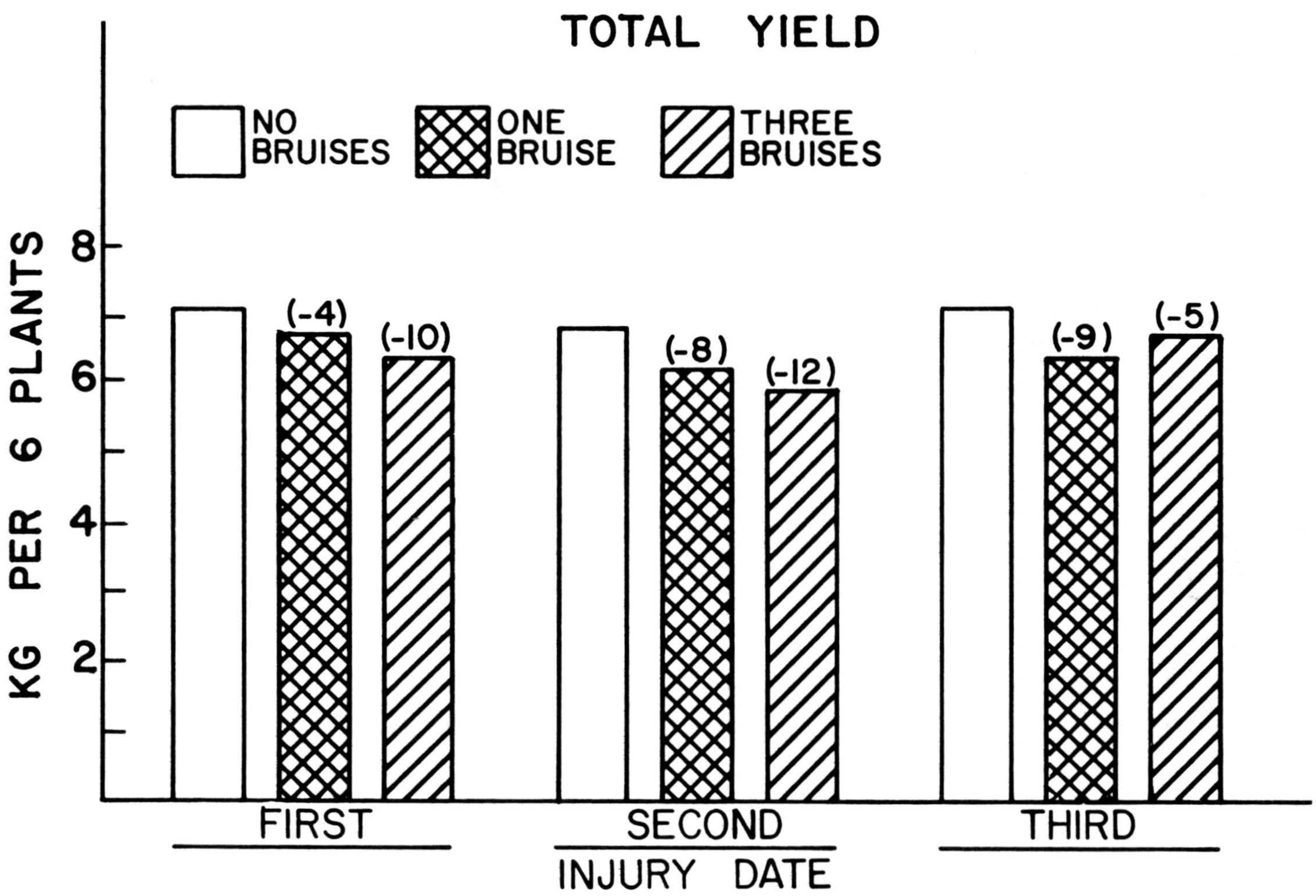

Figure 7. Effects of injury date and bruising on total yield; each bar is the mean of five cultivars, three defoliation treatments and three replications. Number in parenthesis is the percent loss relative to the non-bruised treatment on each date.

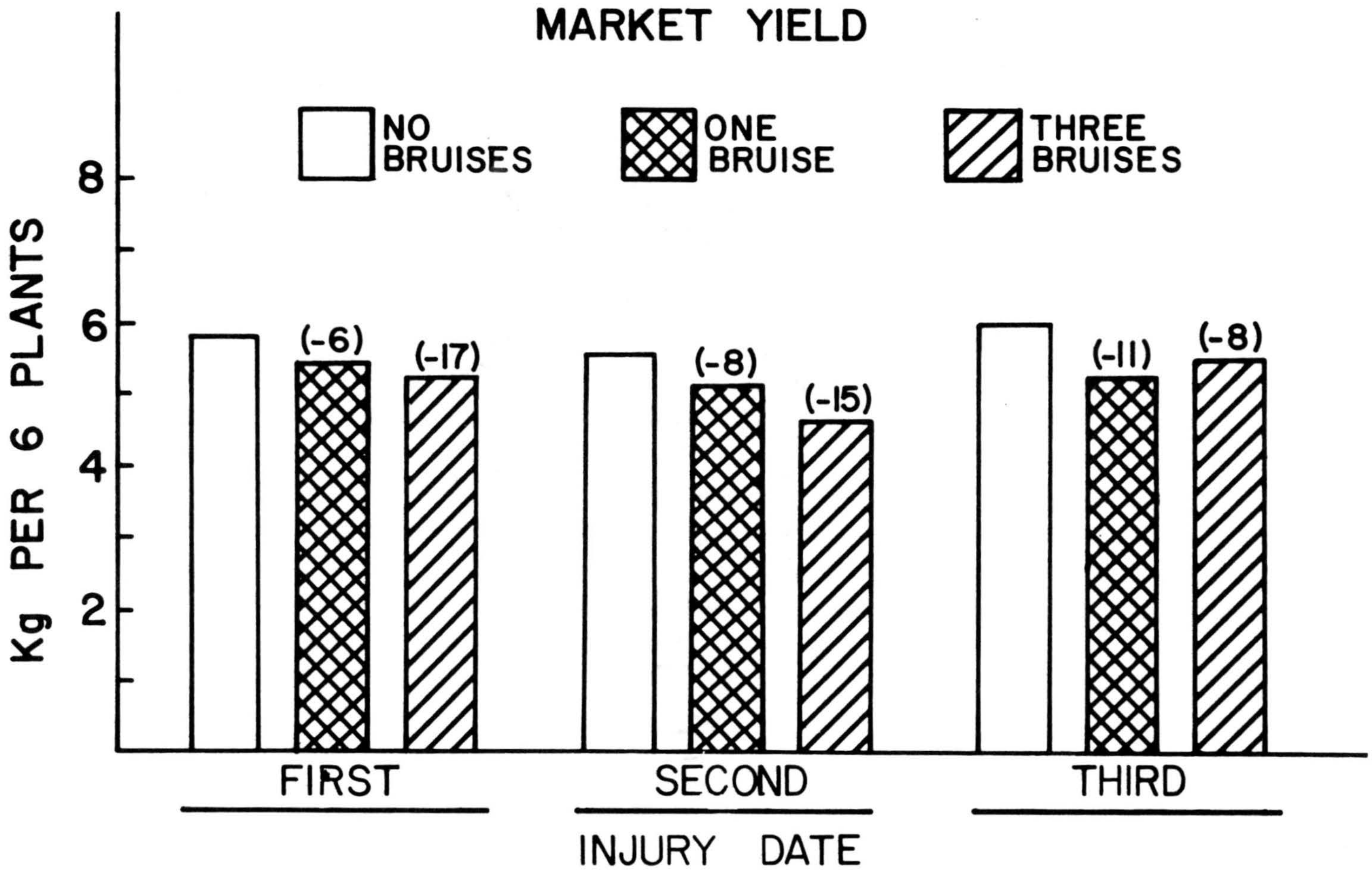

Figure 8. Effects of injury date and bruising on market yield; each bar is the mean of five cultivars, three defoliation treatments and three replications. Number in parenthesis is the percent loss relative to the non-bruised treatment on each date.

reaction between one and three bruises. In contrast to the first and second date, three bruises on the third date resulted in less total and market yield loss than one bruise. One bruise depressed mean total yields from 4 to 9 percent and mean market yields from 6 to 11 percent depending on the injury date. Three bruises depressed mean total yields from 5 to 12 percent and mean market yields from 8 to 17 percent.

The relationship between bruising and defoliation in their effect on mean total and mean market yields is shown in Figures 9 and 10, respectively. These two figures summarize the mean effects of bruising and defoliation when cultivar response and date effects are averaged, showing the mean effects of defoliation alone, bruising alone and combinations of defoliation and bruising. Each value is the mean of 45 observations. Twenty-five percent defoliation reduced mean total and mean market yields 8 percent. Seventy-five percent defoliation reduced mean total yield 11 percent and mean market yield 12 percent. One bruise depressed mean total and mean market yield 9 percent while three bruises reduced mean total yield 12 percent and mean market yield 15 percent. When considering the mean effect of defoliation and bruising combinations it is seen that the effects tended to be additive.

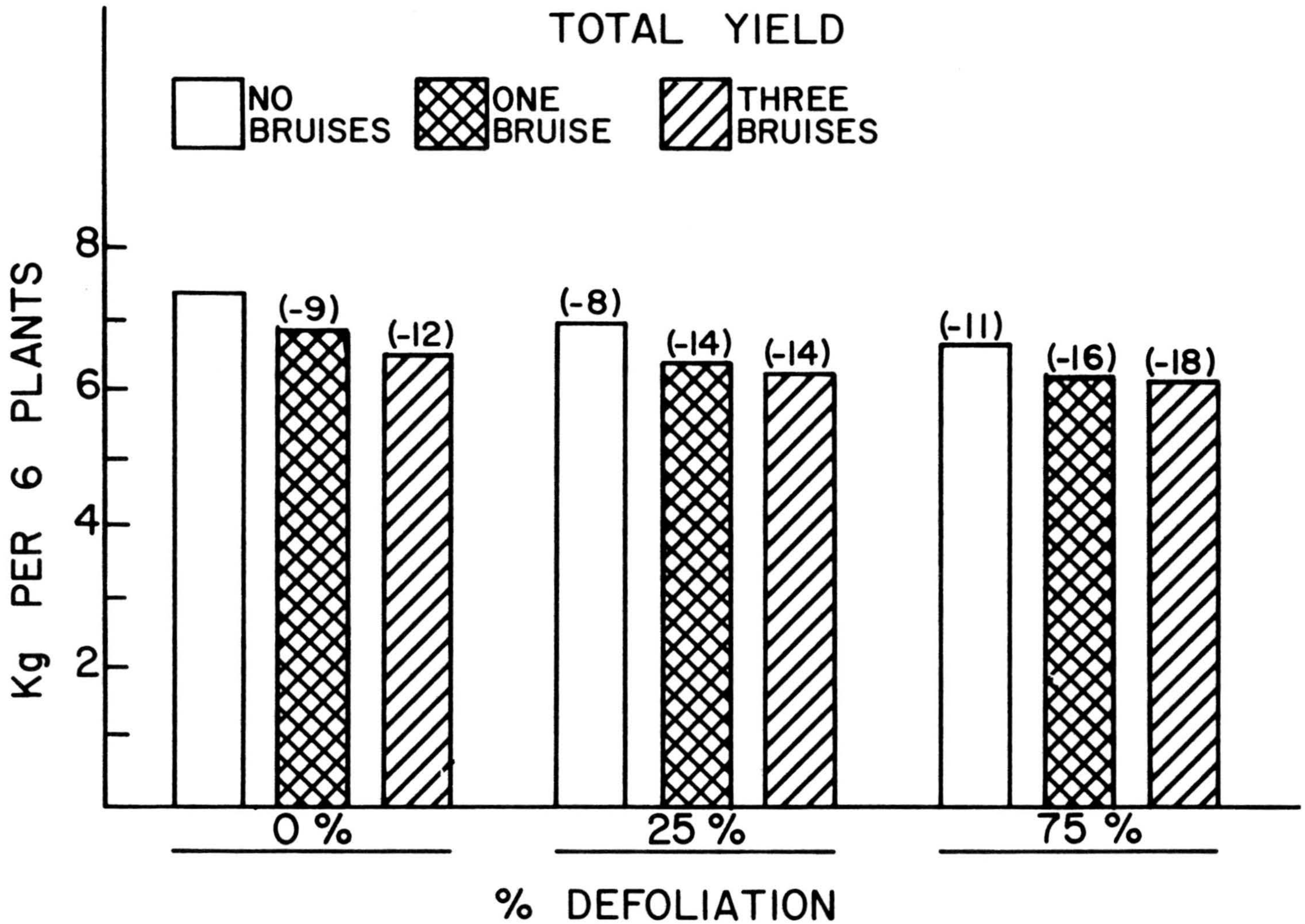

Figure 9. Effects of defoliation and bruising on total yield; each bar is the mean of five cultivars, three injury dates and three replications. Number in parenthesis is the percent loss relative to the non-defoliated and non-bruised treatment (bar #1).

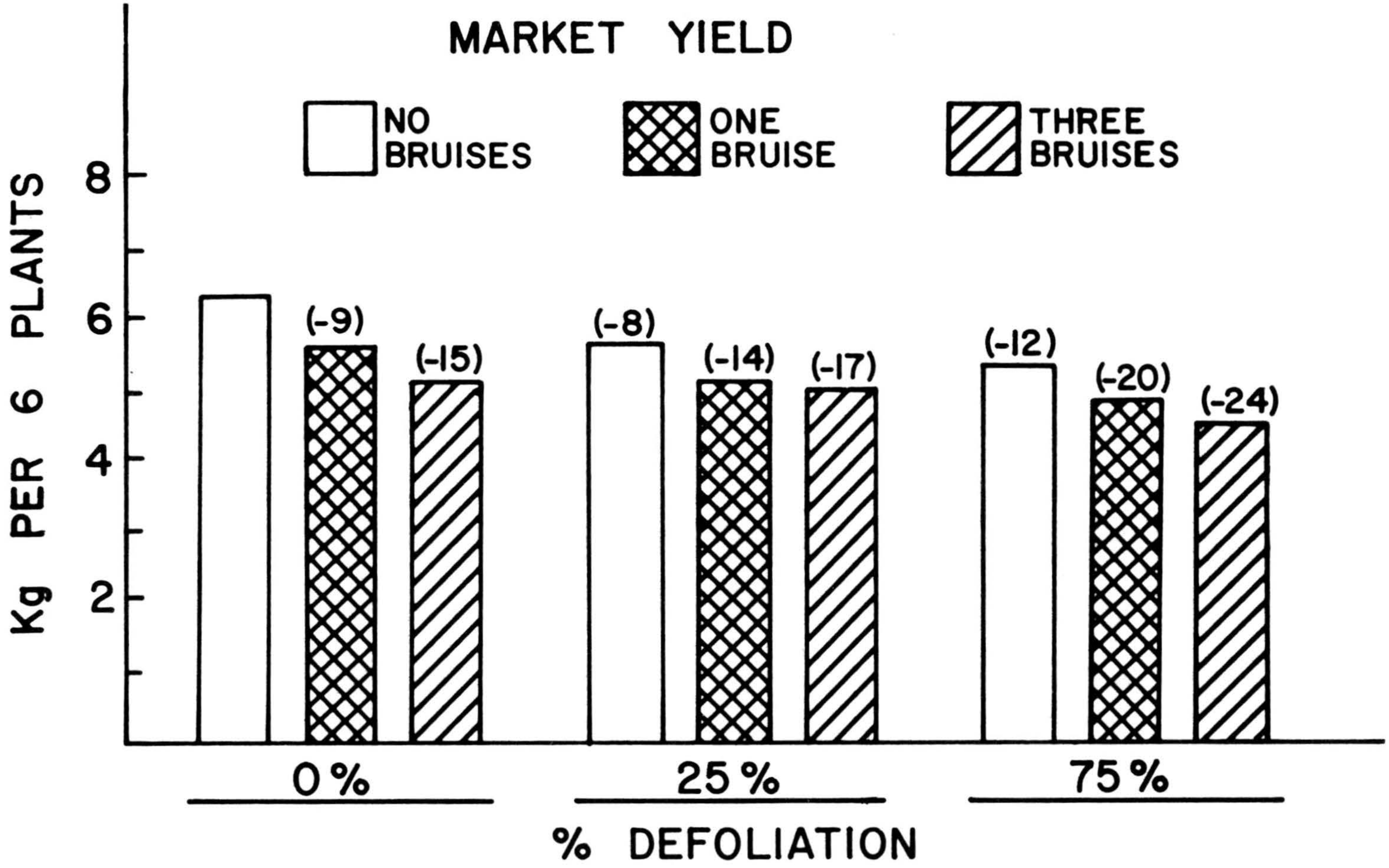

Figure 10. Effects of defoliation and bruising on market yield; each bar is the mean of five cultivars, three injury dates and three replications. Number in parenthesis is the percent loss relative to the non-defoliated and non-bruised treatment (bar #1).

Part II: Anatomical Studies of Stem Bruises

Figure 11 is a photomicrograph of a transverse section of the uninjured potato stem. This will be compared to damaged stems to show the effects of bruising injury on cell structure and vascular continuity. In the upper left corner (location 1) of Figure 11 are six to eight layers of oval shaped cells with dark stained areas in between. These are collenchyma cells and their main function in the stem is that of support. These cells are located directly under the epidermal and sub-epidermal layers of the stem. The thin walled parenchymatous cells of the cortex are next. These are the largest cells seen in the figure and have few dark staining intercellular areas. The dark staining cells located next to the inner edge of the cortex are pericyclic fibers. These very thick walled cells, with the small lumen, also function in support. A few scattered islands of outer phloem are evident about 200 microns from the pericyclic fibers. These cellular regions can be distinguished by their small inner region which is surrounded by larger cells. Proceeding into the stem, secondary and some primary xylem can be seen (locations 4 and 5). The rectangular cambial cells are not evident. Both types of xylem are characterized by their dark staining walls. The primary xylem is located inwards from the secondary xylem. The last cells (location 6) seen in Figure 11 are the parenchyma cells of the pith. Only a few scattered groups of inner phloem are seen next to the pith.

Figure 12 is a photomicrograph of the upper section of a bruised area one week after injury. In the upper left corner (location 1) the epidermal and sub-epidermal layers are shown to be badly torn and disrupted. The collenchyma cells are flattened and broken. The cortical layer of parenchyma, adjacent to the collenchyma, are also broken. In the cortical region larger gaps are present since the cell walls have been torn away and organization has been disrupted. The outer phloem elements, which translocate assimilates, are not disrupted although more compacted. Most cells inside to the outer phloem (secondary and primary xylem, inner phloem, pith) are normal in structure.

Figure 13 shows the lower section of the bruise one week after injury. The epidermal, sub-epidermal and collenchyma region of the stem (location 1) are disrupted. Small portions of the cortical area are broken in the outer edges of the bruise. The vascular tissue is generally intact. The groups of dark stained inner phloem cells at the right side (location 2) of Figure 13 indicates vascular continuity.

Figures 14 and 15 are photomicrographs of upper and lower sections, respectively, of bruises three weeks after injury. Figure 14 does not provide a clear picture of the epidermal and sub-epidermal layers but does show that the organization of the collenchyma cells are distorted. The dark scattered areas seen at the left side of the photomicrograph are collenchyma cell walls (location 1). Inwards from the collenchyma most of the cortical cells are broken, but some cellular detail is still evident. Note that after the cortical area the cells have an appearance somewhat similar to Figure 11. Figure 14 clearly shows the rectangular cells of the cambial layer.

Epidermal, sub-epidermal and cortical regions are not shown in Figure 15. The first cells seen are the parenchyma cells of the cortex (location 1). Detail in the outer phloem is not clear, but parts of phloem structure are seen. The larger xylem cells are still intact. Inwards from the larger secondary and smaller primary xylem, distinct groups of inner phloem are seen. The pith is badly distorted and only a few intact cells are seen.

Photomicrographs of the upper and lower sections of a bruise five weeks after injury are shown in Figures 16 and 17, respectively. In Figure 16 only a few epidermal and sub-epidermal cells are shown to be intact (location 1). The scattered dark areas under the outer layers are broken collenchyma cells. No complete collenchyma cells are visible. The aggregate of dark staining tissue next to the collenchyma region are collapsed parenchyma cells of the cortex; cellular detail is completely obscured. Next there are two to three islands of intact outer phloem (location 2). Most striking in Figure 16 are the larger and blacker staining xylem cells with their organization being relatively intact (location 3). Secondary xylem is observed.
Evidently the initial injury had little effect on cambial functioning. In

the upper right corner of Figure 16 scattered groups of inner phloem are seen. These are located close to the larger thin walled pith cells (location 6).

Figure 17 is the lower section of a bruise after five weeks. The epidermal, other inward areas, and most of the outer phloem cells are badly disrupted (location 1). Very few cortical cells are intact, but inside this region a few phloem groups can be seen approximately 900 microns from the epidermal layer. Both secondary and primary xylem cells are visible and still retain some of their original shape. The inner phloem and neighboring pith cells are normal in appearance. Either the injury did not disrupt their organization or healing took place rapidly.

Photomicrographs of upper and lower sections of bruises seven weeks after are shown in Figures 18 and 19, respectively. In Figure 18 the epidermal and sub-epidermal cells are not present. Collenchyma and parenchyma cells of the cortex are moderately disrupted (location 1). Deeper in the stem the cells are more normal in appearance, but some cell walls are broken. A few clusters of outer phloem are seen about 50 microns inwards from these broken cells (location 2). Some secondary xylem cell walls are torn, but the primary xylem cells are relatively intact (below location 3). Some inner phloem groups are located on the outer edges of the pith. They can be distinguished by the small darker staining areas in their center.

The lower section of the bruise does not show the epidermal tissue or the collenchyma area of the cortex (Figure 19). The cortical parenchyma cells are uniform in appearance with most cells being intact (location 1). Below the cortical parenchyma distinct islands of intact outer phloem are apparent. Secondary xylem, internal phloem and primary xylem show normal structure and organization.

Figure 11. Transection of sector of uninjured stem. Epidermal layer starts at number one. Sector proceeds inwards to a depth of 4 mm into stem in numerical order.

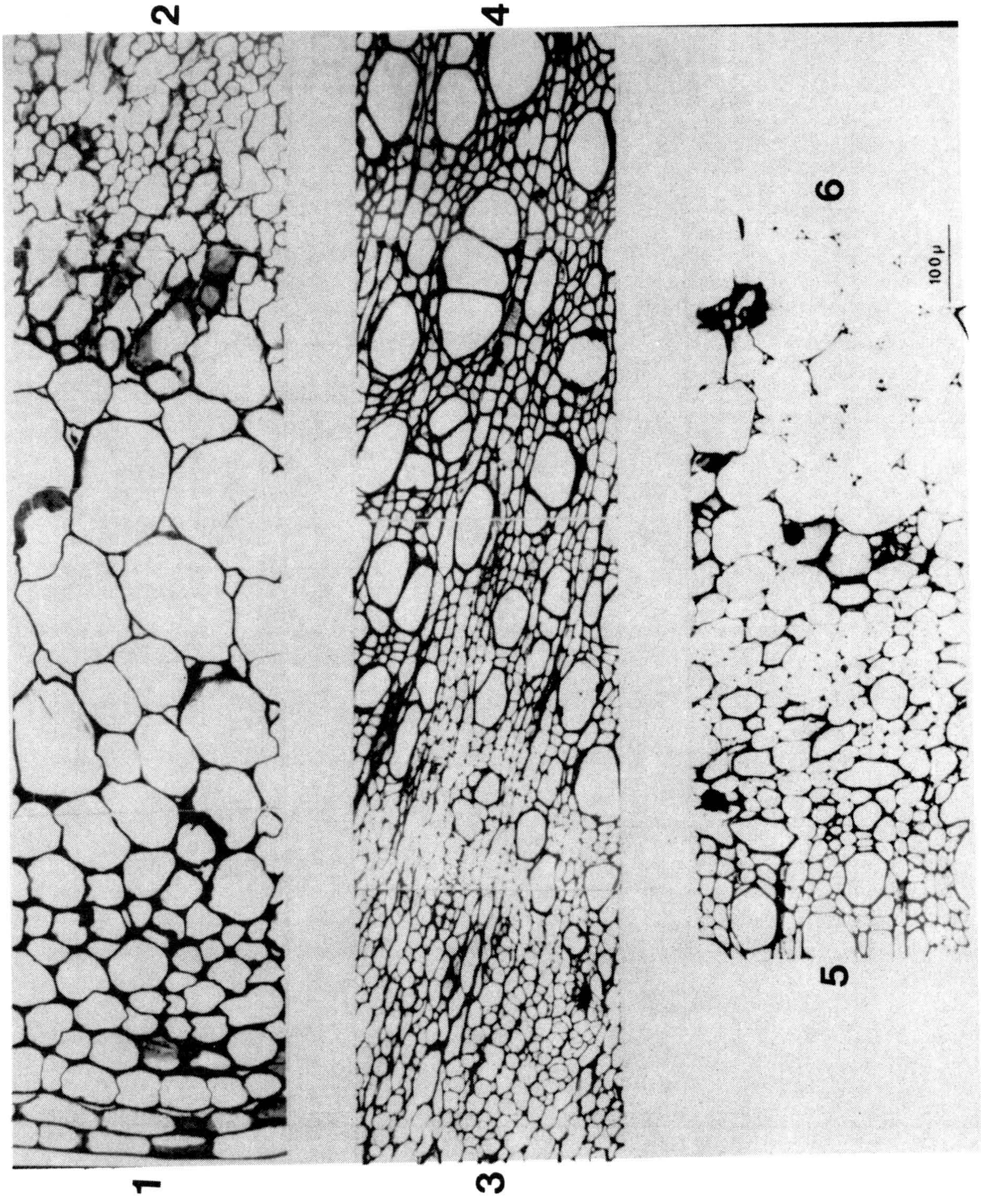
2
4
6
100μ
1
3
5

Figure 12. Transection of sector through upper portion of bruise one week after injury. Outer most layer starts at number one. Sector proceeds inwards into stem in numerical order.

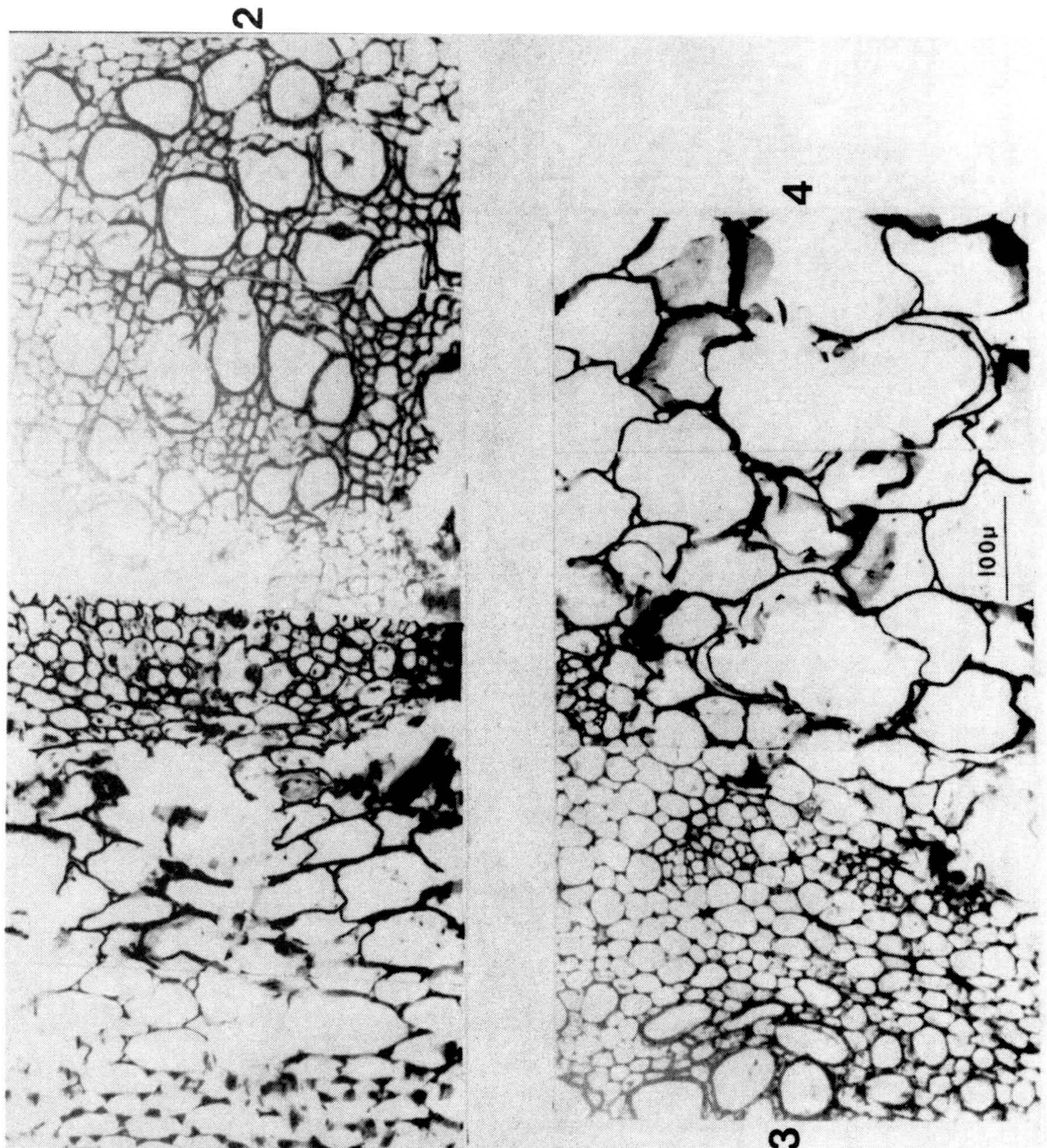
2
4
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Figure 13. Transection of sector through lower portion of bruise one week after injury. Outer most layer starts at number one. Sector proceeds inwards into stem in numerical order.

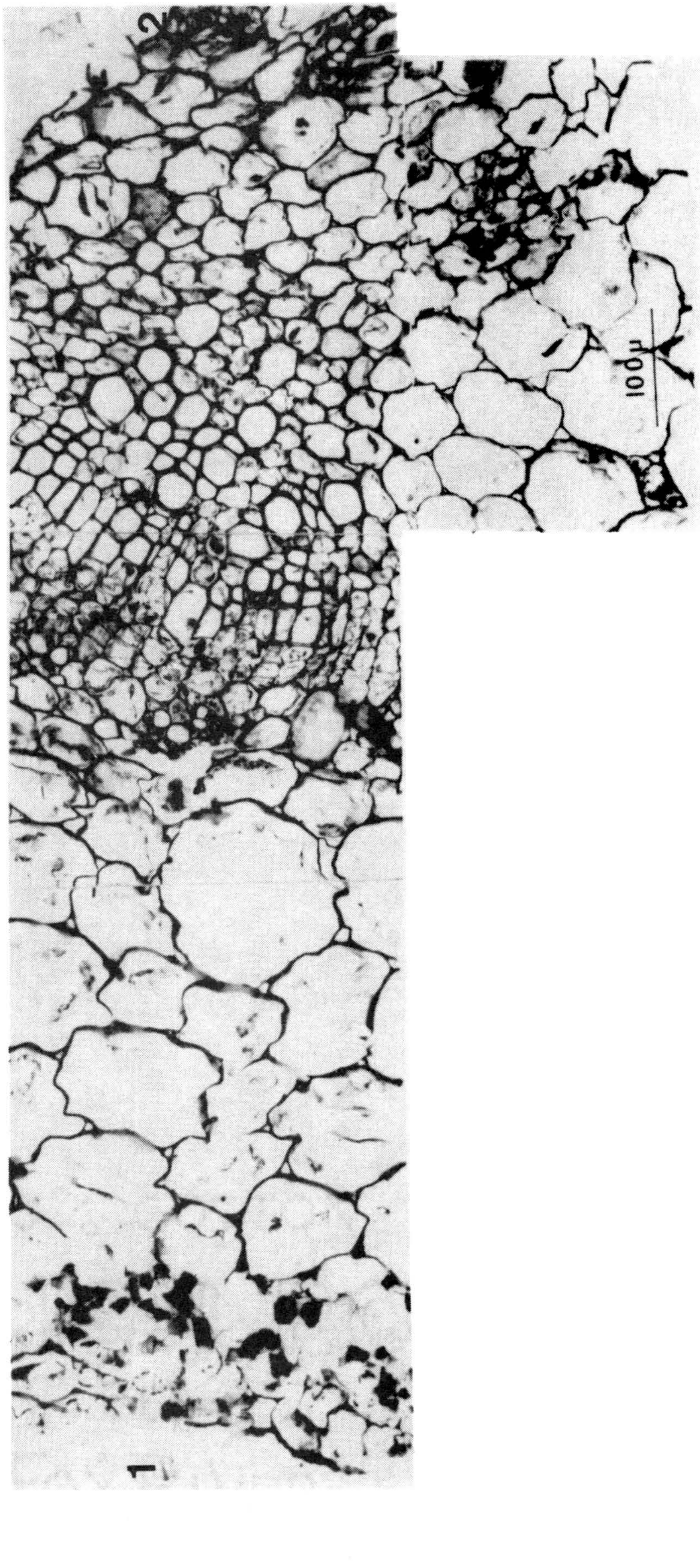

100µ

Figure 14. Transection of sector through upper portion of bruise three weeks after injury. Outer most layer starts at number one. Sector proceeds inwards into stem in numerical order.

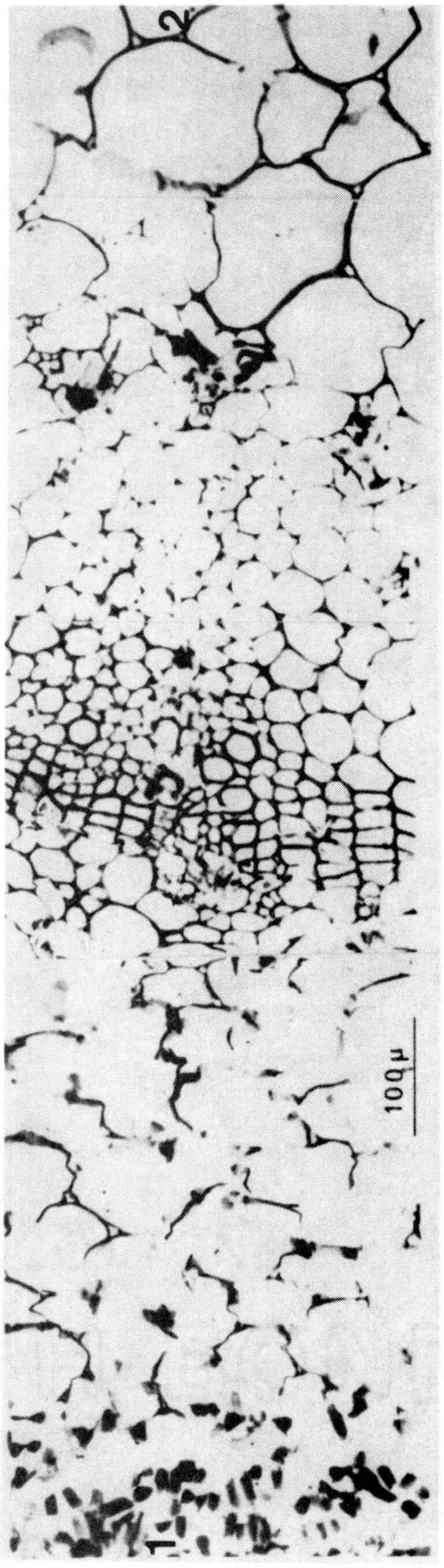

100µ

Figure 15. Transection of sector through lower portion of bruise three weeks after injury. Outer most layer starts at number one. Sector proceeds inwards into stem in numerical order.

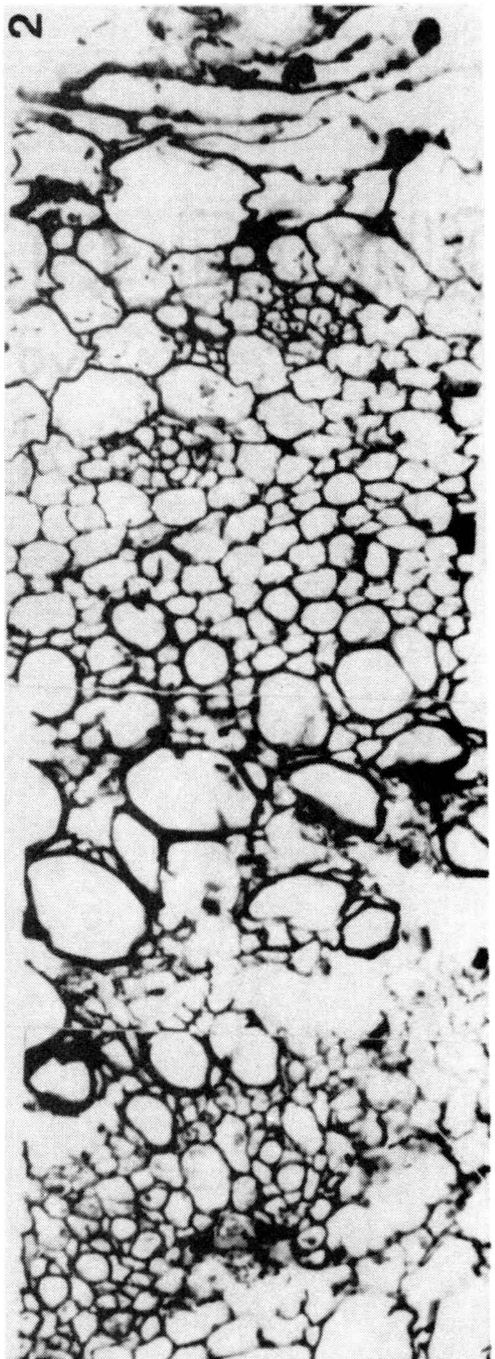

2
1
100µ

Figure 16. Transection of sector through upper portion of bruise five weeks after injury. Outer cellular layer starts in lower left corner. Outer most layer starts at number one. Sector proceeds inwards into stem in numerical order.

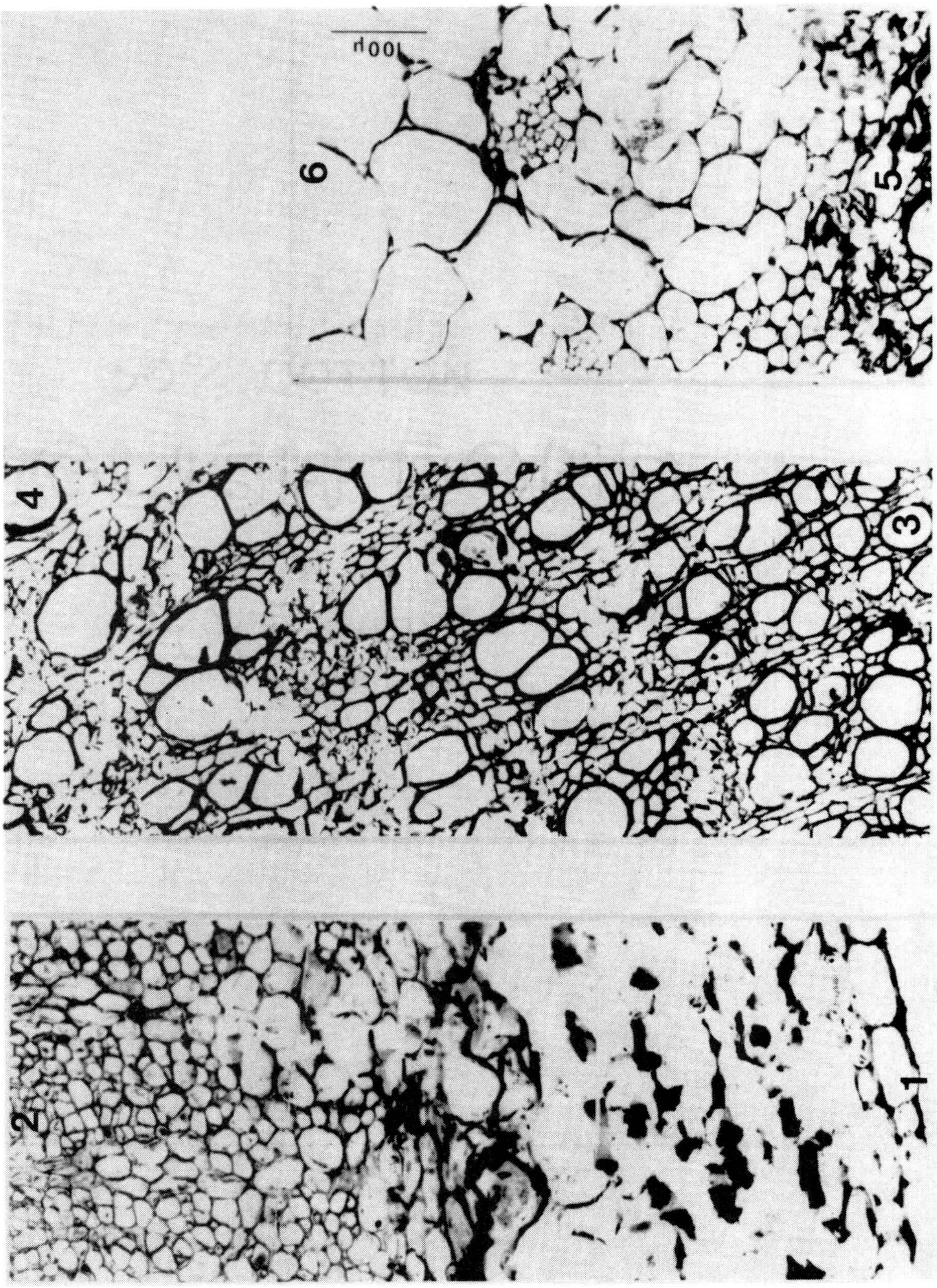

100μ
6
5
4
3
2
1

Figure 17. Transection of sector through lower portion of bruise five weeks after injury. Outer most layer starts at number one. Sector proceeds inwards into stem in numerical order.

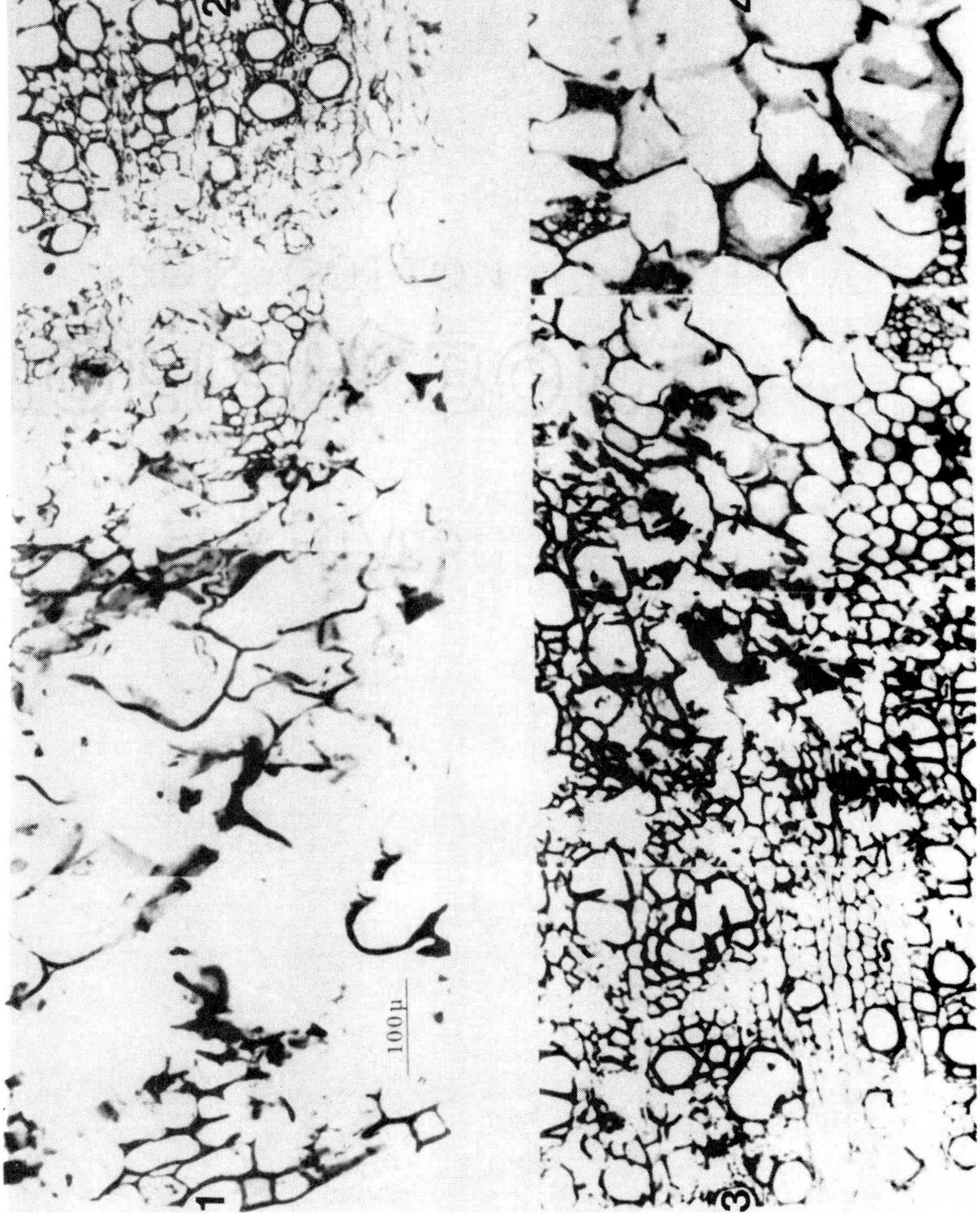
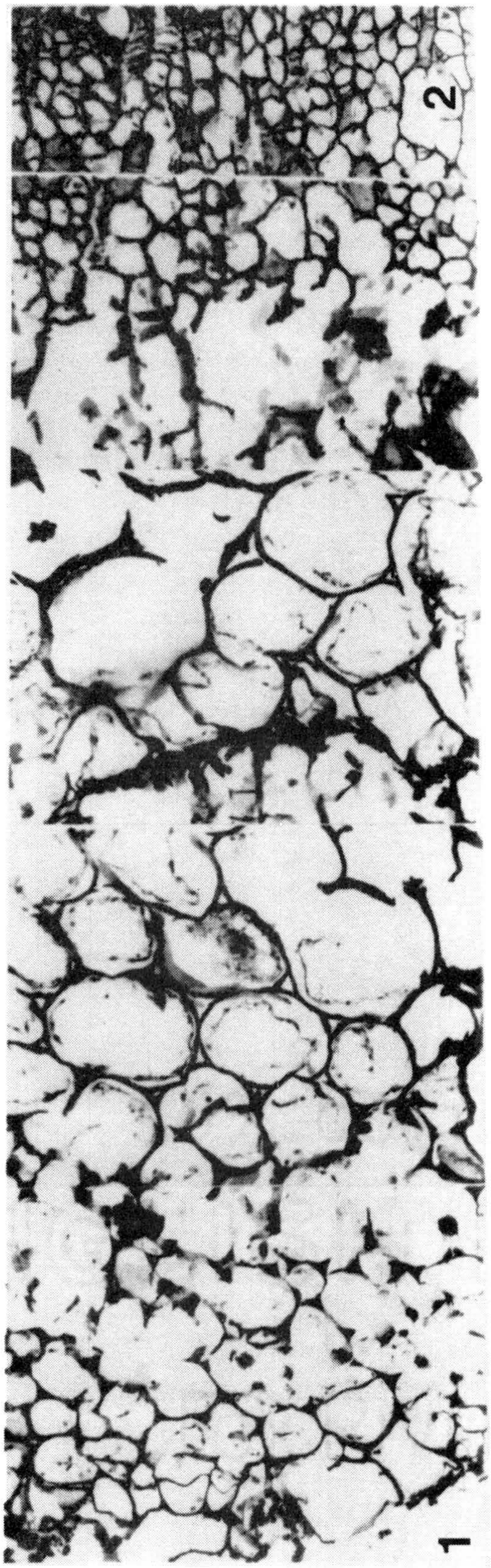

1
2
3
4
100μ

Figure 18. Transection of sector through upper portion of bruise seven weeks after injury. Outer most layer starts at number one. Sector proceeds inwards into stem in numerical order.


2
1

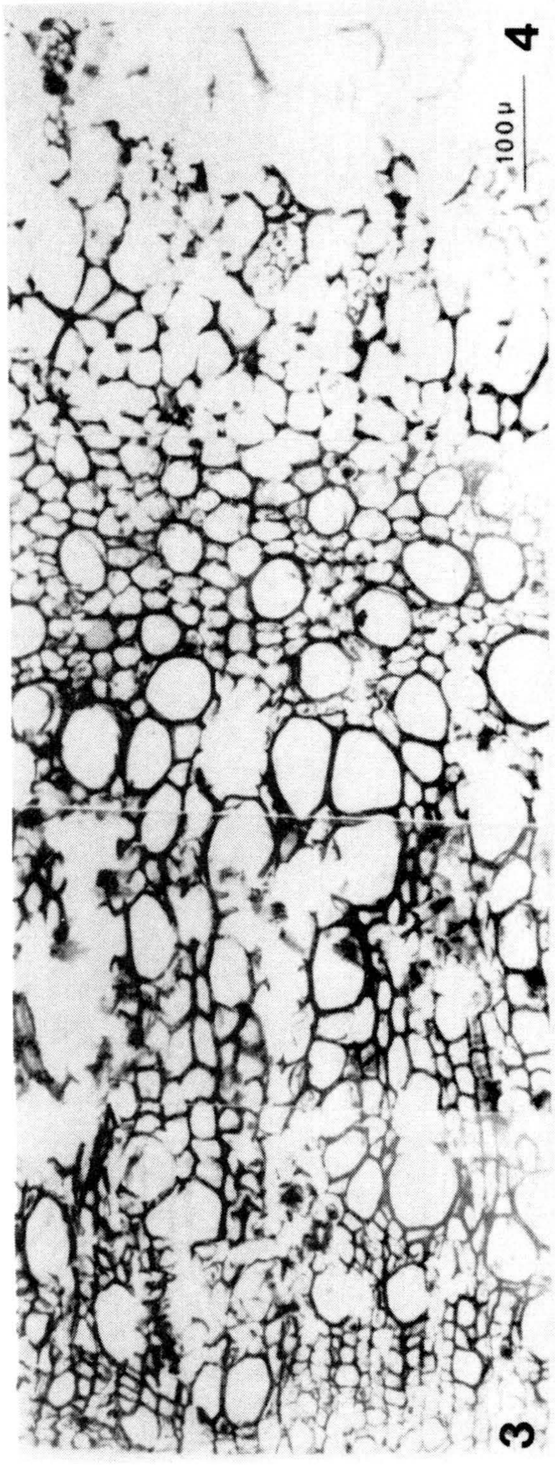
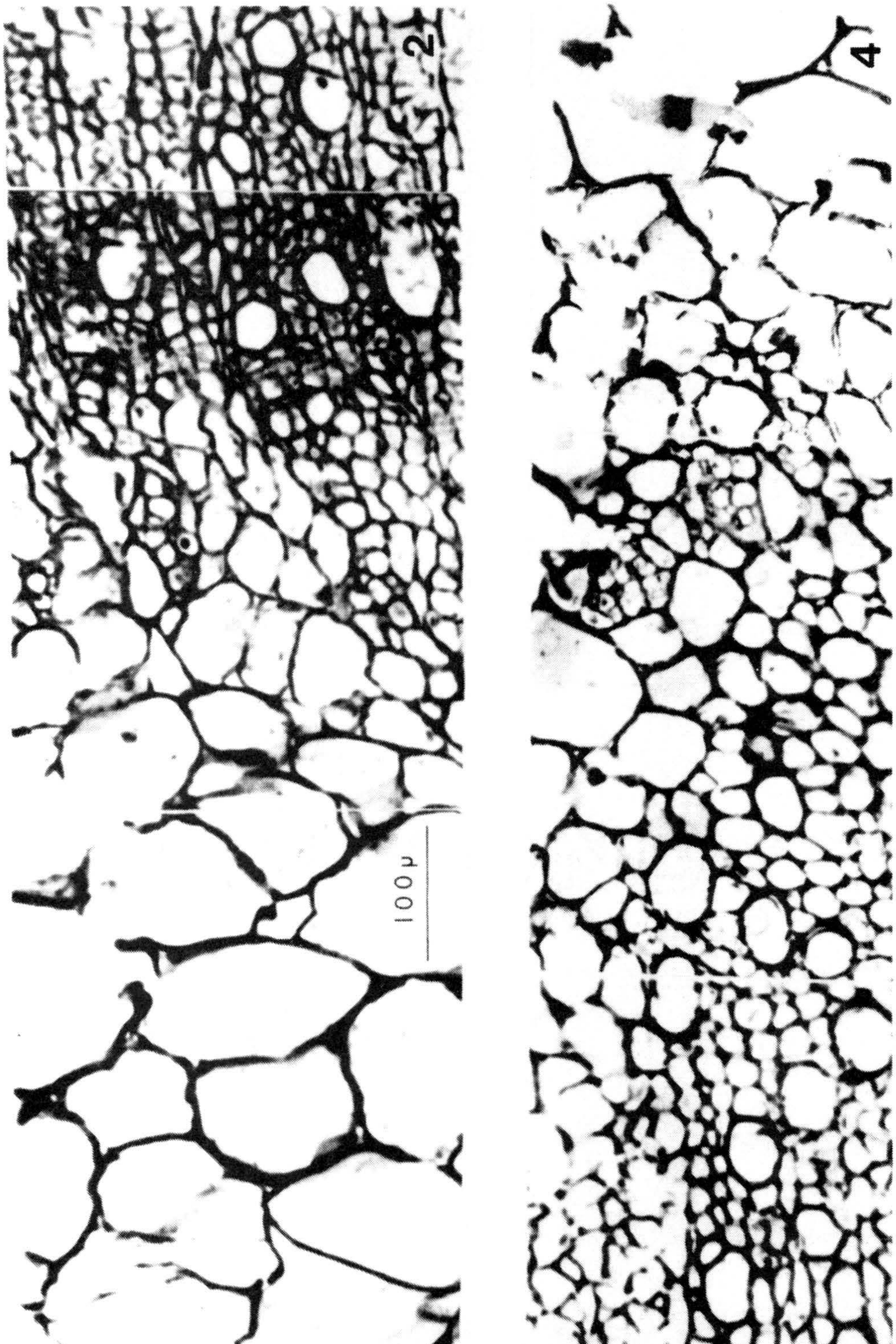

4
100μ
3

Figure 19. Transection of sector through lower portion of bruise seven weeks after injury. Outer most layer starts at number one. Sector proceeds inwards into stem in numerical order.


1
2
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CHAPTER V

DISCUSSION AND CONCLUSIONS

Potato cultivars have certain distinguishing characteristics. Some of these characteristics are tuber skin color, vine type, disease resistance, etc. It was expected that cultivars would also differ in response to injury. A difference in response was observed between three of four test cultivars and 'Russet Burbank' when plants were injured on the first date. The mean percent loss in yield for the three cultivars was greater than that of the 'Russet Burbank' cultivar. However, no statistically significant differences occurred between cultivars when plants were injured on the second or third date. The three cultivars were all earlier maturing types than 'Russet Burbank'. Hence, when injured on the first date tubers may have been more developed. This may have rendered the plants somewhat more sensitive to injury. The fourth cultivar, Russet Seedling 'BC 8370-4', required the same time to reach maturity as 'Russet Burbank' and also responded similarly to injury.

Some literature concluded that leaf removal at full bloom is the most sensitive stage in the growth of the potato plant (37, 44, 45). However, Beresford (5) concluded that leaf removal when 50 percent of the plants were past full bloom reduced yields more than leaf removal at any other period. Apparently, there is no general agreement as to the most sensitive stage. In this study yield losses were slightly greater following the second injury date. This may possibly be explained as follows. Plants injured on the first date had sufficient time to recover, while plants injured on the third date had well developed tubers with a sufficient carbohydrate reserve. Plants injured on the second date had less carbohydrate reserve and, therefore were the most sensitive to damage.

Murphy and Goven (37), from their 1962 simulated hail experiment, reported that bruising tended to be more detrimental than defoliation. However, this is a difficult comparison to make since the two types of injury have completely different effects on plant function. Defoliation removes photosynthetic tissues while bruising disrupts the plants vascular transport system. Bruising also destroys the plant canopy.

In this study the mean losses from defoliation and bruising were similar for the two levels of injury tested. Losses following 25 percent defoliation were similar to those following one bruise, and 75 percent defoliation was equivalent to three bruises. This does permit a comparison to be made between the two types of injury.

Prior work (5, 37, 49) has indicated that as the degree of injury increased, yield decreased proportionately. This trend could be seen to some extent in this study. However, yield reductions did not occur linearly with the degree of injury. In other words, 75 percent defoliation did not always reduce yields three times that of 25 percent defoliation. The literature provides some possible explanations for this. Several researchers (16, 31, 33, 46, 48, 57) reported that defoliation increased the growth rate of remaining leaves by reducing competition for growth substances and nutrients. Also, defoliation was reported to increase the photosynthetic capabilities of the remaining leaves. Defoliation would also open the plant canopy, thus allowing light to strike lower leaves.

Similarly, three bruises per stem did not reduce yield three times that of one bruise. There are also explanations for this in the literature. One possible reason that the plant is able to absorb severe bruising and still function is the complexity of its vascular system. Several researchers (2, 15, 17) state that leaf traces constitute a prominent part of the vascular system of the stem. In addition, there is also a high degree of anastomosing between these leaf traces. The vascular system is also well protected by layers of support cells. This was observed in the study reported here. Photomicrographs showed that most of the damage to the stem was absorbed by the various support cells (epidermis, collenchyma, pericyclic fibers, parenchyma (cortex, pith)). In some cases the support cells were completely obliterated, but some functional phloem and xylem remained. If the stem is not completely severed, some non-injured phloem and xylem remains intact. These non-injured elements provide assimilates for plant development until new elements can be differentiated through the activity of the vascular cambium. Various researchers (4, 19, 41, 47, 52) have postulated that this cambial activity is initiated by a hormone. Others have observed that reestablishment of the transport system is a rapid process (27).

Some conclusions which may be drawn from this study follow:

1) Three earlier maturing cultivars experienced greater yield loss than 'Russet Burbank' following injury on the first date. No significant differences existed between cultivars following injury on the second and third dates.

2) Defoliation and bruising reduced tuber yield and number, but in most cases the differences were small. Losses did not increase in proportion with the degree of injury. This suggests that the magnitude of yield losses from hail damage may often be over estimated.

3) Anatomically, it was found that the potato plant has a complex vascular system which may permit translocation following bruising to continue relatively uninterrupted. Photomicrographs through bruised stem sections showed the ability of the stem to tolerate severe bruising while still maintaining a certain amount of functional vascular system.

4) There were few significant interactions between defoliation, bruising and injury date.

5) For this experiment the randomized complete block design proved feasible. It permitted a combining of data from all cultivars to obtain a larger number of observations. With future research a larger number of plants and more replications would help eliminate variability. In this study a larger experiment was not possible because of the time factor.

LITERATURE CITED

1. Aloni, R. 1976. Regeneration of phloem round a wound: A new experimental system for studying the physiology of fiber differentiation. Ann. Bot. 40: 395-397.

2. Artschwager, E. F. 1918. Anatomy of the potato plant, with special reference on the ontogeny of the vascular system. J. Ag. Res. 15: 221-252.

3. Baker, D. A. and J. Moorby. 1969. The transport of sugar, water, and ions into developing potato tubers. Ann. Bot. 33: 729-741.

4. Benayoun, J., R. Aloni and T. Sachs. 1975. Regeneration around wounds and the control of vascular differentiation. Ann. Bot. 39: 447-454.

5. Beresford, B. C. 1967. Effect of similated hail damage on yield and quality of potatoes. Am. Potato J. 44: 347-354.

6. Bloch, R. 1952. Wound healing in higher plants. Bot. Rev. 28: 655-679.

7. Burt, R. L. 1964. Carbohydrate utilization as a factor in plant growth. Aust. J. Bio. Sci. 17: 867-877.

8. Busch, R. H. and F. E. Salveson. 1972. Stem breakage simulating hail damage to spring wheat. North Dakota Farm Res. 28: 3-7.

9. Crafts, A. S. 1933. Sieve tube structure and translocation in the potato. Plant Physiol. 8: 81-98.

10. Crafts, A. S. 1938. Translocation in plants. Plant Physiol. 13: 791-814.

11. Crafts, A. S. 1961. Translocation in plants. Holt, Rinehart and Winston Inc. New York. (182 pp.)

12. Crafts, A. S. and C. E. Crisp. 1971. Phloem transport in plants. W. H. Freeman and Co. San Francisco. (481 pp.)

13. Davidson, J. L. and F. L. Milthorpe. 1966. The effect of defoliation on the carbon balance in Dactylis glomerata. Ann. Bot. 30: 185-198.

14. Dimond, A. E. 1966. Pressure and flow relations in vascular bundles of the tomato plant. Plant Physiol. 41: 119-131.

15. Esau, K. 1965. Plant anatomy. John Wiley and Sons. New York. (767 pp.)

16. Fick, G. A., W. A. Williams and R. S. Loomis. 1971. Recovery from partial defoliation and root pruning in sugar beet. Crop Sci. 11: 718-721.

17. Gray, D. and D. J. Smith. 1973. The pattern of assimilate movement in potato plants. Potato Res. 16: 293-295.

18. Hayward, H. E. 1938. The structure of economic plants. MacMillan Co. New York. (674 pp.)

19. Jacobs, W. P. 1970. Regeneration and differentiation of sieve tube elements. Intern. Rev. Cytol. 28: 239-273.

20. Jensen, W. A. 1962. Botanical histochemistry. W. H. Freeman Co. San Francisco. (408 pp.)

21. Johansen, D. A. 1940. Plant microtechnique. McGraw-Hill Co. New York. (523 pp.)

22. Johansen, R. H. 1965. Norgold russet, a new early maturing potato variety with good type and scab resistance. Am. Potato J. 42: 201-204.

23. Johansen, R. H., J. T. Schulz and J. E. Huguelet. 1969. Norchip, a new early maturing chipping variety with high total solids. Am. Potato J. 46: 254-258.

24. Jones, H., R. V. Martin and H. K. Porter. 1959. Translocation of 14C in tobacco following assimilation of $14CO_2$ by a single leaf. Ann. Bot. 23: 493-507.

25. Khan, A. and G. R. Sagar. 1969. Alternation of the pattern of distribution of photosynthetic products in the tomato by manipulation of the plant. Ann. Bot. 33: 753-762.

26. Kittock, D. L. and J. H. Williams. 1976. Effect of leaf removal at four stages of growth on yield of castor beans. Agron. J. 59: 489-490.

27. LaMotte, C. E. and W. P. Jacobs. 1962. Quantitative estimation of phloem regeneration in coleus internodes. Stain Tech. 37: 63-73.

28. Lucas, D. and R. D. Asana. 1968. Effect of defoliation on the growth and yield of wheat. Physiol. Plant. 21: 1217-1223.

29. MacKay, J. F. and P. E. Weatherly. 1973. The effects of transverse cuts through stems of transpiring woody plants on water transport and stress in the leaves. J. Expt. Bot. 24: 15-28.

30. Milthorpe, F. L. and J. Moorby. 1969. Vascular transport and its significance in plant growth. Ann. Rev. Plant Physiol. 20: 117-138.

31. Milthorpe, F. L. and J. Moorby. 1975. An introduction to crop physiology. Cambridge Univ. Press. New York. (202 pp.)

32. Mokronsov, A. T. and N. B. Bubenshehikova. 1961. Translocation of assimilates in potato plants. Fiziol. Rast. 8: 447-454.

33. Mokronsov, A. T. and N. A. Ivanova. 1970. Peculiarities of the photosynthetic function during partial plant defoliation. Fiziol. Rast. 18: 563-570. (In Russian with English summary)

34. Moorby, J. 1968. The influence of carbohydrate and mineral nutrient supply on the growth of potato tubers. Ann. Bot. 32: 57-68.

35. Moorby, J. 1969. The production, storage, and translocation of carbohydrates in developing potato plants. Ann. Bot. 34: 297-308.

36. Moorby, J. 1976. Inter stem and inter tuber competition in potatoes. Eur. Potato J. 10: 189-205.

37. Murphy, H. J. and M. J. Goven. 1962. The effect of simulated hail damage on yield and quality of potatoes in Maine. Maine Ag. Exp. Sta. Bull. 607.

38. Nosberger, J. and E. C. Humphries. 1965. The influence of removing tubers on dry matter production and net assimilation rate of potato plants. Ann. Bot. 29: 579-588.

39. Rieman, G. H. 1972. Superior: A new white, medium maturing scab resistant potato variety with high chipping quality. Am. Potato J. 39: 19-28.

40. Sass, J. E. 1940. Elements of botanical microtechnique. McGraw-Hill Co. New York. (222 pp.)

41. Simons, R. K. and R. V. Lott. 1964. The morphological and anatomical development of apples injured by early season hail. Proc. Am. Soc. Hort. Sci. 85: 60-73.

42. Snyder, G. B. and L. F. Michelson. 1959. The effects of simulated hail damage on potatoes. Massachusetts Ag. Exp. Sta. Res. Bull. 506-A.

43. Soine, O. 1967. The effects of simulated hail damage on sugar beets. J. Am. Soc. Sugar Beet Tech. 14: 424-432.

44. Sparks, W. C., G. W. Woodbury and F. H. Takatori. 1957. Univ. of Idaho Exp. Sta. Res. Bull. 274.

45. Sparks, W. C. and G. W. Woodbury. 1959. Stages of potato growth -- a guide in estimating losses from defoliation. Univ. of Idaho Exp. Sta. Res. Bull. 309.

46. Stoy, V. 1969. Physiological aspects of crop yield. (pp. 191-202). Edited by J. D. Eastin. Pub. by Am. Soc. Agron. Madison, Wisc.

47. Sussex, I. M., M. E. Clutter and M. H. Goldsmith. 1972. Wound recovery by pith cell redifferentiation: Structural changes. Am. J. Bot. 59: 797-804.

48. Sweet, G. B. and P. F. Wareing. 1966. Role of plant growth in regulating photosynthesis. Nature 210: 77-79.

49. Takatori, F. H., W. C. Sparks and G. W. Woodbury. 1952. A study of simulated hail injury on potatoes. Univ. of Idaho Exp. Sta. Res. Bull. 22.

50. Teigen, J. B. and J. J. Vorst. 1975. Soybean response to stand reduction and defoliation. Agron. J. 67: 813-816.

51. Thompson, N. P. and C. Heimsch. 1964. Stem anatomy and aspects of development in tomato. Am. J. Bot. 51: 7-19.

52. Thompson, N. P. and W. P. Jacobs. 1966. Polarity of IAA effect on sieve tube and xylem regeneration in coleus and tomato stems. Plant Physiol. 41: 673-682.

53. Thorne, G. N. and A. F. Evans. 1964. Influence of tops and roots on net assimilation rate of sugar beet and spinach beet and grafts between them. Ann. Bot. 28: 499-508.

54. Thrower, S. L. 1962. Translocation of labelled assimilates in the soybean. II. Pattern of translocation in intact and defoliated plants. Aust. J. Biol. Sci. 15: 629-649.

55. Von Daebler, F., H. Weniger, B. Hinz and H. J. Giessmann. 1973. The effects of leaf losses of different degrees at different times on potato yields. Wiss Z (Leipz) Math-Naturwiss Reihe. 3: 357-361.

56. Wardlaw, I. F. 1968. The control and pattern of movement of carbohydrate in plants. Bot. Rev. 34: 79-105.

57. Wareing, P. F., M. M. Khalifa and K. J. Treharne. 1969. Rate limiting processes in photosynthesis at saturating light intensities. Nature 220: 453-457.

APPENDICES

Table A-1. Influence of injury date, defoliation and bruising on yield of potatoes weighing less than 112 grams of 'Russet Burbank' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	1343 (+8)	1311 (+6)	1058 (14)	1238[a]
	one	927 (25)	1176 (5)	1730 (+40)	1277 (+3)
	three	1742 (+41)	1567 (+26)	893 (28)	1400 (+13)
25%	none	1060 (14)	1011 (18)	1293 (+4)	1121 (9)
	one	1204 (3)	1072 (13)	1343 (+8)	1206 (3)
	three	1272 (+3)	1241 (0)	1288 (+4)	1267 (+2)
75%	none	1458 (+18)	1066 (14)	1167 (6)	1230 (1)
	one	1680 (+36)	1329 (+7)	1463 (+18)	1491 (+20)
	three	2046 (+65)	1429 (+15)	1056 (15)	1510 (+22)
Date Means		1414	1245	1254	1304
Defoliation Means	none	1337 (0)	1351 (0)	1227 (0)	1305 (0)
	25%	1179 (12)	1108 (18)	1308 (+7)	1198 (8)
	75%	1728 (+30)	1275 (6)	1228 (0)	1410 (+8)
Bruising Means	none	1287 (0)	1129 (0)	1172 (0)	1196 (0)
	one	1270 (1)	1192 (+6)	1512 (+29)	1325 (+11)
	three	1687 (+31)	1412 (+25)	1079 (8)	1393 (+16)

Analysis of Variance

	F ratio	Signif.
Date	1.419	N.S.
Defoliation	1.754	N.S.
Bruising	1.547	N.S.
Date x Def	1.654	N.S.
Date x Bru	2.589	0.05
Def x Bru	0.186	N.S.

Error mean square	173244
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table A-2. Influence of injury date, defoliation and bruising on yield of cull potatoes of 'Russet Burbank' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	380 (+64)	131 (43)	186 (20)	232[a]
	one	0 (100)	310 (+34)	176 (24)	162 (30)
	three	347 (+50)	63 (73)	516 (+122)	309 (+33)
25%	none	193 (17)	0 (100)	382 (+65)	191 (18)
	one	388 (+67)	64 (72)	175 (25)	209 (9)
	three	520 (+124)	0 (100)	0 (100)	173 (25)
75%	none	208 (10)	0 (100)	97 (58)	101 (56)
	one	32 (86)	114 (51)	447 (+93)	197 (15)
	three	0 (100)	195 (16)	112 (52)	102 (56)
Date Means		230	97	232	186
Defoliation Means	none	242 (0)	168 (0)	293 (0)	234 (0)
	25%	367 (+51)	21 (88)	186 (37)	191 (18)
	75%	80 (67)	103 (39)	219 (25)	134 (43)
Bruising Means	none	260 (0)	44 (0)	221 (0)	175 (0)
	one	139 (47)	162 (+268)	266 (+20)	189 (+8)
	three	289 (+11)	86 (+95)	209 (5)	195 (+11)

Analysis of Variance

	F ratio	Signif.
Date	1.502	N.S.
Defoliation	0.643	N.S.
Bruising	0.025	N.S.
Date x Def	0.903	N.S.
Date x Bru	0.440	N.S.
Def x Bru	0.356	N.S.

Error mean square 106876
Error degrees of freedom 54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table A-3. Influence of injury date, defoliation and bruising on yield of potatoes weighing less than 112 grams of Russet Seedling 'BC 8370-4'. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	931 (25)	1494 (+20)	1309 (+5)	1245[a]
	one	1169 (6)	828 (33)	915 (26)	971 (22)
	three	1405 (+13)	1208 (3)	1264 (+2)	1292 (+4)
25%	none	947 (24)	1558 (+25)	1100 (12)	1202 (3)
	one	837 (33)	1423 (+14)	1424 (+14)	1228 (1)
	three	1419 (+14)	1282 (+3)	984 (21)	1228 (1)
75%	none	1898 (+52)	1653 (+33)	972 (22)	1507 (+21)
	one	1613 (+30)	1469 (+18)	1405 (+13)	1496 (+20)
	three	1851 (+48)	1961 (+57)	1810 (+45)	1874 (+50)
Date Means		1341	1431	1243	1338
Defoliation Means	none	1168 (0)	1176 (0)	1163 (0)	1169 (0)
	25%	1068 (9)	1421 (+21)	1169 (+1)	1219 (+4)
	75%	1787 (+53)	1694 (+44)	1396 (+20)	1626 (+39)
Bruising Means	none	1259 (0)	1568 (0)	1127 (0)	1318 (0)
	one	1207 (4)	1240 (21)	1248 (+11)	1232 (7)
	three	1558 (+24)	1484 (5)	1353 (+20)	1465 (+11)

Analysis of Variance

	F ratio	Signif.
Date	0.731	N.S.
Defoliation	5.177	0.05
Bruising	1.149	N.S.
Date x Def	0.667	N.S.
Date x Bru	0.497	N.S.
Def x Bru	0.479	N.S.

Error mean square	326825
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table A-4. Influence of injury date, defoliation and bruising on yield of cull potatoes of Russet Seedling 'BC 8370-4'.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	0	0	0	0
	one	0	0	0	0
	three	0	0	0	0
25%	none	0	0	0	0
	one	0	35	0	12
	three	0	0	0	0
75%	none	0	0	0	0
	one	52	0	0	17
	three	0	0	68	23
Date Means		6	4	7	6
Defoliation Means	none	0	0	0	0
	25%	0	12	0	4
	75%	17	0	23	13
Bruising Means	none	0	0	0	0
	one	17	12	0	10
	three	0	0	23	6

Analysis of Variance

	F ratio	Signif.
Date	0.094	N.S.
Defoliation	1.335	N.S.
Bruising	0.736	N.S.
Date x Def	0.833	N.S.
Date x Bru	1.132	N.S.
Def x Bru	0.512	N.S.

Error mean square	945.30
Error degrees of freedom	54

Table A-5. Influence of injury date, defoliation and bruising on yield of potatoes weighing less than 112 grams of 'Norgold' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	1422 (12)	1874 (+16)	1530 (5)	1609[a]
	one	1239 (23)	1965 (+22)	1693 (+5)	1632 (+1)
	three	1509 (6)	1122 (30)	1474 (8)	1369 (15)
25%	none	1225 (24)	1130 (30)	1459 (9)	1271 (21)
	one	1236 (23)	1184 (26)	1410 (12)	1276 (21)
	three	1457 (9)	1387 (14)	1741 (+8)	1528 (5)
75%	none	1215 (24)	1392 (13)	842 (48)	1150 (29)
	one	1820 (+13)	1359 (16)	1091 (32)	1423 (12)
	three	1138 (29)	1285 (20)	1238 (23)	1220 (24)
Date Means		1362	1411	1387	1387
Defoliation Means	none	1390 (0)	1653 (0)	1566 (0)	1537 (0)
	25%	1306 (6)	1234 (25)	1537 (2)	1359 (12)
	75%	1391 (0)	1345 (19)	1057 (32)	1264 (18)
Bruising Means	none	1287 (0)	1465 (0)	1277 (0)	1343 (0)
	one	1432 (+11)	1503 (+3)	1398 (+9)	1444 (+8)
	three	1368 (+6)	1265 (14)	1484 (+16)	1372 (+2)

Analysis of Variance

	F ratio	Signif.
Date	0.071	N.S.
Defoliation	2.314	N.S.
Bruising	0.327	N.S.
Date x Def	1.496	N.S.
Date x Bru	0.492	N.S.
Def x Bru	1.109	N.S.

Error mean square 222842
Error degrees of freedom 54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table A-6. Influence of injury date, defoliation and bruising on yield of cull potatoes of 'Norgold' cultivar.

Defoliation	Bruising	Injury Dates First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	0	0	39	13
	one	0	0	0	0
	three	0	0	171	57
25%	none	0	0	0	0
	one	0	0	0	0
	three	0	0	0	0
75%	none	0	0	88	29
	one	0	0	0	0
	three	0	0	0	0
Date Means		0	0	33	11
Defoliation Means	none	0	0	70	23
	25%	0	0	0	0
	75%	0	0	29	10
Bruising Means	none	0	0	43	14
	one	0	0	0	0
	three	0	0	57	19

Analysis of Variance

	F ratio	Signif.
Date	2.310	N.S.
Defoliation	0.867	N.S.
Bruising	0.614	N.S.
Date x Def	0.867	N.S.
Date x Bru	0.614	N.S.
Def x Bru	0.932	N.S.
Error mean square	4300	
Error degrees of freedom	54	

Table A-7. Influence of injury date, defoliation and bruising on yield of potatoes weighing less than 112 grams of 'Superior' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

		Injury Dates			
Defoliation	Bruising	First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	440 (+6)	335 (20)	476 (+14)	417[a]
	one	911 (+118)	493 (+18)	396 (5)	600 (+44)
	three	465 (+11)	554 (+33)	529 (+27)	516 (+24)
25%	none	714 (+71)	428 (+3)	655 (+57)	599 (+44)
	one	795 (+91)	516 (+24)	572 (+37)	628 (+51)
	three	534 (+28)	617 (+48)	499 (+20)	550 (+32)
75%	none	551 (+32)	534 (+28)	448 (+7)	511 (+22)
	one	796 (+91)	563 (+35)	608 (+46)	656 (+57)
	three	612 (+47)	360 (14)	503 (+21)	492 (+18)
Date Means		647	489	521	552
Defoliation Means	none	605 (0)	461 (0)	467 (0)	511 (0)
	25%	681 (+13)	521 (+13)	575 (+23)	592 (+16)
	75%	653 (+8)	486 (+5)	520 (+11)	553 (+8)
Bruising Means	none	569 (0)	433 (0)	526 (0)	509 (0)
	one	834 (+47)	524 (+21)	526 (0)	628 (+23)
	three	537 (6)	510 (+18)	510 (3)	519 (+2)

Analysis of Variance

	F ratio	Signif.
Date	3.015	N.S.
Defoliation	0.716	N.S.
Bruising	1.879	N.S.
Date x Def	0.025	N.S.
Date x Bru	1.163	N.S.
Def x Bru	0.360	N.S.

Error mean square	62136
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table A-8. Influence of injury date, defoliation and bruising on yield of cull potatoes of 'Superior' cultivar.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	0	0	0	0
	one	176	251	0	142
	three	0	89	0	30
25%	none	0	0	0	0
	one	126	0	0	42
	three	251	100	0	117
75%	none	0	67	0	22
	one	0	0	0	0
	three	72	0	607	226
Date Means		69	56	67	64
Defoliation Means	none	59	113	0	57
	25%	126	33	0	53
	75%	24	22	202	83
Bruising Means	none	0	22	0	7
	one	101	84	0	61
	three	108	63	202	124

Analysis of Variance

	F ratio	Signif.
Date	0.035	N.S.
Defoliation	0.187	N.S.
Bruising	2.454	N.S.
Date x Def	2.151	N.S.
Date x Bru	0.952	N.S.
Def x Bru	1.723	N.S.

Error mean square	37686
Error degrees of freedom	54

Table A-9. Influence of injury date, defoliation and bruising on yield of potatoes weighing less than 112 grams of 'Norchip' cultivar. Percentage decrease or increase (+) resulting from injury shown in parenthesis.

Defoliation	Bruising	Injury Dates: First	Injury Dates: Second	Injury Dates: Third	Means
		Grams Per 6 Plants			
0%	none	1536 (+14)	1262 (6)	1229 (8)	1342[a]
	one	1331 (1)	1276 (5)	904 (33)	1170 (13)
	three	1433 (+7)	1039 (23)	993 (26)	1155 (14)
25%	none	568 (58)	1461 (+9)	1004 (25)	1011 (25)
	one	912 (32)	1242 (7)	582 (57)	912 (32)
	three	1098 (18)	1400 (+4)	1118 (17)	1205 (10)
75%	none	1659 (+24)	913 (32)	1320 (2)	1297 (3)
	one	1305 (3)	602 (55)	1638 (+22)	1182 (12)
	three	2128 (+59)	1402 (+6)	1444 (+8)	1664 (+24)
Date Means		1330	1180	1137	1215
Defoliation Means	none	1433 (0)	1192 (0)	1042 (0)	1222 (0)
	25%	859 (40)	1368 (+15)	901 (14)	1043 (15)
	75%	1697 (+18)	978 (18)	1467 (+41)	1381 (+13)
Bruising Means	none	1254 (0)	1212 (0)	1184 (0)	1217 (0)
	one	1183 (6)	1040 (14)	1041 (12)	1088 (11)
	three	1553 (+24)	1287 (+6)	1185 (0)	1342 (+10)

Analysis of Variance

	F ratio	Signif.
Date	1.248	N.S.
Defoliation	3.476	0.05
Bruising	1.953	N.S.
Date x Def	4.507	0.05
Dage x Bru	0.268	N.S.
Def x Bru	0.978	N.S.

Error mean square	222316
Error degrees of freedom	54

[a]Mean value for non-injured plants used to calculate percent increase or decrease.

Table A-10. Influence of injury date, defoliation and bruising on yield of cull potatoes of 'Norchip' cultivar.

Defoliation	Bruising	Injury Dates: First	Second	Third	Means
		Grams Per 6 Plants			
0%	none	0	0	0	0
	one	0	0	0	0
	three	118	0	0	39
25%	none	0	0	329	110
	one	0	0	0	0
	three	0	181	0	60
75%	none	0	0	0	0
	one	0	133	0	44
	three	0	0	0	0
Date Means		13	35	37	28
Defoliation Means	none	39	0	0	13
	25%	0	60	110	58
	75%	0	44	0	15
Bruising Means	none	0	0	110	37
	one	0	44	0	15
	three	39	60	0	33

Analysis of Variance

	F ratio	Signif.
Date	0.240	N.S.
Defoliation	0.858	N.S.
Bruising	0.195	N.S.
Date x Def	0.863	N.S.
Date x Bru	1.194	N.S.
Def x Bru	0.885	N.S.

Error mean square	19202
Error degrees of freedom	54