Environmental Factors Affecting *Citrus*

George Yelenosky[1]

The importance of environmental factors (climate) affecting the genus *Citrus* is evident in the origin and natural habitat of citrus contrasted with the growth and development of commercial citriculture in the world. Citrus is generally classified as a cold-tender evergreen and most of the commercial cultivars seemingly have developed from sources in humid tropical regions of China, Southeast Asia, western borders of India and Pakistan, Indonesia, and the Philippines (25, 29). However, commercial world production of citrus and citrus products is most heavily concentrated in subtropical regions, latitudes 20 and 40 degrees north and south of the equator, although considerable citrus is grown closer to the equator. In general, world citrus production involves 5 climatic regions (34) and 6 major citrus-producing countries. Brazil has recently surpassed the United States as the largest citrus producer with Japan, Spain, Italy, and Mexico following in order of total production (23). World supply and demand for citrus and citrus products are greatly influenced by a number of environmental factors which characterize the wide divergence of climatic conditions where citrus is grown.

During the past 20 years, production of citrus in the world has more than doubled from approximately 24 million metric tons annually to more than 56 million tons (24). Much of this increase in production and future increases (32) are the result of not only more citrus plantings (predominately in the southern hemisphere, especially in Brazil and Argentina), but also of new knowledge and the gradual development of a better understanding of citriculture achieved through cooperative research efforts throughout the world. The unraveling and manipulation of environmental factors affecting citrus has been slow but steady in the history of citriculture. Much remains to be done as demands increase for greater food production in the world. There are concerns for the rapidly increasing world population where urban growth and development are replacing prime agricultural land, excessive demands are being made for available water, and pollutants continue to spread and increase in the atmosphere and soil (31).

Prior to 1973, Reuther (20) summarized available knowledge on the effects of different environmental factors on tree size, crop production, flower development, fruit-set-growth-maturation, and metabolic processes in citrus. Concepts developed and presented by Reuther are still viable in today's commercial citriculture and his work is frequently referred to in this report.

CLIMATE AND CITRUS

Individual citrus scions and rootstocks as seedling material behave differently to environmental factors. The scion/rootstock interaction represented in commercial citrus trees further complicates the study of environmental factors in citriculture. In many instances, general concepts developed will vary somewhat depending on the particular scion/rootstock combination. But it is not always good practice to expect commercial citrus trees

[1]Plant Physiologist, United States Department of Agriculture, Agricultural Research Service Horticultural Research Laboratory, Orlando, Florida 32803.

to perform somewhere between the responses of respective scion and rootstock seedling-trees to environmental factors. Thus, there are no good substitutes for long-term field studies in extrapolating greenhouse and controlled-environment observations to field conditions.

TREE GROWTH

Citrus trees are likely to be smaller with more compact canopies (thicker leaves and shorter internodes) if grown in relatively cool and arid conditions in contrast to warmer and more humid conditions. Excessively hot temperatures, 49°C, will distort citrus leaves, modify their shape, produce abnormal veination, and inhibit budbreak (21). For practical purposes, citrus trees seemingly stop growing below 12° and above 37°C (2). Shoot growth, largely determined on citrus seedlings in controlled-temperature studies, is a maximum between 25° and 31°C with progressive decreases in growth starting at about 32° to 33°C. Root growth seemingly is best between 25° and 26°C. There are temperature-growth differences among citrus selections segregated by Young (40) into 6 horticultural groups comprised of 23 citrus cultivars. In this instances, bud dormancy-inducing temperatures were between 15° and 15.6°C for trifoliate orange (*Poncirus trifoliata* (L.) Raf.); 8.9° and 10°C for citrumelos (*C. paradisi* Macf. X *P. trifoliata*), limes (*C. aurantifolia* (Christm.) Swing.), and lemons (*C. limon* Burm. f.); and between 8.9° and 15.6°C for mandarins (*C. reticulata* Blanco and citranges (*C. sinensis* L. (Osb.) X *P. trifoliata*). Citrus apparently does not have "true" dormancy similar to that associated with the growth of trees in temperate zones. The relatively brief stage of "arrested or quiescent" growth during nongrowing temperature conditions for citrus apparently deepens with longer durations of cooler but not freezing temperatures. It has been suggested by other researchers (8) that citrus trees are more likely to produce a uniform, prolific spring flush of vegetative growth and bloom (flowers), if "quiescent" growth temperatures prevail sufficiently during the winter season. Otherwise, vegetative growth and bloom tend to be "spotty" and/or irregular. Much of this is attributed to differences in "reserve" accumulation, especially carbohydrates, and the availability of growth substances (such as gibberellins) immediately prior to the onset of spring growth. In the United States, the winter temperatures in 3 of the major citrus-producing areas reflect the apparent dormancy of the respective trees (6). It is this apparent dormancy or quiescent stage of growth that greatly enhances the development of cold hardiness in citrus trees (39).

FLOWERING

Reuther (20) cites a number of studies (1, 9, 10) that indicate citrus flower induction under orchard conditions in subtropical climates occurs about one month before flower differentiation is evident in histological investigations. Flower induction usually follows a few weeks of cooler and nongrowing temperatures and may peak in late December or early January. Moss (15) found that cool temperatures help to produce flower clusters with fewer leaves but low temperature-induced dormancy of the tree is not essential to induce flower formation in citrus. Flower induction in citrus apparently can also be increased with periods of low soil moisture (23). It is suggested by Reuther (20) that flower induction in citrus is not directly dependent on temperature but rather on internal factors such as hormones, food reserves, and size of crop. Cool weather and/or dry periods just prior to flowering can delay flowering for one or more weeks and, apparently, flowering of lemon trees is influenced more by environmental factors than is flowering of orange, grapefruit, and mandarin cultivars. Temperatures above 30°C may impair flowering in citrus trees. Ambient air temperatures and soil moisture are more influential than photoperiods (day length) in affecting flowering. But photoperiod does elicit growth responses in different citrus rootstocks (28).

FRUIT SET-GROWTH-MATURATION

Available data suggest citrus fruit set satisfactorily in a very wide range of temperature conditions in many different citrus-growing regions in the world. However, only a small number of the flowers on citrus trees will set fruit which develop to maturity (8). Studies in Japan indicate that temperatures between 15° and 20°C enhance pollen production in the anthers of 'Satsuma' mandarin orange flowers while cool temperatures result in many nonviable gametes (13, 33). Fusion of gametes may be temperature dependent. Abnormally cool temperatures, but above freezing, probably do not cause severe set problems under most orchard conditions. However, lack of moisture and/or high temperatures will significantly increase the dropping of fruitlets during the early growth stages (3). It is also suggested by Reuther (20) that 30° to 34°C for 12 hours for a few days will abscise young fruitlets of citrus but high temperature effects on internal factors, such as ethylene formation, need to be taken into account.

During the later stages of fruit growth, high temperatures tend to cause thicker peels and rougher peel surfaces to develop on oranges (22). Citrus growing in cool, humid areas of California tends to be "smooth skinned" with considerably more water in the peel and more easily bruised than coarser textured fruit produced in hot and arid areas (14). Fruit also tend to be flatter in cool, humid areas than in hot, arid areas. In different climates, the rate of fruit growth will vary usually according to temperature regimes provided soil moisture is adequate. Dry periods as well as cool night temperatures (less than 13°C) will slow the growth of citrus fruit. Reuther (20) cites many studies that show citrus fruit enlarge mostly at night and during the early morning. Some shrinkage of fruit during relatively hot, dry days seemingly is the result of greater loss of water through transpiration than the roots can absorb and transport per unit time (7, 12). Cooper *et al.* (5) found 'Valencia' orange tree trunks shrinking and swelling on a cycle similar to that of the fruit on the trees. Temperatures under orchard conditions are not very well correlated with growth of citrus fruit but controlled-environment studies indicate an increase in the rate of fruit growth with an increase in air temperatures between 10°C and 30°C (20). It is postulated that night and not day temperatures largely influence the growth of citrus fruit.

Fruit maturity varies significantly among different climatic zones. Temperature relationships are suggested in general terms but there does not seem to be any strong correlation between the time required from anthesis to marketable fruit maturity and temperature-degree hours (16). It is suggested by other researchers that conventional air temperatures are not useful in determining energy units needed to mature citrus fruit, but summations based on radiant temperatures are reasonable estimates for determining citrus fruit maturity. The concentration of citric acid is one indicator of maturity and in most instances, decreases in citric acid concentrations occur during cooler temperatures of the winter season. Total soluble solids, another indicator, will usually be lower in 'Valencia' oranges at the market-maturity level when grown in very cool, subtropical climate sites in contrast to warmer and drier subtropical sites (22). Controlled-environment studies by Reuther (20) indicate that widely fluctuating temperatures during different stages of fruit maturity will influence market quality as well as fruit appearance (pigments in the peel). The concentrations of carotenoids in the peel of oranges and mandarins are inversely related to prevailing air temperatures during preharvest stages. Cool soil temperatures have little effect on the concentration of carotenoids in 'Valencia' orange (4). The development of peel color in grapefruit seemingly is much less affected by air temperatures than oranges and largely unaffected at 13°C and cooler. Young *et al.* (42) found no increase in carotenoids in the peel of 'Redbush' grapefruit with decreasing temperatures in controlled environments. But cooler temperatures did increase the concentration of anthocyanins in the flesh of grapefruit, and lycopene formation was directly related to temperatures lower than 35°C. Higher temperatures apparently inhibit lycopene accumulation in grapefruit.

PHYSIOLOGICAL PROCESSES

The physiology of citrus trees is intricately balanced with numerous environmental factors (8). In general, leaves of citrus apparently photosynthesize better at somewhat cooler temperatures than most other crop plants that have adapted to hot, dry climates (20). Temperatures from 22° to 30°C did not strongly affect apparent photosynthesis in rough lemon leaves when humidity was at least 90 percent and light was low, 300 foot-candles (26). Maximum apparent photosynthesis in 'Washington' navel orange leaves was at 25° and for 'Eureka' lemon at 30°C (18). In 'Valencia' orange leaves, carbohydrates accumulated most rapidly between 5° and 15°C (37). Between 20° and 35°C, dark respiration in orange leaves is almost linear with temperature and a Q_{10} of about 2 (18). Guy *et al.* (11) found that leaves of 'Valencia' orange photosynthesize efficiently at 10°C although distribution of photosynthetic assimilates was more reduced at 10° than 25°C. Cooler and drier conditions during winter tend to induce increases in sugars, concentration of sap, bound water, proline, colloidal stability, fatty acids, and decreases in water-soluble proteins and water content (17, 35, 40). All of these changes apparently contribute to increased cold hardiness in citrus, which is of great importance in the United States (27, 38). It is suggested that cool temperatures in the soil reduce the hydraulic conductivity in citrus roots which helps to import cold hardiness (30), and that leaves of citrus may be the source of sugar and proline accumulation in grapefruit flavedo during cold-hardening conditions, which helps the fruit withstand chill injury during cold but not freezing conditions (19). Chill injury of citrus leaves is not a practical problem but does occur at 1.7°C with light under controlled temperatures (36).

It is largely the apparent differences in the physiology and genetic potential that segregates citrus cultivars into different cold-hardy groups (40). One of the most cold-hardy rootstocks is trifoliate orange (*P. trifoliata*) followed by sour orange (*C. aurantium* L.), with rough lemon (*C. limon*) one of the most cold-sensitive rootstocks (Fig. 1). In general, the citrumelos (*C. paradisi* X *P. trifoliata*) tend to be more cold hardy than the citranges (*C. sinensis* X *P. trifoliata*) (38). The mandarin types (*C. reticulata*) are some of the most cold-hardy scions followed by sweet oranges (*C. sinensis*), grapefruit (*C. paradisi*), with lemons (*C. limon*) and limes (*C. aurantifolia*) the most cold-sensitive scions. Most of these ratings are the result of many observations of citrus cultivars after natural freezes; but recently, citrus breeders are utilizing controlled-environments (Fig. 2) to evaluate and screen the

Fig. 1. Five-year-old 'Valencia' orange tree on rough lemon rootstock (left) severely injured during —12.8°C, 1981 January freeze in Florida, while tree on 'Swingle' citrumelo rootstock only slightly injured (right).

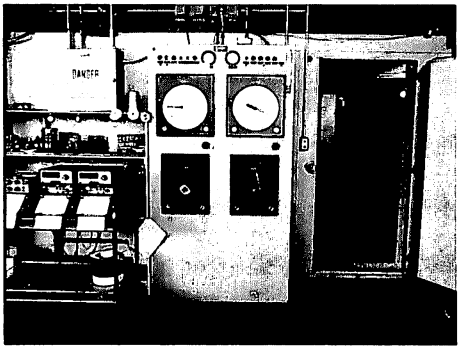

Fig. 2. Controlled-environment facilities used to screen cold-hardy citrus types at the USDA Horticultural Research Laboratory, Orlando, FL.

genetic potential of new citrus hybrids (41). This has greatly accelerated the screening process since severe natural freezes for screening purposes may occur on the average of only one every 10 years in Florida.

New developments in genetic engineering probably will help greatly in developing new citrus hybrids; but there are considerable obstacles in new and innovative approaches of recombinant DNA techniques. Some of these obstacles may take years to circumvent and thus citrus breeding through "classical' procedures is expected to continue in the development of new citrus germplasm. Also, plant explorations are invaluable in obtaining germplasm from different climatic zones. Such searches have brought cold-hardy *Eremocitrus* types from Australia, and *Eremocitrus* is being used to develop cold-hardy citrus in Florida. Probably the greatest source for new citrus germplasm is the humid regions of southwest China which is one of the origins and natural habitats for *Citrus*.

CONCLUDING STATEMENTS

Three of the most important environmental factors that affect citrus are temperature (air and soil), rainfall, and intensity and amount of daylight. These 3 factors greatly influence the growth and development of trees including annual crop yields. They also play important roles in survival of citrus trees under excessively stressful conditions such as severe drought and freezes. Some relief from lack of rainfall is available through improvements in irrigation methods provided adequate water is available. Otherwise, searches must continue for drought-resistant citrus varieties through breeding-improvement programs. Severe freezing temperatures continue to cause periodic devastating effects on citrus in the United States and research continues to search for solutions to this major problem. In addition to droughts and freezes, there are other problem areas that environmental factors impact. For example, hurricanes cause excessive losses in wind-blown fruit, and also trees when winds are sufficiently strong and/or flooding conditions prevail for one or more weeks in low-lying orchard sites. Lightning is known to kill trees under Florida conditions, whereas high winds during dry spells cause fruit and trees to be damaged by flying sand particles from the soil. Hail is not common, but it is very damaging to citrus fruit in Florida. Finally, excessively high radiation temperatures during intensive sunlight can cause heat injury to citrus fruit. It is hoped that cooperative efforts in citrus-producing countries will greatly alleviate some of the environmental problems in the world's supply and demand for citrus and citrus products.

Literature Cited

1. Ayalon, S. and S. P. Monselise. 1960. Flower bud induction and differentiation in the Shamouti orange. Proc. Amer. Soc. Hort. Sci. 75:216-221.
2. Bain, F. M. 1949. Citrus and climate. California Citrograph 34:382, 412-414, 426, 448-449.
3. Bain, J. M. 1958. Morphological, anatomical, and physiological changes in the developing fruit of the Valencia orange, *Citrus sinensis* (L.) Osbeck. Australian J. Bot. 6:1-24.
4. Coggins, C. W., Jr., A. E. Hull and W. W. Jones. 1981. The influence of temperature on regreening and carotenoid content of the 'Valencia' orange rind. J. Amer. Soc. Hort. Sci. 106:251-254.
5. Cooper, W. C., R. H. Hilgeman and G. K. Rasmussen. 1964. Diurnal and seasonal fluctuation of trunk growth of the Valencia orange as related to climate. Proc. Fla. State Hort. Soc. 77:101-106.
6. Cooper, W. C. and A. Peynado. 1959. Winter temperatures of 3 citrus areas as related to dormancy and freeze injury of citrus trees. Proc. Amer. Soc. Hort. Sci. 74:333-347.
7. Elfying, D. C. and M. R. Kaufmann. 1972. Diurnal and seasonal effects of environment on plant water relations and fruit diameter of citrus. J. Amer. Soc. Hort. Sci. 97:566-570.
8. Erickson, L. C. 1968. The general physiology of citrus. pp. 86-126. In: W. Reuther, L. D. Batchelor, and H. Webber (eds.), The Citrus Industry, Vol. 2, Div. of Agric. Sci., Univ. California, Berkeley.
9. Furr, J. R. and W. W. Armstrong. 1956. Flower induction in Marsh grapefruit in the Coachella Valley, California. Proc. Amer. Soc. Hort. Sci. 67:176-182.
10. Furr, J. R., W. C. Cooper and P. C. Reece. 1947. An investigation of flower formation in adult and juvenile citrus trees. Amer. J. Bot. 34:1-8.
11. Guy, C. L., G. Yelenosky and H. C. Sweet. 1981. Distribution of ^{14}C photosynthetic assimilates in 'Valencia' orange seedlings at 10° and 25°C. J. Amer. Soc. Hort. Sci. 106:433-437.
12. Hilgeman, R. H., W. L. Ehrler, C. E. Everling and F. O. Sharp. 1969. Apparent transpiration and internal water stress in Valencia oranges as affected by soil water, season, and climate. pp. 1713-1724. In: H. D. Chapman (ed.) Proc. First Intern. Citrus Symp., Vol. 3, Univ. California, Riverside.
13. Iwamasa, M. and T. Iwasaki. 1963. On the sterility phenomenon caused by low temperatures in the Mexican lime (*Citrus aurantifolia* Swingle). Bul. Hort. Res. Sta. Japan, Ser. B. No. 2:25-45.
14. Monselise, S. P. and F. M. Turrell. 1959. Tenderness, climate, and citrus fruit. Science 129:639-640.
15. Moss, G. I. 1969. Influence of temperature and photoperiod on flower induction and influorescence development in sweet orange (*Citrus sinensis* (L.) Osbeck). J. Hort. Sci. 44:311-320.
16. Newman, J. E., W. C. Cooper, W. Reuther, G. A. Calhoon and A. Peynado. 1967. Orange fruit maturity and net heat accumulation. pp. 127-147. In: R. H. Shaw (ed.) Ground Level Climatology. Amer. Assoc. Adv. Sci. Publ. No. 86.
17. Nordby, H. E. and G. Yelenosky. 1982. Relationships of leaf fatty acids to cold hardening of citrus seedlings. Plant Physiol. 70:132-135.
18. Possingham, J. V. and P. E. Kriedmann. 1969. Environmental effects on the formation and distribution of photosynthetic assimilates in citrus. pp. 325-328. In: H. D. Chapman (ed.), Proc. First Intern. Citrus Symp. Vol. 1, Univ. California, Riverside.
19. Purvis, A. C. and G. Yelenosky. 1982. Sugar and proline accumulation in grapefruit flavedo and leaves during cold hardening of young trees. J. Amer. Soc. Hort. Sci. 107:222-226.
20. Reuther, W. 1973. Climate and citrus behavior. pp. 280-337. In: W. Reuther (ed.), The Citrus Industry, Vol. 3, Div. Agric. Sci., Univ. California, Berkeley.
21. Reuther, W., E. M. Nauer and C. N. Roistacher. 1979. Some high temperature effects on citrus growth. J. Amer. Soc. Hort. Sci. 104:353-356.
22. Reuther, W., G. K. Rasmussen, R. H. Hilgeman, G. A. Calhoon and W. C. Cooper. 1969. A comparison of maturation and composition of 'Valencia' oranges in some major subtropical zones of the United States. J. Amer. Soc. Hort. Sci. 94:144-517.
23. Reuther, W. and D. Rios-Castano. 1969. Comparison of growth, maturation, and

composition of citrus fruits in subtropical California and tropical Colombia. pp. 277-300. In: H. D. Chapman (ed.), Proc. First Intern. Citrus Symp., Vol. 1, Univ. California, Riverside.

24. Riemenschneider, C. H. 1983. World supply and demand for citrus and citrus products. Citrograph 68:243-245.
25. Stebbins, G. L. 1969. The effect of asexual reproduction on higher plant genera with special reference to citrus. pp. 455-458. In: H. D. Chapman (ed.), Proc. First Intern. Citrus Symp., Vol. 1, Univ. California, Riverside.
26. Thompson, C. R., L. H. Stolzy and O. C. Taylor. 1965. Effects of soil suction, relative humidity and temperature on apparent photosynthesis and transpiration of rough lemon (*Citrus jambhiri*). Proc. Amer. Soc. Hort. Sci. 87:168-175.
27. Turrell, F. M. 1973. The science and technology of frost protection. pp. 387-389. In: W. Reuther (ed.), The Citrus Industry, Vol. 3, Div. Agric. Sci., Univ. California, Berkeley.
28. Warner, R. M., Z. Worku and J. A. Silva. 1979. Effect of photoperiod on growth responses of citrus rootstocks. J. Amer. Soc. Hort. Sci. 104:232-235.
29. Webber, H. J., W. Reuther and H. W. Lawton. 1967. History and development of the citrus industry. pp. 1-39. In: W. Reuther, H. J. Webber, and L. D. Batchelor (eds.), The Citrus Industry, Vol. 1, Dev. Agric. Sci., Univ. California, Berkeley.
30. Wilcox, D. A., F. S. Davies and D. W. Buchanan. 1983. Root temperature, water relations, and cold hardiness in two citrus rootstocks. J. Amer. Soc. Hort. Sci. 108:318-321.
31. Wittwer, S. H. 1978. Agricultural production—research imperatives for the future. pp. 11-33. In: T. K. Scott (ed.), Plant Regulation and World Agriculture, NATO Advanced Study Institute Series 22, Plenum Press, New York.
32. Wolf, J. and H. D. Ruck. 1977. Production in the eighties: the world. Citrograph 66:227-229.
33. Yang, H. J. and S. Nakagawa. 1970. Studies on the male sterility of Satsuma orange (*Citrus unshiu* Marc.). The effect of temperature on the recovery of pollen fertility concerning the metabolism of carbohydrates and enzyme activities in anther. J. Jap. Soc. Hort. Sci. 39:6-19.
34. Yelenosky, G. 1977. The potential of citrus to survive freezes. pp. 199-203. In: W. Grierson (ed.), Proc. Intern. Soc. Citriculture, Orlando, Florida.
35. Yelenosky, G. 1982. Indicators of citrus cold-hardening in the field. Proc. Fla. State Hort. Soc. 95:7-10.
36. Yelenosky, G. 1982. Chilling injury in leaves of citrus plants at 1.7°C. HortScience 17:385-387.
37. Yelenosky, G. and C. L. Guy. 1977. Carbohydrate accumulation in leaves and stems of "Valencia' orange at progressively colder temperatures. Bot. Gaz. 138:13-17.
38. Yelenosky, G., R. Young, C. J. Hearn, H. C. Barrett and D. J. Hutchison. 1981. Cold hardiness of citrus trees during the 1981 freeze in Florida. Proc. Fla. State Hort. Soc. 94:46-51.
39. Young, R. 1963. Climate—cold hardiness—citrus. J. Rio Grande Valley Hort. Soc. 17:3-14.
40. Young, R. 1970. Induction of dormancy and cold hardiness in citrus. HortScience 5:411-413.
41. Young, R. and C. J. Hearn. 1972. Screening citrus hybrids for cold hardiness. HortScience 7:14-18.
42. Young, R., F. Meredith and A. Purcell. 1969. Redbush grapefruit quality as affected by controlled artificial climates. J. Amer. Soc. Hort. Sci. 94:672-674.

'Mark'— New Apple Rootstock

MARK (previously MAC 9) was selected from a group of open-pollinated seedlings of M9 in 1959 by Dr. Robert F. Carlson, Michigan State University, Horticulture Professor emeritus. Trees on MARK are reportedly slightly smaller than the same cultivars on M26, very precocious, free standing. Oregon Rootstock, Inc., Woodburn, Oregon has a limited supply of MARK rootstocks and are taking custom-budding orders for finished trees for planting in the spring of 1987. Pacific Coast Nursery, Sunnyside, WA and Adams Rootstock and Nursery, Toledo, WA are also licensed to propagate MARK.