HortScience 26(5):549-553. 1991.

Calcium Deficiency of Artichoke Buds in Relation to Salinity

L.E. Francois[1], T.J. Donovan[2], and E.V. Maas[3]
U.S. Salinity Laboratory, Agricultural Research Service, U.S. Department of Agriculture, 4500 Glenwood Drive, Riverside, CA 92501

Additional index words. Cynara scolymus, Botrytis sp., soil salinity, transpiration, root pressure

Abstract. **Globe artichokes *(Cynara scolymus* L.) were grown for 2 years in artificially salinized field plots in the irrigated desert area near Brawley, Calif. Saline treatments were imposed by irrigation with waters that contained equal weights of NaCl and CaCl,. Increased incidence and severity of Ca deficiency in the inner bracts of artichoke buds were directly related to increased levels of salinity. The Ca-deficient bracts were subject to infection by species of *Botrytis* and *Erwinia.* The number of marketable artichokes was reduced 20% or more when irrigation water salinity exceeded 2.0 dS·m^{-1}, and up to 50% at 10 dS·m^{-1}. Calcium deficiency in the artichoke bud is believed to be the result of disparate Ca distribution among the tissues, which is caused by high transpiration rates in the desert environment and the reduction in root pressure by soil salinity. Elemental analysis of leaf tissues can not be used to predict Ca deficiency within the artichoke buds.**

Globe artichoke production in the United States has long been confined to the central California coastal counties of Monterey and Santa Cruz. However, in recent years new plantings have been made in the irrigated desert area of the Imperial Valley near Brawley, where climatic conditions are far different than the coastal community. While the coastal area is uniformly mild, cool, and foggy in summer, with relatively few frosty nights in winter, the desert area has extreme temperature fluctuations between day and night during summer and winter.

Cultural practices also differ between the two areas. In the coastal counties, new plantings are vegetatively propagated from basal stem pieces with attached root sections. Once established, these plantings are maintained in perennial culture for 5 to 10 years (Ryder et al., 1983). In contrast, artichokes grown in the desert area are generally seed-propagated annuals.

These new desert plantings may be on soils where salinity problems already exist or may develop. Although this study was initiated to

Received for publication 28 Sept. 1990. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

[1]Research Agronomist.
[2]Agronomist.
[3]Supervisory Plant Physiologist.

Table 1. Elemental composition of leaf blades (B) and midribs (M) from artichokes grown at six levels of salinity in 2 years.

Irrigation water salinity (κ_{iw}) (dS·m^{-1})	Root-zone soil salinity (κ_e) (dS·m^{-1})	Concn (mmol·kg^{-1} dry wt)[z]							
		Ca		Na		Mg		K	
		M	B	M	B	M	B	M	B
					1986–87				
1.4 (control)	4.6	306	231	647	992	112	85	916	1106
2.0	6.6	332	275	585	840	111	92	990	1167
4.0	7.4	336	317	589	939	95	78	999	1201
6.0	8.7	348	314	591	863	93	71	973	1105
8.0	10.6	362	402	721	974	91	69	979	1052
10.0	11.6	374	410	800	986	90	69	999	1032
Significance									
Treatment		NS	***	***	NS	***	***	NS	*
Linear[y]		**	***	***	NS	***	***	NS	*
Quadratic[y]		NS	NS	***	NS	NS	NS	NS	*
					1987–88				
1.4	4.4	275	220	534	646	105	99	836	966
2.0	5.9	285	252	551	721	94	84	906	1002
4.0	8.3	315	291	630	789	85	73	873	897
6.0	10.4	276	342	643	862	82	75	869	971
8.0	11.3	315	371	725	886	87	68	796	843
10.0	13.8	318	429	745	940	81	72	765	868
Significance									
Treatment		NS	***	***	**	***	***	*	NS
Linear[y]		NS	***	***	***	***	***	**	NS
Quadratic[y]		NS	NS	NS	NS	*	**	*	NS

[z]ppm or mg·kg^{-1} = mmol·kg–1 × atomic weight
[y]Single-degree-of-freedom comparisons.
[NS], *, **, ***Nonsignificant or significant at P = 0.05, 0.01, or 0.005, respectivey.

Table 2. Elemental composition of inner and outer bracts sampled from artichoke buds grown at six levels of salinity in 1987.

Irrigation water salinity (κ_{iw}) (dS·m^{-1})	Root-zone soil salinity (κ_e) (dS·m^{-1})	Concn (mmol·kg^{-1} dry wt)[z]			
		Ca	Na	Mg	K
			Inner bracts		
1.4	4.6	25.1	58.4	77.9	665
2.0	6.6	35.3	62.7	74.9	635
4.0	7.4	16.5	47.2	79.1	682
6.0	8.7	14.4	71.2	79.4	688
8.0	10.6	13.7	72.6	72.7	703
10.0	11.6	14.0	65.6	59.5	649
Significance					
Treatment		***	NS	NS	NS
Linear[y]		***	NS	*	NS
Quadratic[y]		NS	NS	NS	NS
			Outer bracts		
1.4	4.6	101	91	77.1	646
2.0	6.6	105	118	75.7	575
4.0	7.4	100	87	66.1	589
6.0	8.7	131	147	65.2	611
8.0	10.6	120	142	59.1	617
10.0	11.6	143	137	52.8	630
Significance					
Treatment		NS	**	***	NS
Linear[y]		*	***	***	NS
Quadratic[y]		NS	NS	NS	*

[z]ppm or mg·kg^{-1} = mmol·kg–1 × atomic weight
[y]Single-degree-of-freedom comparisons.
[NS], *, **, ***Nonsignificant or significant at P = 0.05, 0.01, or 0.05, respectively.

determine the effect of salinity on artichoke yield, this paper discusses a salinity-induced Ca deficiency observed during the study.

Artichoke seed used in this study was the germplasm breeding line '86-024' released in 1986 by the Agricultural Research Service, U. S. Dept. of Agriculture. Seed of this breeding line is from the fourth generation of within-line sib pollination of an original cross between an unidentified line from France and an Italian line obtained from V. Rubatzky, Univ. of California, Davis.

Seed was planted 22 Sept. 1986 and 17 Sept. 1987 in 18 level field plots located at the Irrigated Desert Research Station, Brawley, Calif. Each plot (6 × 6 m square) contained six rows 0.9 m apart, with seed placed 0.15 m apart within each row. After establishment, the seedlings were thinned to a 0.75-respacing within each row. This plant spacing provided a population of ≈14,000 plants/ha. Plot soil was a Holtville clay [clayey over loamy, montmorillonitic (calcareous), hyperthermic Typic Torrifluvent]. Each plot was enclosed by acrylic-fortified fiberglass borders that extended 0.75 m into the soil. The fiberglass borders protruded 0.15 m above the soil level of the plot and were covered with a berm 0.18 m high and 0.60 m wide. Walkways, 1.2 m wide, between plots and good vertical drainage effectively isolated each plot.

Before planting, triple superphosphate was mixed into the top 0.25 m of soil at the rate of 73 kg P/ha. To ensure adequate N fertility throughout the experiment, $Ca(NO_3)_2$ was added at each irrigation at 0.14 kg N/ha per millimeter of water applied. The soil contained adequate levels of K, so no additional K was added.

The experimental design consisted of six treatments replicated three times in a randomized complete block design. At the time of planting each year, the soil profiles in each plot had been differentially presalinized with the same quality irrigation waters that were to be used throughout the study. To ensure good germination, 90 mm of low-salinity water (1.4 dS·m^{-1}), was applied before planting to leach salts below the seed bed, another 90 mm of low-salinity water was applied after planting to prevent soil crusting.

Approximately 35 days after planting, when the plants were at the three- to four-leaf stage of growth, differential salivation was resumed. Irrigation water salinities were increased stepwise in two increments over 14 days by adding equal weights of NaCl and $CaCl_2$ until desired salt concentrations were achieved. The electrical conductivities of the six irrigation waters (κ_{iw}) both years were 1.4 (control), 2.0, 4.0, 6.0, 8.0, and 10.0 dS·m^{-1}. All plots were irrigated about every

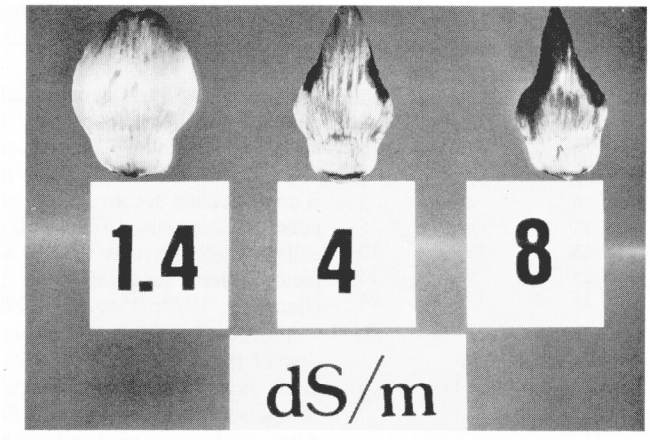

Fig. 1. Inner artichoke bracts from plants grown at three irrigation water salinity levels showing Ca-deficient tissue infected with botrytis rot at 4 and 8 $dS \cdot m^{-1}$.

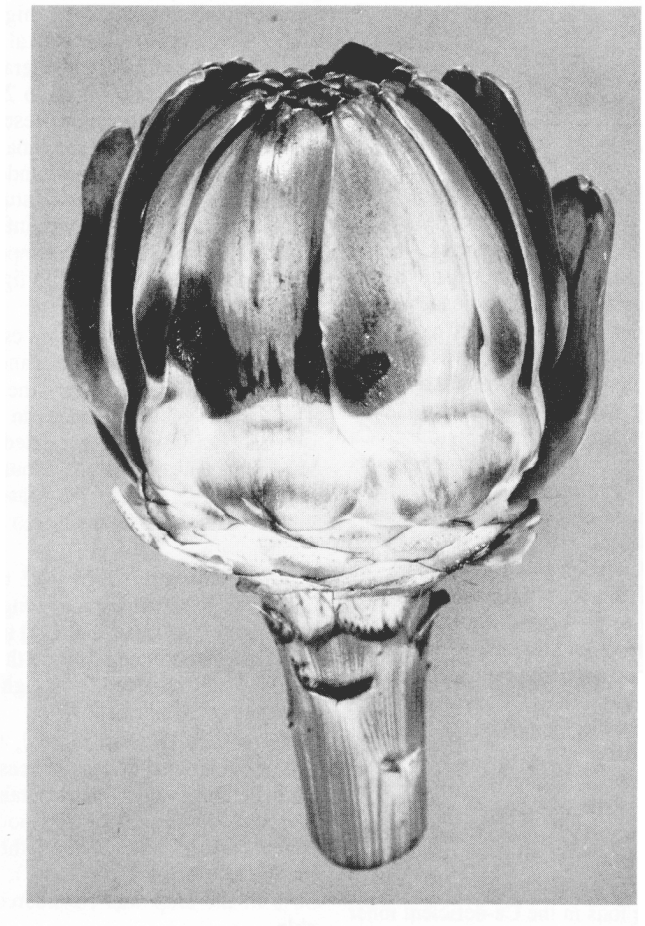

Fig. 2. Artichoke bud showing Ca-deficient tissue and botrytis rot on the fifth whorl of bracts.

3 to 4 weeks during both growing seasons to keep the soil matric potential of the control treatments above 85 kPa in the 0.15- to 0.30-m zone. The total amounts of irrigation water applied during the growing season were 563 mm in 1986-87 and 463 mm in 1987-88.

The electrical conductivity of the saturated-soil extract (κ_e) was determined on soil samples taken three times each year during the growing season. Samples were taken within the plant row in 0.3-m increments to a depth of 0.9 m. The average κ_e over the course of the experiment was 4.6, 6.6, 7.4, 8.7, 10.6, and 11.6 $dS \cdot m^{-1}$ in 1986-87 for the six treatments, and 4.4, 5.9, 8.3, 10.4, 11.3, and 13.8 $dS \cdot m^{-1}$ in 1987-88.

The mean daytime high temperature for the month preceding the first harvest was 23C in 1987 and 26C in 1988. During the harvest period, the mean highs were 31C and 30C in 1987 and 1988, respectively. The respective cumulative Class A pan evaporation during the same preharvest and harvest periods were 218 mm and 370 mm in 1987 and 214 mm and 466 mm in 1988.

Artichokes were harvested when their circumference exceeded 250 mm. The first harvests occurred on 20 Mar. 1987 and 17 Mar. 1988. Subsequent harvests were made at 5- to 6-day intervals for the next 48 days in 1987 and 30 days in 1988. The onset of plant senescence and delayed artichoke development determined when harvests were discontinued.

At harvest; each artichoke was weighed and the circumference measured. In addition, the outer bracts of each artichoke were removed to determine damage to the inner bracts. The extent of damage was then rated from 0 (no damage) to 4 (extreme damage). Artichokes exhibiting damage of the internal bracts were examined for pathogens at the Plant Pathology Dept., Univ. of California, Riverside.

Outer bracts (whorls 1, 2, 3) and inner bracts (whorls, 5, 6, 7) were sampled for elemental analysis from artichokes harvested in 1987. In addition, mature, fully expanded leaves were sampled midway through the 1987 and 1988 harvest. Leaf midribs were removed from the rest of the leaf blade for separate analysis. All sampled material was washed, dried at 70C, and finely ground in a blender. Nitric-perchloric acid digests of the sampled material were analyzed for Ca, Na, Mg, and K by atomic absorption spectrophotometry.

Calculated coefficients for unequally spaced treatments were used to determine single-degree-of-freedom comparisons.

The first indication of a physiological disorder was a brown discoloration on bracts in whorl 5, 6, and 7 of the bud. The damage usually occurred along the midmargin of these bracts (Fig. 1). However, in some instances, the discoloration occurred slightly internal from the midmargin (Fig. 2). The size of the damaged area was directly related to the salinity treatment. As salinity increased, the damaged area enlarged inwardly toward the center of the bract and upwardly toward the tip. At a κ_{iw} of 10 $dS \cdot m^{-1}$, the damage encompassed the entire upper two-thirds of each bract. Regardless of salinity treatment, the lower one-third of each bract was never affected.

Brown discoloration has been associated with Ca deficiency in other crops (DeKock et al., 1975; Faust and Shear, 1968; Spurr, 1959). It is reported to be the result of polyphenol oxidation that occurs in Ca-deficient tissues (Kirkby and Pilbeam, 1984). When Ca is adequate, this oxidation is inhibited by chelation of the phenolic compounds (DeKock et al., 1975).

calcium deficiencies in various crops have been associated with high temperature. Spurr (1959) reported a high incidence of blossom-ed rot of tomatoes following periods of high field temperatures. The occurrence of tip-bum of lettuce has been associated with high temperatures (Tibbitts and Rae, 1968). Geraldson (1954) has suggested that high temperature, through its effect of increasing transpiration, might be partially responsible for the high incidence of blackheart in greenhouse-grown celery.

Since long-distance transport of Ca from

Table 3. Percentage of artichoke buds at each damage rating harvested from plants grown at six levels of salinity in 2 years.

Irrigation water salinity (κ_{iw}) ($dS \cdot m^{-1}$)	Root-zone soil salinity (κ_e) ($dS \cdot m^{-1}$)	Damage rating[z] (%)				
		0	1	2	3	4
				1987		
1.4 (control)	4.6	69	20	8	2	1
2.0	6.6	73	16	4	4	3
4.0	7.4	55	23	11	6	5
6.0	8.7	47	18	13	12	10
8.0	10.6	37	21	15	9	18
10.0	11.6	27	17	15	17	24
Significance						
Treatment		***	NS	***	**	***
Linear[y]		***	NS	***	***	***
Quadratic[y]		NS	NS	NS	NS	NS
				1988		
1.4	4.4	96	4	0	0	0
2.0	5.9	83	13	4	0	0
4.0	8.3	56	28	8	5	3
6.0	10.4	45	23	11	6	15
8.0	11.3	23	33	17	9	18
10.0	13.8	18	33	27	16	6
Significance						
Treatment		***	***	***	***	***
Linear[y]		***	***	***	***	***
Quadratic[y]		NS	NS	NS	NS	***

[z]Damage rating: 0 = none, 1 = slight, 2 = moderate, 3 = severe, 4 = extreme.
[y]Single-degree-of-freedom-comparisons.
[NS], **, ***Nonsignificant or significant at $P = 0.01$ or 0.05, respectively.

the roots to the shoots of plants is thought to occur in the xylem by way of the transpiration stream (Bell and Biddulph, 1963; Biddulph et al., 1961), the distribution of the ion is closely related to the intensity of the transpiration rate (Clarkson, 1984). However, high transpiration rates have been found to decrease rather than increase Ca influx into low-transpiring organs, such as rosettes of cauliflower *(Brassica oleracea* L. Botrytis group) (Krug et al., 1972) or the inner leaves of cabbage *(Brassica oleracea* L. Capitata group) (Palzkill et al., 1976) and lettuce (Bangerth, 1979). The Ca in the xylem sap is directed to the high-transpiring outer leaves at the expense of the inner leaves or the rosettes.

In addition to transpiration, root pressure plays an important role in Ca transport within the plant. Root pressure flow occurs under conditions that discourage transpiration and encourage ion and water uptake by the roots (Kramer, 1969). This occurs particularly at night or during periods of high relative humidity when transpiration is greatly reduced. The importance of root pressure in the transport of Ca has been reported by Palzkill and Tibbitts (1977), who showed that the low-transpiring leaves from the inner head of cabbage obtained adequate amounts of Ca only when root pressure occurred. Similar evidence of the beneficial effect of root pressure has been reported for leaves enclosed in the stipules of strawberry *(Fragaria ananassa* Duch.) (Guttridge et al., 1981).

Salinity in the soil solution has been shown to significantly reduce root pressure and, thus, cause Ca deficiencies in low-transpiring tissues (Bradfield and Guttridge, 1984; Ende et al., 1975). The Ca deficiency observed on the inner bracts of the artichoke buds in this study likely is the result of reduced Ca transport, a result of reduced root pressure as salinity levels increased. Calcium concentration in the leaf blades and midribs, as well as in the outer bracts of the buds, was significantly higher than the concentration in the low-transpiring inner bracts (Tables 1 and 2). With increasing levels of salinity, Ca concentration in the midribs and outer bracts increased significantly, while the concentration in the inner bracts decreased significantly. Although the plant took up an abundance of Ca under saline conditions, the distribution of the Ca within the plant was predominantly to the high-transpiring leaves and outer bracts. Root pressure, which would normally provide a mechanism for Ca movement to the inner bracts, was severely reduced as soil salinity increased.

Although excess Mg, K, and Na in the root zone has been shown to enhance Ca deficiencies in diverse crops (Cerda et al., 1979; Geraldson, 1957; Maas and Grieve, 1987), they apparently did not contribute to the Ca deficiency in this study. The concentration of these ions in the Ca-deficient inner bracts showed no significant change as salinity increased (Table 2). In contrast, the leaf and outer bract tissues that contained abundant Ca showed that Mg and K concentrations tended to decrease while Na increased with increased levels of salinity (Tables 1 and 2). Although Ca and Na were the two salinizing cations in this study, the concentration of Ca in the leaf and outer bract tissue would indicate that the competition from Na in the soil solution for uptake and translocation was insufficient to cause a Ca deficiency.

Since Ca was not limiting in either the leaf blade or midrib, mineral analyses of these tissues would not provide information pertaining to the Ca deficiency occurring within the buds.

Physiologically, Ca in an integral component in the protein–pectin "cement" of the middle lamella (Clarkson and Hanson, 1980). When Ca concentration is low, there is an associated decomposition of the middle lamella (Poovaiah, 1979). This decrease in cell wall integrity may well be an important factor in tissue susceptibility to fungal attack (Bangerth, 1979; Poovaiah, 1979).

Shortly after the initial brown discoloration of the tissue, the affected area turned black. A pathological test of the tissue showed the presence of *Botrytis* and *Erwinia* spp. Although botrytis rot has long been associated with artichoke production in California (Link et al., 1924), it is not a particularly severe problem in the field, except during periods of rainy weather and moderate temperatures accompanied by high humidity (Sims et al., 1977). Link et al. (1924) reported that the optimum temperature for *Botrytis* growth is between 22 to 25C and that adequate moisture must be present to enable the pathogen to establish and maintain itself. The soil salinity and climate under which the artichokes were grown in this study provided ideal conditions for *Botrytis* infection; i.e., susceptible tissue, optimum temperature, and, presumably, moisture held in tightly packed inner bracts.

Once the infection became established in the Ca-deficient bracts, it advanced progressively inward to bracts near the bud center. The severity of the infection in these bracts appeared to be directly related to salinity treatment. Occasionally, the outer bracts on buds harvested late in the season from the highest salinity treatment also became infected.

At harvest, the severity of the Ca deficiency and the subsequent fungal infection were rated from 0 (no damage) to 4 (extreme damage) for marketability of the artichokes (Table 3). Buds rated 2 or higher were determined to be unmarketable.

As salinity levels increased, the percentage of unmarketable buds increased. The use of irrigation waters that contained salinity levels of 2.0 $dS \cdot m^{-1}$ caused moderate to extreme damage in $\approx$ 20% of the artichokes harvested. At 10 $dS \cdot m^{-1}$ (κ_{iw}), as much as 50% of the crop was considered unmarketable.

Damaged and undamaged buds, harvested from the same salinity treatment, showed no significant difference in weight or circumference (data not presented).

Although Ca sprays have been used to help alleviate Ca disorders in some crops (Kirkby and Pilbeam, 1984; Thibodeau and Minotti, 1969), they may or may not be beneficial in reducing the Ca disorder observed in this study. Instead, to overcome this Ca-related disorder, it maybe necessary to make use of possible genotypic differences within the artichoke species with regard to the maintenance of root pressure and the distribution of Ca at both the tissue and cellular level.

Literature Cited

Bangerth, F. 1979. Calcium-related physiological disorders in plants. Annu. Rev. Phytopathol. 17:97-122.

Bell, C.W. and O. Biddulph. 1963. Translocation of calcium. Exchange versus mass flow. Plant Physiol. 38:610-614.

Biddulph, O., F.S. Nakayama, and R. Cory. 1961. Transpiration stream and ascention of calcium. Plant Physiol. 36:429-436.

Bradfield, E.G. and C.G. Guttridge. 1984. Effects of night-time humidity and nutrient solution concentration on the calcium-content of tomato fruit. Scientia Hort. 22:207–217.

Cerda, A., F.T. Bingham, and C.K. Labanauskas. 1979. Blossom-end rot of tomato fruit as influenced by osmotic potential and phosphorous concentrations of nutrient solution media. J. Amer. Soc. Hort. Sci. 104:236-239.

Clarkson, D.T. 1984. Calcium transport between tissues and its distribution in the plant. Plant, Cell & Env. 7:449-456.

Clarkson, D.T. and J.B. Hanson. 1980. The mineral nutrition of higher plants. Annu. Rev. Plant Physiol. 31:239-298.

DeKock, P. C., P.W. Dyson, A. Hall, and F. Grabowska. 1975. Metabolic changes associated with calcium deficiency in potato sprouts. Potato Res. 18:573-581.

Ende, J. vanden, P. Koornneef, and C. Sonneveld. 1975. Osmotic pressure of the soil solution: Determination and effects on some glasshouse crops. Neth. J. Agr. Sci. 23:181–190.

Faust, M. and C.B. Shear. 1968. Corking disorder of apples: A physiological and biochemical review. Bet. Rev. 34:441-469.

Geraldson, C.M. 1954. The control of blackheart of celery. Proc. Amer. Soc. Hort. Sci. 63:353–358.

Geraldson, C.M. 1957. Factors affecting calcium nutrition of celery, tomato, and pepper. Soil Sci. Soc. Amer. Proc. 21:621-625.

Guttridge, C. G., E.G. Bradfield, and R. Holder. 1981. Dependence of calcium transport into strawberry leaves on positive pressure in the xylem. Ann. Bet. 47:473-480.

Kirkby, E.A. and D.J. Pilbeam. 1984. Calcium as a plant nutrient. Plant, Cell & Env. 7:397–405.

Kramer, P.J. 1969. Plant and soil water relationships: A modern synthesis. McGraw-Hill, New York.

Krug, H., H.J. Wiebe, and A. Jungk. 1972. Kalciummangel an Blumenkohl unter konstanten Klimabedingungen. Z. Pflanz. Bodenkd. 133:213-226.

Link, G. K. K., G.B. Ramsey, and A.A. Bailey. 1924. Botrytis rot of the globe artichoke. J. Agr. Res. 29:85-92.

Maas, E.V. and C.M. Grieve. 1987. Sodium-induced calcium deficiency in salt-stressed corn. Plant, Cell & Env. 10:559-564.

Palzkill, D.A. and T.W. Tibbitts. 1977. Evidence that root pressure flow is required for calcium transport into the head leaves of cabbage. Plant Physiol. 60:854-856.

Palzkill, D. A., T.W. Tibbitts, and P.H. Williams. 1976. Enhancement of calcium transport to inner leaves of cabbage for prevention of tipburn. J. Amer. Soc. Hort. Sci. 101:645-648.

Poovaiah, B.W. 1979. Role of calcium in ripening and senescence. Commun. Soil Sci. Plant Anal. 10:83-88.

Ryder, E. J., N.E. De Vos, and M.A. Bari. 1983. The globe artichoke *(Cynara scolymus* L.). HortScience 18:646-653.

Sims, W. L., V.E. Rubatzky, R.H. Sciaroni, and W.H. Lange. 1977. Growing globe artichokes in California. Univ. Calif. Div. Agr. Sci. Lflt. 2675.

Spurr, A.R. 1959. Anatomical aspects of blossom-end rot in the tomato with special reference to calcium nutrition. Hilgardia 28:269-295.

Thibodeau, P.O. and P.L. Minotti. 1969. The influence of calcium on the development of lettuce tipburn. J. Amer. Soc. Hort. Sci. 94:372–376.

Tibbitts, T.W. and R.R. Rae. 1968. Light intensity and duration in the development of lettuce tipburn. Proc. Amer. Soc. Hort. Sci. 93:454-461.