14. Crane, J. C., B. T. Iwakiri, and T-S Lin. 1982. Effects of ethephon on shell dehiscence and flower bud abscission in pistachio. HortScience 17:383-384.

15. Joley, L. E. 1979. Pistachios. pp. 163-174. In R. A. Jaynes (ed). Nut tree culture in North America. Northern Nut Growers Assoc., Broken Arrow Road, Hamden, Conn.

16. Lilleland, O. 1930. Growth study of the apricot fruit. Proc. Amer. Soc. Hort. Sci. 27:237-245.

17. Lin, T-S., J. C. Crane, and K. Ryugo. 1984. Gibberellin-like substances in pistachio as related to inflorescence bud abscission. HortScience 19.

18. Nevo, A., E. Werker, and R. Ben-Sasson. 1974. The problem of dehiscence of pistachio (*Pistacia vera* L.) fruit. Israel J. Bot. 23:1-13.

19. Porlingis, I. C. 1974. Flower bud abscission in pistachio (*Pistacia vera* L.) as related to fruit development and other factors. J. Amer. Soc. Hort. Sci. 99:121-125.

20. Takeda, F. and J. C. Crane. 1980. Abscissic acid in pistachio as related to inflorescence bud abscission. J. Amer. Soc. Hort. Sci. 105:573-576.

21. Takeda, F., J. C. Crane, and J. Lin. 1979. Pistillate flower bud development in pistachio. J. Amer. Soc. Hort. Sci. 104:229-232.

22. Takeda, F., K. Ryugo, and J. C. Crane. 1980. Translocation and distribution of ^{14}C-photosynthate in bearing and nonbearing pistachio branches. J. Amer. Soc. Hort. Sci. 105:642-644.

23. Uriu, K. and J. C. Crane. 1977. Mineral element changes in pistachio leaves. J. Amer. Soc. Hort. Sci. 102:155-158.

24. Whitehouse, W. E. 1957. The pistachio nut—a new crop for the Western United States. Econ. Bot. 11:281-321.

25. Zohary, M. 1952. A monographical study of the genus *Pistacia*. Palestine J. Bot., Jerusalem Ser. 5:187-228.

The California Almond Industry

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Almonds have been grown in California for over 100 years. The climatic requirements of the almond are such that production in the U.S. is restricted almost entirely to California (99%) where the Sacramento and San Joaquin Valleys are almost ideally suited to production.

Characteristics that allow almonds to be successfully grown in these California valleys include:

a. Sufficient winter chilling (300 to 500 hours below 45°F) to allow bloom of major cultivars to occur from mid-February to early March with normally enough sunny, warm days free of rain and wind during bloom to allow for cross pollination by bees.

b. Relative freedom from spring frosts in most years and districts. Almonds are vulnerable to frost in most parts of U.S. and world due to their early bloom. In areas of frequent spring frosts in California, protection has been provided in recent years by application of irrigation water, often by under tree sprinklers.

c. Usually a long, rainless spring, summer and fall. These conditions avoid diseases accentuated by spring and summer rains as well as harvest interference and disease from late summer and fall rains. The most significant crop limiting diseases which attack the almond at bloom are fungi, brown rot *(Monilinia)*, shot-hole fungus *(Stigmina)*, and bacterial blast *(Pseudomonas)*. The first two are controlled by fungicides, but timing is critical.

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d. An abundance of favorable soils and water for irrigation which can produce maximum yields. In many parts of the world and in the earlier years in California, almonds have traditionally been grown on shallow marginal hillside soils without irrigation. However, trees respond so well to deep, well drained, light to medium-textured soils and adequate irrigation by higher yields that in California almonds are planted under these more intensive conditions where yields of one ton or more of kernels per acre are relatively common.

Growth of the Industry

Although almond trees were first grown in California by the Spanish missions, the first significant attempt at commercial plantings began in mid-1800's (21). The entire period of growth can be considered as occurring in four stages (Fig. 1).

a. Introduction — 1875-1925

   Almond growing was a risky business with little knowledge of growing site or conditions, no suitable cultivars or no established market outlet. The U. S. supply was mostly imported, and during early 1900's a tariff was levied to protect the California industry.

b. Establishment — 1925-1950

   By the beginning of the period, some of primary parameters of production had been sorted out (varieties, growing sites) and planting expanded rapidly in the 1920's primarily in the coastal region of Paso Robles with more continuing in the Sacramento and northern San Joaquin valleys in 1930's and 1940's (19). However, during this latter period, the Paso Robles district declined such that shifts in location of acreage might be obscured in the overall trends.

c. Transition — 1950-1960

   Seemingly no growth took place but highly significant changes were occurring, as described later in this article, that brought about the next phase.

d. Expansion and modernization — 1960-date

   Dramatic increases in acreage, production and yield/acre occurred. This trend is continuing but may be leveling off during the 1980's as the industry may be reaching a point of saturation of production.

   During this period the acreage has increased about 3 times. On the other hand, production increased about 4 to 4.5 times. Such changes reflect a real continuous increase in the average yield per acre (7). However, these averages conceal the fact that good producing orchards should be yielding 1500 to 1800 kernel-lbs per acre on good soils although much higher yields are sometimes possible reaching 3000 to 3500 lbs per acre, at least in some years, in the best orchards.

Scope of the Industry

In the early 1980's, the almond industry has reached a preeminence in California in the acreage devoted to the crop and in the size of production and value of the product as compared to other fruit and nut industries with the exception of grapes.

a. Bearing acreage as of 1982 was 335,000 acres plus an additional 85,000 acres non-bearing (3). Recent annual plantings have amounted to 12 to 15 thousand acres. The two next largest fruit and nut industries are walnuts (200,000 acres) and oranges (178,000 acres). Almond plantings extend from the north end of the Sacramento Valley to the south end of the San Joaquin Valley.

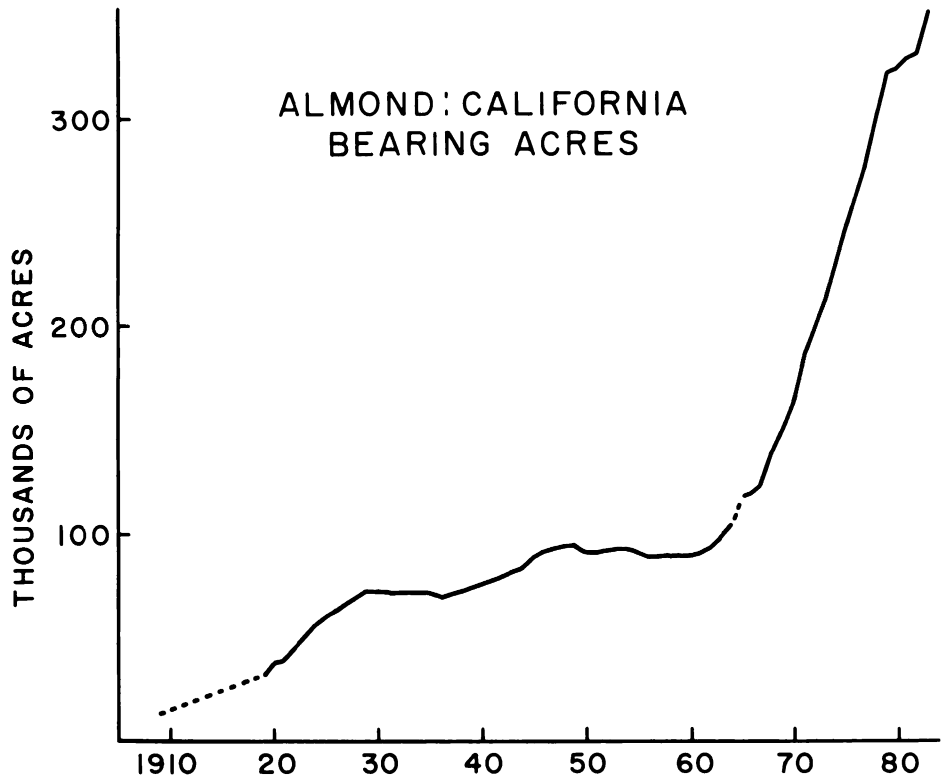

Fig. 1. Trends in bearing acreage of almonds in California. Data from California Crop and Livestock Reporting Service, Acreage Estimates. California Food and Agricultural Service, Sacramento, CA.

b. Annual production in 1981 and 1982 amounted to 350 to 400 million pounds with projections for future major increases (1). This production accounts for 2/3 of the world's supply.

Parameters of Production

By the end of the first period of introduction, some of the basic parameters of production had been sorted out. Two developments require special acknowledgment.

One was the selection of seedlings from a large assortment of imported cultivars initially used. Six principal adapted cultivars of California origin were selected—Nonpareil, Texas Prolific, Ne Plus Ultra, Peerless, I.X.L. and Drake. These became part of the basic orchard plantings since 1920's (19, 21). The first four are still important cultivars in California.

Nonpareil has established itself as the predominant cultivar both in the orchard and in the market place. The attractiveness of the kernel, thin pellicle, ease of blanching, uniformity and adequate flavor have made it very versatile and adaptable to a wide range of uses on the market. Likewise, in the orchard, the cultivar has had a reputation for good, consistent production.

Texas Prolific (later changed to Mission) is the second major cultivar gaining a reputation over the years of consistent high production in the orchard, in part due to its late bloom. The shells are hard and resist worm infestation. In the market, kernels of this cultivar have gained some preeminence as a highly flavored, unblanched, roasted and salted "cocktail" almond.

Ne Plus Ultra is an old cultivar which continues to be planted to a limited amount as an early-blooming pollinizer of Nonpareil despite its obvious defects, both in the orchard and in the market. It produces a large, elongated, flat kernel that has limited use in the market because of its shape.

Likewise Peerless is an old cultivar that maintains an important but limited place in the industry because of its use as an early blooming pollinizer of Nonpareil and as an in-shell product on the market. With its very hard shell, it is resistant to worms.

Along with this early selection of cultivars was the discovery that each cultivar was self-incompatible, and separate cultivars must be planted in adjoining rows for cross-pollination (20). Most orchards consisted of a combination where either one-half or two-thirds of the rows of nonpareil combined with one or two other cultivars to provide cross-pollination. For efficient hand harvest onto canvas sheets, two or (sometimes) four rows of one cultivar were planted together. Also, the vital role of honey bees became known.

Another major development before 1920 was the beginning of the cooperative marketing system which became a basic characteristic of the California almond industry (18).

Two main types of site locations were involved in these early plantings. Hillside culture, primarily to escape frosts, occurred either in the lower slopes of the foothills surrounding the Sacramento Valley and northern San Joaquin Valley or in particular sites in the coastal range. A particularly significant development occurred near Paso Robles about half way between San Francisco and Los Angeles where almost 40,000 acres were planted and sold to outside investors. In both of these types of site locations, orchards were largely grown on shallow, marginal soils without irrigation. Because of low production, these districts survived for a time but within 15 to 20 years gradually declined to nonsignificance and account for losses in 1930's and 1940's.

In contrast, orchards planted on deep, alluvial valley soils in the Sacramento and northern San Joaquin Valleys not only thrived but showed remarkable capacity for growth and yield potential. Abundant irrigation water, either from wells or from the many rivers originating on the western slopes of the Sierra Nevada mountains, made possible increases in yield of 3 to 4 times that of nonirrigated counterpart orchards. During this period of establishment, increased knowledge of disease and insect control, fertilization and management developed. Originally, most almond cultivars were budded to almond seedling rootstocks (19). With the shift to irrigation, a parallel shift to the peach seedling rootstock occurred which produced more precocious trees, better adapted to irrigated conditions (12). Research and Extension programs of the University of California and the U. S. Department of Agriculture contributed to the understanding and control of many production problems and development of improved practices.

Several changes occurred in the 1950's which led to a spectacular increase in acreage and production:

a. Major water projects were completed that opened up vast areas of the southern and western San Joaquin Valley not previously suited to tree crops because of low supply and poor quality water.

b. Within the industry, further improvements occurred in irrigation management, use of fertilizers, e.g., nitrogen (200-250 lbs or more/acre /year), zinc sprays where needed and orchard floor management. Non-tillage became widely practiced, with strip weed sprays along tree rows and closely mowed winter and spring cover crops in centers. This method improved soil structure and permeability of many soils and was closely associated with changes in harvesting.

c. A shift took place in harvest procedures to nearly complete mechanization which resulted in a readjustment of the orchard management system.

d. A major shift in world marketing of almonds took place in that the U.S. changed from an almond-importing country, with the California industry protected by a tariff, to an almond-exporting country with world prices rising to match those in the U. S. Associated with this shift was a loss of production in Italy although Spain has continued to increase in acreage and production (Fig. 2) (7). In essence, the loss of production from Italy was offset by increased output from the U.S. and, to some extent, Spain. This change was greatly aided by the establishment of a Federal Marketing Order for almonds which provided the industry with tools to meet this transition in an orderly fashion. Consequently, marketing has kept pace with production up to the present time, although concerns for the marketing and distribution of future crops have been expressed by many inside and outside of the industry. This increase in distribution has involved aggressive marketing, development of new products and, in particular, the development of export markets. Recently, nearly 50% or more of the production from California has been exported to markets in Europe, Japan and elsewhere.

e. Sometime during this period, the navel orangeworm (NOW) found its way into California orchards from Mexico and became established as a major production problem in almonds. Nonpareil was highly susceptible because of its paper shell. A re-evaluation was needed of the entire mechanical almond-harvesting system, as well as consideration of cultivars. With evolving programs, prompt harvest, orchard sanitation, and fumigation emerged as dominant controls — with pesticide application used as a backup.

f. Shifts in choice of cultivar and pollination arrangements occurred with the introduction of new pollinizers for Nonpareil and Mission which coincided more closely in time of bloom (9). The proportion of the pollinizer trees has increased from 1:2 (33%) to 1:1 (50%). Beehive number has increased up to 2 to 3 or more per acre with more attention given to improving hive strength.

With mechanization and NOW problems, additional attention was given to cultivar selection for harvest sequence to extend the harvest period and utilize equipment and facilities more efficiently. Mixing the nuts of different cultivars must be avoided at harvest in most cases, and sequential harvest can help avoid this situation. The harvest problem is particularly important with large acreages involved.

Cultivars

Although many cultivars have come from breeding programs, the most significant introductions have been chance seedlings appearing on ditch banks, roadsides or orchards which showed high early production with good cross-pollination capacity for Nonpareil and/or Mission. The two most important of this group were Merced and Thompson, introduced in the late 1950s (2). While they were good pollinizers, their susceptibility to navel orangeworm, difficulties in harvesting and susceptibility to noninfectious bud-failure (Merced) has since resulted in their replacement by other more recently introduced cultivars. Carmel and Price Cluster are extensively planted as Nonpareil blooming pollinizers and Butte and Ruby as later-blooming pollinizers for Mission. LeGrand is a self-fertile cultivar whose ultimate status is unclear due to its difficulty in harvest.

The introduction of new cultivars, particularly Davey, Merced, and Thompson created a marketing problem (15). Their kernels were plump and different in shape and appearance from the Nonpareil with which they could not be satisfactorily mixed. As a response, a new marketing category of kernel was created called California which combined kernels of different cultivars that had this intermediate shape and which could be blanched.

Rootstocks

Further changes in rootstocks have occurred with the shift from almond seedlings. Lovell peach seedlings became dominant. This rootstock is well adapted to the conditions in the Sacramento Valley providing soil drainage conditions are reasonable and rootknot nematodes do not occur.

Because of the presence of root-knot nematodes in the San Joaquin Valley, the nematode-resistant peach rootstock Nemaguard has been the predominant one used in that area. Growers in the Sacramento Valley, however, have been concerned about its somewhat greater susceptibility to wet soil conditions than Lovell peach seedlings.

The Marianna 2624 plum is a vegetatively propagated selection that is somewhat tolerant to oak root fungus *(Armillarea)* and to heavy, wet soil conditions where crown rot *(Phytophthora)* prevails. It has come into use for these problem areas. Mission, Perless, Ne Plus Ultra and various other cultivars are compatible and produce a small but relatively productive tree. On the other hand, Nonpareil is incompatible as are certain other cultivars, includnig many seedling selections of Nonpareil. Interstocks of compatible almonds (cultivars such as Mission or Ne Plus Ultra) do not overcome incompatibility with Nonpareil, but a plum interstock, known as Havens 2B, produces a reasonably satisfactory tree with Nonpareil (14).

In recent years the F_1 hybrid between peach and almond has come into use in commercial orchards through the efforts of a nurseryman, Arthur Bright, who pioneered its propagation by controlled open cross-pollination of the parents (12). Research by the USDA (5, 6) and University of California (10, 13) has also involved this type of rootstock. These hybrid rootstocks provide a high degree of

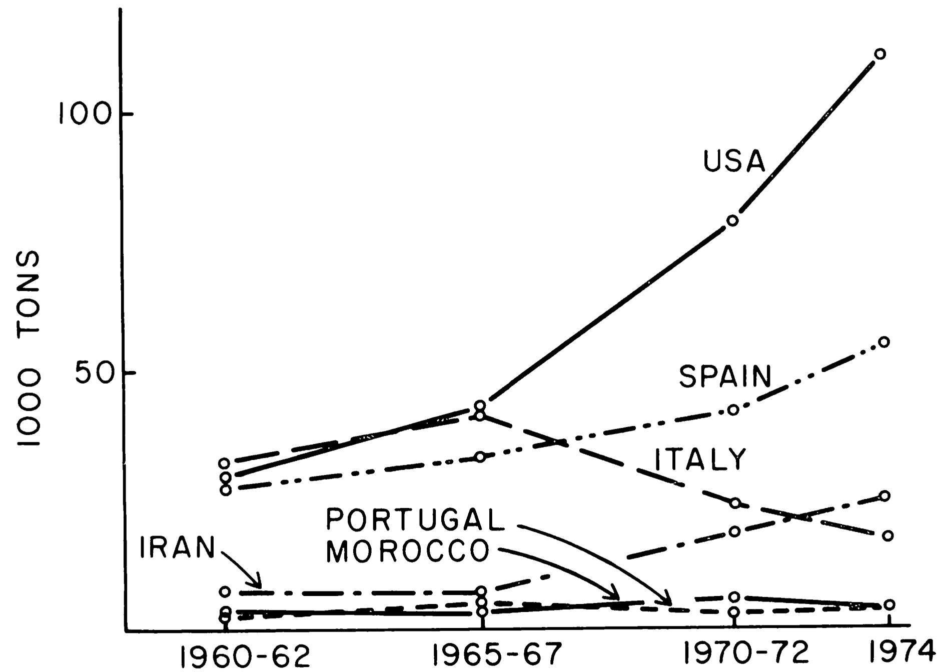

Fig. 2. Trends in almond production in major almond producing countries of the world. Reprinted from (7).

vigor and a deep, extensive root system which can be translated into increased yield, excellent anchorage, and greater drought tolerance during the harvest period. Nematode resistance can be transmitted from the peach parent to the seedling offspring. These hybrids show intermediate susceptibility to crown-rot conditions associated with *Phytophthora*. Trees with hybrid rootstocks tend to show delayed nut maturity. Hybrid rootstocks have been mostly grown in the southern part of the San Joaquin Valley where there is less winter rainfall and crown rot danger, and where orchards are subject to more heat and moisture stress during the growing season. This rootstock may be less adapted to the Sacramento Valley except, perhaps, in areas on marginal, shallower soil along the edges of the valley where greater tree vigor may improve yield and size.

Present cultural practices (16)

Almond trees are trained to an open center, vase, shape system. Almonds branch readily and require little, if any, heading cuts in order to get branching. Selection of scaffold branches is done by a thinning out selection process. Older trees require less pruning than many fruit tree species. Normally, pruning is accomplished by removing 6-10 limbs of one to one and a half inches in diameter through the bearing area of the tree. This is done in such a way that after a 5-7 year period the entire bearing area of the tree has been replaced. Excess sucker growth and dead, diseased, and broken limbs are also removed.

While almond may be considered drought tolerant, they actually require as much soil moisture (irrigation) as other fruit tree species. In much of the central valley of California, almonds require about 3 acre feet of rain and/or irrigation per year, while in the Southern San Joaquin Valley, 4 acre feet may be required in many years because of higher water use in that area. Losses from application inefficiency need to be added to these amounts. Almonds are normally irrigated by either sprinkler or flood irrigation with a limited amount of drip and micro-sprinkler irrigation.

Almond kernels are high in nitrogen containing about 3½ to 4% nitrogen. Therefore, the nitrogen requirement of almond orchards is quite high, and heavy-producing orchards generally require 200-250 lbs. or more of actual nitrogen per acre per year. Zinc is commonly deficient in many almond-producing areas of California and is best corrected by spray applications. Less frequently, but still common, are deficiencies of potassium and boron.

Most almond orchards in California are maintained under a non-tillage form of orchard floor management. This is most commonly accomplished by maintaining a weed-free strip in the tree row with the use of herbicides and then mowing or flailing the row centers. As harvest approaches, the centers are either mowed close or treated with herbicide in order to give a relatively weed-free, smooth area from which to pick up the nuts. The other method of orchard floor management practiced in a significant number of orchards is tillage where orchards are cultivated throughout the season and then smoothed for harvest. Reasons for utilizing tillage include method of irrigation (some forms of flood irrigation require temporary levees), noxious weed problems, water penetration problems under non-tillage (with some soils) and grower preference.

Various pests and diseases are a concern to almond growers in California. Among the most common insect pest problems that growers must be alert for are navel orangeworm, peach twig borer, San Jose scale, ants and mites. Diseases that can occur in almond orchards include brown rot, shot-hole, botrytis rot, leaf blight, scab, bacterial blast and canker, mallet wound canker, *Verticillium* wilt, *Phytophthora* crown, root and limb rot, crown gall, oak root fungus, hull rot, and leaf scorch. Other pests that can be a problem in almond orchards include nematodes, squirrels, birds, and pocket gophers.

Significant problems

Despite the apparent strong position of the almond industry, significant production and marketing problems remain. The Almond Board of California, a Federal Marketing Order, has provisions for collecting funds to support production research. The following list of research problems is not complete but represents areas of significance, some of these are supported by the Almond Board (1).

a. **Worm damage.** Much of the initial effort of the Almond Board-sponsored research dealt with efforts to control navel orangeworm (NOW). Although the NOW problem will, no doubt, continue as long as soft-shelled susceptible cultivars are grown, procedures have been developed to minimize the hazard. This involves an integrated pest management program including early or prompt harvest and handling. Fumigation of nuts in the orchard or before storage, orchard sanitation by mummy nut removal and selected spray application.

b. **IPM.** Integrated Pest Management (IPM) programs have included the development of phenological models based on temperature summation for the development of NOW and peach twig borer. In addition, IPM programs for the control of mites, ants, and some specific diseases, such as shot-hole fungus are being developed. Parallel to all of these pest models, models for the phenological development of the almond tree and its fruit are under development.

c. **Cultivar selection and development.** In 1982 acreage reports, 39 cultivars were listed, and 31 of these had some nonbearing acreage. More new selections are in test plots or are being reported by growers or nurserymen. Critical factors that need evaluation include long-term productivity, cross-pollination requirements, market suitability, susceptibility to noninfectious bud-failure and compatibility with Marianna 2624. An extensive program of cultivar evaluation is underway involving five Regional Variety Trials located in various important almond producing areas. Self-fertile cultivars, and some that reduce tree sizes, are being introduced. Their role in the industry needs to be evaluated.

d. **Rootstocks.** Interest has recently developed in using Marianna 2624 plum on a wider scale than previously to produce smaller trees planted at closer spacings. Previously, the principal reasons for this rootstock were to combat crown rot and oak root fungus problems that have been characteristic of the Sacramento Valley in some years and in some locations.

A second problem is the adaptation of the hybrid rootstocks to different areas and particular types of soil. Orchard management, particularly in regard to irrigation and drainage, may need to be modified from that occurring for peach rootstock in order to take full advantage of this vigorous rootstock.

e. **Nursery source selection.** Several nursery source-related problems exist in almond. One is a virus-caused nonproductivity (infectious bud-failure or calico) which can be prevented by selecting negatively indexed source plants for propagation (17). A second is a genetically caused nonproductivity ("bull" or "rooster" trees) which is related to certain budwood sources (11). A third is a genetically caused vegetative bud-failure (noninfectious bud-failure, "crazy top") which is an inherited disorder that is characteristic of particular cultivars and appears more prevalent in certain propagation sources and in particular locations, primarily under conditions of high summer temperature and moisture stress (8, 9).

f. **Pollination.** High almond production results from high fruit set which requires maximum cross-pollination by honey bees. Factors that contribute to the most favorable combination of conditions for fruit set include good weather during bloom, the favorable arrangements of cross-compatible cultivars for cross-pollination, adequate numbers of bees/acre, bee quality and healthy trees. Problems of cold, rainy weather during bloom in some years and some districts, particularly in the Sacramento Valley, result in severe seasonal fluctuation of production.

g. **Irrigation management.** Proper water management is a key not only to high production but also to the continued production from healthy trees year after year as the trees age. The seasonal pattern is complicated by the need to withhold irrigation during the harvest period. As a result, trees can become stressed for long periods of time if an extended season occurs and deep soil moisture is not present. Moisture stress problems may contribute to seasonal fluctuations and to decline as the trees get older. This problem is a complex one, and the plant reaction may vary with location (e.g., Sacramento vs. San Joaquin Valleys), with rootstock and with crop load. It is likely that many orchards have never experienced a full crop potential and the relationship of crop load to tree physiology needs to be investigated.

Literature Cited

1. Almond Board of California. Annual and periodic reports, Sacremento, CA.
2. Brooks, R. M. and H. P. Olmo. 1972. Register of Fruit and Nut Crops. University of California Press (also subsequent supplemental lists in HortScience).
3. California Crop and Livestock Reporting Service (Annual) Acreage Estimates. Dept. Food and Agr., Sacramento, CA.
4. Day, L. H. 1953. Rootstocks for stone fruits. Calif. Agr. Expt. Sta. Bull. 736.
5. Jones, R. W. 1969. Selection of intercompatible almond and root knot nematode resistant peach rootstocks as parents for production of hybrid rootstock seed. J. Amer. Soc. Hort. Sci. 94:89-91.
6. Jones, R. W. 1972. Titan, a seed source for F_1 almond x Nemaguard peach hybrids. Fruit Var. Hort. Dig. 26:18-20.
7. Kester, D. E. 1976. Cultural systems and rootstock of the almond. I. Congress international de almonds y avellano. Feria oficial de muestras prov. de tariagona, Reus, Spain, pp.783-799.
8. Kester, D. E. 1976. Noninfectious bud failure in almond. *In.* Virus Diseases and Noninfectious Disorders of Stone Fruits in North America. USDA Agr. Handbook No. 437.
9. Kester, D. E. 1978. Variety improvement and genetic problems. *In.* Almond Orchard Management, W. C. Micke and D. E. Kester, eds., University of California Priced Publ. 4092.
10. Kester, D. E. 1982. Almond x peach hybrid clones as rootstocks for *Prunus.* XXIst Intern. Hort. Cong. Abstracts, Vol, I. Intern. Soc. Hort. Sci.
11. Kester, D. E. 1982. A nonproductive variant of almond in California. XXIst Intern. Hort. Cong. Abstracts, Vol. II, Intern. Soc. Hort. Sci.
12. Kester, D. E. and R. N. Asay. 1975. Almonds. *In.* Advances in Fruit Breeding, J. Janick and J. N. Moore, eds., Purdue University Press, West Lafayette, Indiana.
13. Kester, D. E. and C. J. Hansen. 1966. Rootstock potentialities of F_1 hybrids between peach (*Prunus persica* L.) and almond *Prunus amygdalus* Batsch). Proc. Amer. Soc. Hort. Sci. 89:100-109.
14. Kester, D. E., C. J. Hansen and C. Panetsos. 1962. Plum rootstock for almonds. Calif. Agr. 16:10-11.
15. Kester, D. E., W. C. Micke, D. Rough, D. Morrison and R. Curtis. 1980. Almond variety evaluation. Calif. Agr. 34(10):4-7.
16. Micke, W. N. and D. E. Kester. 1978. Almond Orchard Management, University of California Priced Publ. 4092.
17. Nyland, G. 1976. Almond virus bud failure. *In.* Virus Diseases and Noninfectious Disorders of Stone Fruits in North America. USDA Agr. Handbook No. 437.
18. Taylor, R. H. 1916. Marketing California Almonds. University of California J. Agr. IV:44-45.
19. Taylor, R. H. and G. L. Philp. 1925. The almond in California. University of California Circ. No. 284, pp. 1-57.
20. Tufts, W. P. and G. L. Philp. 1922. Almond pollination. Calif. Agr. Exp. Sta. Bull. 346:1-36.
21. Wood, M. N. 1925. Almond varieties in the United States. USDA Bull. 1282: 1-101.